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[Bulletin No. 86.]

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WASHINGTON, D. C.

WASHINGTON, D. C., *December, 1892.*

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UNITED STATES GEOLOGICAL SURVEY

J. W. POWELL, DIRECTOR

CORRELATION PAPERS

ARCHEAN AND ALGONKIAN

BY

CHARLES RICHARD VAN HISE

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CONTENTS.

ILLUSTRATIONS.

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
U. S. GEOLOGICAL SURVEY,
DIVISION OF GEOLOGIC CORRELATION,
Washington, D. C., January 30, 1892.

SIR: I have the honor to transmit herewith a memoir by Prof. C. R. Van Hise on the Archean and Algonkian of North America, prepared for publication as a bulletin.

The Division of Geologic Correlation was created for the purpose of summarizing existing knowledge with reference to the geologic formations of North America, and especially of the United States; of discussing the correlation of formations found in different parts of the country with one another and with formations in other countries; and of discussing the principles of geologic correlation in the light of American phenomena. The formations of each geologic period were assigned to some student already well acquainted with them, and it was arranged that he should expand his knowledge by study of the literature and by field examination of classic localities, and embody his results in an essay. The general plan of the work has been set forth on page 16 of the Ninth Annual Report of the Survey, and on pages 108 to 113 of the Tenth Annual Report, as well as in a letter of transmittal of Bulletin No. 80.

The present essay is the seventh of the series, having been preceded by essays on the Carboniferous and Devonian, the Cambrian, the Cretaceous, the Eocene, the Neocene, and the Newark systems; prepared severally by Messrs. Williams, Walcott, White, Clark, Dall and Harris, and Russell, and constituting Bulletins 80, 81, 82, 83, 84, and 85.

The voluminous literature of the pre-Cambrian rocks of North America is abstracted in a thorough manner, being classified for this purpose primarily by geographic districts and secondarily by dates. The division of the rocks into two great classes, the Archean and Algonkian, taxonomically coordinate with the periods under which the fossiliferous clastic rocks are classified, is then advocated and set forth at length. As these rocks do not contain faunas available for purposes of correlation, their classification, both major and minor, is necessarily based on physical characters and relations, and much attention is therefore given to the discussion of the possibilities and limitations of correlation by means of physical data. It is concluded that with present information the correlation of pre-Cambrian series and formations of different geologic provinces is impracticable.

Very respectfully, your obedient servant,

G. K. GILBERT,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey.

OUTLINE OF THIS PAPER.

This book is a review of the present state of knowledge of the general structure of the pre-Cambrian rocks of the United States and Canada. The material contained in the historical chapters is of two kinds: Summaries of all articles pertaining to the subject considered, and summaries of the conclusions which appear to be established. The first represents the substance of the literature; the second brings together the important ascertained structural facts, and oftentimes becomes a more or less extended discussion. The final chapter covers the same grounds as the historical chapters for the various pre-Cambrian general successions proposed by different authors, and also contains a discussion of results and the principles upon which they are based. Within the chapters, individual districts or regions are given separate sections, and the summary of literature for each is arranged in chronological order. As used in this volume, the term Cambrian is defined as delimited below by the base of the Olenellus fauna; Algonkian includes the pre-Olenellus clastics and their equivalent crystallines; while the Archean includes the completely crystalline rocks below the Algonkian.

The several chapters have the following scopes: Chapter I: The Original Laurentian and Huronian areas—treats of eastern Ontario and western Quebec, and the area from the north channel of lake Huron to lake Temiscamang. Chapter II: Lake Superior Region—summarizes the work of the official geologists of the Canadian Survey and associates, of the early United States geologists and associates, of the Michigan geologists and associates, of the Wisconsin geologists and associates, of the Minnesota geologists and associates, of the later United States geologists and associates, and gives a summary and discussion of results. Chapter III: The Great Northern Area—treats of the region about Hudson bay, northern Canada, and the lower St. Lawrence river region. Chapter IV: Eastern Canada and Newfoundland—treats of the Eastern townships, Gaspé peninsula, central New Brunswick, southern New Brunswick, Nova Scotia and cape Breton, and Newfoundland. Chapter V: Isolated Areas of Dakota, Missouri and Texas—treats of the Black hills, the pre-Cambrian of Missouri, and the central Mineral region of Texas. Chapter VI: The Cordilleras—treats of the many mountain ranges in the far west. Chapter VII: Eastern United States—treats of the New England, Middle Atlantic, and Southern Atlantic states. Chapter VIII: General Successions and Discussions of Principles—summarizes the various general successions proposed, suggests one, and discusses the principles of pre-Cambrian stratigraphy.

The more important conclusions of this chapter are as follows: The Archean is the basal complex of America. It has everywhere, if large areas are considered, an essential likeness. It consists mainly of granitic, gneissic and schistic rocks, among which are never found beds of quartzite, limestone, or any other indubitable clastics. One kind of rock may occupy considerable areas, but when different kinds are associated their structural relations are most intricate. These relations, as well as the completely crystalline schistose character of the rocks, the frequent broken and distorted forms of the mineral constituents, and their involuted foldings, are evidence that these most ancient rocks have passed through repeated powerful dynamic movements.

As to the origin of the Archean rocks, three different views are proposed: (1) They may be considered as metamorphosed detrital rocks. (2) They may be considered as igneous and later in origin than certain of the pre-Cambrian clastics. (3) They may be considered as igneous and representing either a part of the earth's original crust or else originally crystallized material which has now reached the surface as a consequence of inward crystallization and subsequent deep denudation. The Archean rocks have no limit below, but are limited above by the Algonkian. While structural methods have been applied to the Archean rocks, they have not thus far been successful, and the only subdivisions which are at present applicable are those of a lithological character.

In various parts of North America are one or more series of clastic rocks between the Archean and Cambrian. These occur in the Original Laurentian area, the Original Huronian area, in the lake Superior region, in the region about Hudson bay, in the Eastern townships, in southern New Brunswick, in Nova Scotia and cape Bretön, in Newfoundland, in the Black hills, in Missouri, in Texas, in many ranges of the Cordilleras, in the Grand canyon of the Colorado, in British Columbia, in the Adirondacks, and in other areas. Within these rocks, in many localities, are evidences of abundant life, and in a few places are definitely recognized fossils. The U. S. Geological Survey, recognizing that it is too early to classify the great thicknesses of rocks between the Archean and the Cambrian in North America into systems coordinate in value with those of the subdivisions of the Paleozoic, has proposed the term Algonkian for the whole. The Algonkian system is then delimited below by the Archean and above by the Cambrian.

In many regions it is easy to differentiate the Algonkian from other rocks. This is especially true where they are separated from them by unconformities. In other regions it is difficult to separate them from the Archean and Cambrian rocks, as there sometimes appear to be gradations between them. In this respect the Algonkian system is in no way different from others.

Algonkian stratigraphy is more difficult than post-Algonkian stratigraphy; because the further back we go in the history of the world for any given region the more numerous and frequent have been the changes through which any given rock stratum has passed; and because as yet fossils have not been found in sufficient quantity to be of any assistance in stratigraphy. However, in many regions it has been possible to subdivide the Algonkian rocks into series and these series into formations. In different regions these formations and series differ widely in the degree of crystallization, in their lithological character, and in their order of succession. In this respect Algonkian rocks are not different from those of post-Algonkian age. Considering the continent as a whole, age is no guide to the chemical or mineral composition, texture, color, degree of crystallization, or any other property of a formation, or vice versa, although in a given district or region any one of them may become important guides in stratigraphy.

In certain regions it has been found possible to correlate series with a great degree of probability and in some cases formations which occur in different districts. In regions separated from each other by great distances, and which therefore may have had different physical conditions at the same period, it is not yet possible to make safe correlations of subdivisions of the Algonkian of America. If this conclusion be correct, it is evident that the application of such American terms as Keweenawan, Huronian, etc., to European rocks is not warranted. In working out the geology of a region, local names should be applied to formations and series. Later, with fuller knowledge, these may perhaps be correlated with series to which classical names have been applied.

Physical methods of correlation being the only ones at present available, it becomes necessary to closely scrutinize these methods, estimate their relative value, and point out the services that each may be expected to perform. Of these methods unconformity must be given the foremost place for major divisions within a region. Unconformity may be established by any one of the following phenomena, or by a combination of two or more of them: (1) Ordinary discordance of bedding; (2) difference in the number of dynamic movements to which the series have been subjected; (3) discordance of bedding of upper series and foliation of lower; (4) relations with eruptives; (5) difference in degree of crystallization; (6) basal conglomerates; (7) general field relations.

PREFACE.

In the preparation of this book great difficulty has been encountered because of the unequal value of statements of fact by different men. Oftentimes in regions with which the writer is not familiar it is impossible to discriminate surely between good and poor work. 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. But in general, when an author of this class has written much, discrepancies between the statements of facts appear.

Those who change their opinions are of different classes. A man who progresses must change his views, but the descriptive parts, given while an old view was held, ought to be still more useful for support of the new position. The old view may have contained a large element of truth, and is perhaps included in the newer, larger position. In reports the part that purports to be facts should be wholly separable from the general theories held, just as detailed maps, if rightly constructed, indicate the observations made and the generalizations drawn. More frequently than not, facts and theories are 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; "all is grist which comes to his mill;" 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.

During the preparation of this review, I have visited many districts of North America, but I have not been able to see important districts which I hoped to study before the submission of this volume. With the United States side of the lake Superior country I am tolerably familiar, having for a number of years given nearly the full field seasons to work in various parts of this region. Besides doing general work, I have mapped in detail certain districts. From time to time various parts of the Canadian lake Superior region have been visited. While no systematic mapping work has been done in regions other than that of lake Superior, reconnaissances and occasional detailed sections have been made in many. In the far West these include the Black hills of Dakota, southwestern Montana, the Laramie and Medicine Bow mountains of Wyoming; the Uinta and Wasatch mountains of Utah; and the Quartzite mountains and Front range of Colorado. In the Mississippi valley the crystalline region of Missouri has been seen. In company with Raphael Pumpelly, Bailey Willis, J. A. Holmes, C. D. Walcott, G. H. Williams, R. W. Ells, or alone, more or less extended trips have been made in Georgia, east Tennessee, North Carolina, eastern Maryland, eastern Pennsylvania, northern New Jersey, southern New York, the Berkshire hills, Green mountains, Adirondacks, Hastings district of Ontario, and the area of the Grenville series constituting the Original Laurentian. For the most part this work has not been of such a detailed nature as to add greatly to previous knowledge of these regions. The aim has been rather to get such a familiarity with them as would enable the writer to judge accurately of the results already reached. This statement does not apply to a part of the Adirondacks, where a somewhat closer study was made; also, in North Carolina a nearly complete section was made from the eastern side of the Piedmont plain through the Blue ridge to the uncrystalline rocks of east Tennessee. The Original Huronian area has been seen at three different times. The first time, in company with the late Dr. R. D. Irving, the North channel was coasted in a small boat and the interior visited, so that all of Logan's members of this series were seen, as well as the underlying Laurentian. In a second trip, also in company with Prof. Irving, the Canadian Pacific railroad was traversed twice on a hand car from Algoma Mills to Sudbury, a distance of 100 miles. The third trip, with Prof. Raphael Pumpelly, was again along the North channel of lake Huron, the object of special study being the possible existence of two series within the Huronian, and the structural relations between the lowest Huronian and the Laurentian.

The labor involved in abstracting the pre-Cambrian literature of North America has been great. This is shown by the large number of books and articles actually summarized. These, however, give an imperfect idea of the volume of literature covered; for very numerous articles have been examined which repeat what had already been summarized from other papers. Also a vast amount of material from which nothing is taken has been looked through, in order to ascertain whether it contained anything which ought to be considered. In all cases summaries are made from the original articles, with the exception of a part of the section upon northern Canada. Nearly the entire literature of the geology of this region has recently been clearly compiled by Dr. George M. Dawson, and from this compilation the major part of the summary for this region is taken.

To a card catalogue of the Appalachians by N. H. Darton, to Azoic Rocks and other works by Hunt, to the Minnesota reports, to the Azoic System by Whitney and Wadsworth, to Irving's Copper-bearing Rocks, and also to many other works the writer is much indebted as furnishing guides to the pre-Cambrian literature. In this way Darton's catalogue and the Azoic System have been by far the most valuable. After independently preparing abstracts of papers and reports I have compared them with the abstracts contained in the Azoic System in order to discover omissions, and this book has thus enabled me to make the survey of literature more nearly complete than it otherwise would have been. To a certain extent other books have been used in the same fashion.

Mr. W. N. Merriam has drawn all the maps for the illustration of the volume. To Mr. George E. Luther the writer is indebted for most efficient clerical assistance from the outset, without which it would have been impossible to complete this volume within the time allotted.

To Sir Archibald Geikie, Dr. Hans Reusch, Dr. K. A. Lossen, Michel-Levy, and Dr. Johannes Lehmann I am indebted for summary statements of the condition of knowledge with reference to the pre-Cambrian of Great Britain, France, Germany and Scandinavia.

With Messrs. C. D. Walcott, G. H. Williams, Bailey Willis, and R. W. Ells I have been in the field and in consultation, and from them have received much useful information.

Mr. G. K. Gilbert has kindly read the manuscript, and has made many suggestions which have been of value.

To the late Prof. Roland D. Irving, and to Prof. Raphael Pumpelly I am indebted in a peculiar manner. With the former I was associated in work from my earliest studies in geology until his death. With the latter I have been much in the field for the last two seasons and have received many pregnant ideas. What part of the thoughts contained come from these two friends I am unable to specify in detail, but I am conscious that the debt is a heavy one.

No one else will feel so keenly the imperfections of this volume as the writer. Papers will be found to be overlooked of which summaries ought to have been made. Mistakes of interpretation will be found. Undue proportion in the summaries will be discovered. I can only say that I have attempted to reduce these defects to a minimum. It will be esteemed a great favor, with reference to a possible future edition, if all who discover such omissions and mistakes will communicate them to the writer.

C. R. V.

MADISON, WIS., *July, 31, 1891.*

A REVIEW OF THE PRESENT STATE OF KNOWLEDGE OF THE PRE-CAMBRIAN ROCKS OF NORTH AMERICA.

By C. R. Van Hise.

INTRODUCTION.

The purpose of this book is to give an account of the present state of knowledge of the general structure of the pre-Cambrian of the United States and Canada. It is not 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. Mere occurrences of pre-Cambrian or crystalline rocks are not referred to unless the districts are new. 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 historical chapters of this volume is of two kinds: First, a summary of all articles or parts of articles which have contributed knowledge upon the subject considered; and second, summaries of the conclusions which appear to be established in the various regions, while the final chapter covers the same ground for general successions proposed and also a discussion of these results and the principles upon which they are based. No summaries are made of writings based wholly upon the field work and reports of others. This report is not a review of reviews; neither is purely controversial literature noticed. When a paper is made up in part of an original investigation and of a discussion of the works of others, only the first part is summarized. When the same writer repeats the same facts and conclusions several times, summary is made of the most comprehensive article and references are made to the others in the footnotes.[1] Oftentimes a final report includes all found in several annual reports. In this case the final report only is summarized. In making summaries the conclusions reached by the various authors are always given, and as full an account of the facts upon which they are based as is possible without extending this book beyond bounds.

[1] At the end of each chapter.

The abstracts given have the defects of all summaries—a certain amount of inaccuracy, because all modifying and qualifying facts can not be 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 each other.

So far as possible, in the summaries, the original language of the author is used, although a single sentence of the summary may be taken from several sentences of the original. Where the ideas can be conveyed in a briefer manner than in the original language other words are used. No quotations are made; for the ideas contained, whether in the original language or not, are wholly the ideas of the author—the whole is in fact really quoted. It might be thought that better results would have been reached by indicating through quotations what words are taken from the original, but this method would have necessitated an unpleasant and constant alternation from quoted to nonquoted phrases. It would have made it much more difficult to convey briefly the thoughts of the original; for the words which are adapted to complete expositions are often not the best adapted to a résumé. At first the plan of quoting was followed, but this was abandoned, because it was seen that carrying it out would add greatly to the size of this volume without enhancing, if indeed it did not diminish, the accuracy and comprehensiveness of the review.

Due proportion should be maintained between the abstracts of the various writings. Frequently a short article contains much more of structural importance than one of far greater length, although the longer article may contain much of interest which does not come within the scope of the paper. Into the summaries the editor enters only in so far that he must of necessity take what appears to him important and omit what appears unimportant. Undoubtedly in this respect many mistakes are made; future investigations will show that omitted facts and conclusions have greater importance than now appears; but a perfectly proportioned summary could be made only by perfect 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. For this local details are necessary. 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 assist in directing to the important literature.

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 writer does not agree are in general not criticised nor is any refutation attempted, unless the point at issue is one of such a fundamental character that it can not be overlooked.

The maps are in all cases compiled from the original sources, and, like the summaries, have whatever excellence or defects the original work has. In many cases the editor feels assured that the maps will need to be materially modified, but he has not the detailed knowledge necessary to make the modifications. The generalized character of the boundaries is often indicated by the fact that they are straight lines. It need not be said that true geological boundaries are not of this nature in much disturbed regions. In the Appalachians the maps merely outline the crystalline rocks. Much of the area included is known to belong to the Paleozoic, but it is impossible either accurately to separate these areas or to subdivide the pre-Cambrian. All that can be done in many areas is to indicate that the rocks are pre-Cambrian, although it is oftentimes certain that Algonkian and Archean rocks both occur, which have not been separated in mapping. In a few regions, not only can the Archean and Algonkian be discriminated, but the latter has been subdivided into series and these into formations. There are then on the maps all grades of knowledge, from the eastern United States, where the pre-Cambrian is not outlined, to areas in which pre-Cambrian series are divided into formations. The maps, as the summaries, are a résumé of the present imperfect knowledge.

The order in which the districts are taken up is not consistently geographical or geological, but rather the order of the development of exact knowledge of the pre-Cambrian rocks. The great Canadian pre-Cambrian area in all its parts is a geological unit, yet the detailed study of it has been confined somewhat closely to particular regions; and of necessity the regions which have been units of work have to be followed rather than a strictly logical order. Chapter I is devoted to the original Laurentian and original Huronian areas. Chapter II is given to the lake Superior region. These regions are taken first because the exact knowledge of the pre-Cambrian rocks is here greater than in other areas. The Appalachian region, although the earliest to be studied, is reviewed last, for it is the area in which the conditions for obtaining exact knowledge are the least favorable, and about which comparatively little structural knowledge of the pre-Cambrian has been acquired.

In the summaries of the individual districts the order is that of appearance of the papers. 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 and the subject of correlation is here treated.

In regard to regions like the Appalachians and California, in which post-Cambrian rocks have become completely crystalline and have been for many years and are yet confused with pre-Cambrian rocks, summaries unavoidably extend beyond the proper scope of this paper. Of series which were in the past supposed to be pre-Cambrian, but which have been demonstrated to be Cambrian or post-Cambrian, the fact is mentioned, but the literature which concerns them is not summarized, since it does not fall within the scope of this paper. The particular position which such formations shall take in Cambrian or post-Cambrian time is a subject for others to consider.

Of necessity the eruptives which have not been differentiated from the pre-Cambrian have to be considered. Oftentimes it is quite probable that eruptives noted belong to post-Cambrian time. No paper is summarized bearing upon the unmistakable Cambrian or post-Cambrian eruptives unless it has a direct bearing upon the character or relations of the associated rocks of pre-Cambrian age.

All references to literature are given at the ends of the respective 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.

The terms group, system, series, are used with the stratigraphical significance given them by the International Geological Congress. The corresponding chronological terms era and period are used. Formation is used as one of the members of a series, as quartzite formation or limestone formation of the Huronian series. The term "crystalline schist" is rigidly confined to rocks which have a "completely crystalline interlocked texture, which is possessed of a schistose parting due to a parallel or foliated arrangement of the mineral ingredients, or of aggregations of these ingredients." The finely banded gneisses are typical examples. All rock masses which within themselves show indubitable evidence of clastic origin are excluded from the crystalline schists and are regarded as semi or partially crystalline. A clastic or semi-crystalline formation may grade into a crystalline schist.

In the summaries of results and in the general discussion (Chapter VIII), unless otherwise stated, the term Cambrian is delimited below by the Olenellus fauna. The term Algonkian is a system term, covering all recognizable pre-Cambrian clastic rocks. The term Archean is a coordinate-system term, covering all pre-Algonkian rocks. It therefore includes only completely crystalline rocks, but does not include all rocks of this kind, as holocrystalline rocks of eruptive and sedimentary origin may occur in Algonkian or post-Algonkian time. The propriety of these usages will appear in what follows.

CHAPTER I.

THE ORIGINAL LAURENTIAN AND HURONIAN AREAS.

SECTION I. EASTERN ONTARIO AND WESTERN QUEBEC.

LITERATURE.

LOGAN,[1] in 1847, describes between the Ottawa and Mattawa rivers, a metamorphic series of rocks, 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 coarse 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, with 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 ranged 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 half way 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 a widespread occurrence upon the river du Nord and the country to the westward. The Potsdam formation rests unconformably upon the metamorphic series.

MURRAY,[3] in 1852, describes a metamorphic series upon and north of the Upper St. Lawrence. On the Thousand isles are micaceous and hornblende gneisses. Crystalline limestones, quartzites, and conglomerates are all found upon the mainland, and the latter is cited as decisive evidence of the metamorphic character of the series as a whole.

[1] For notes see end of chapter, p. 48.

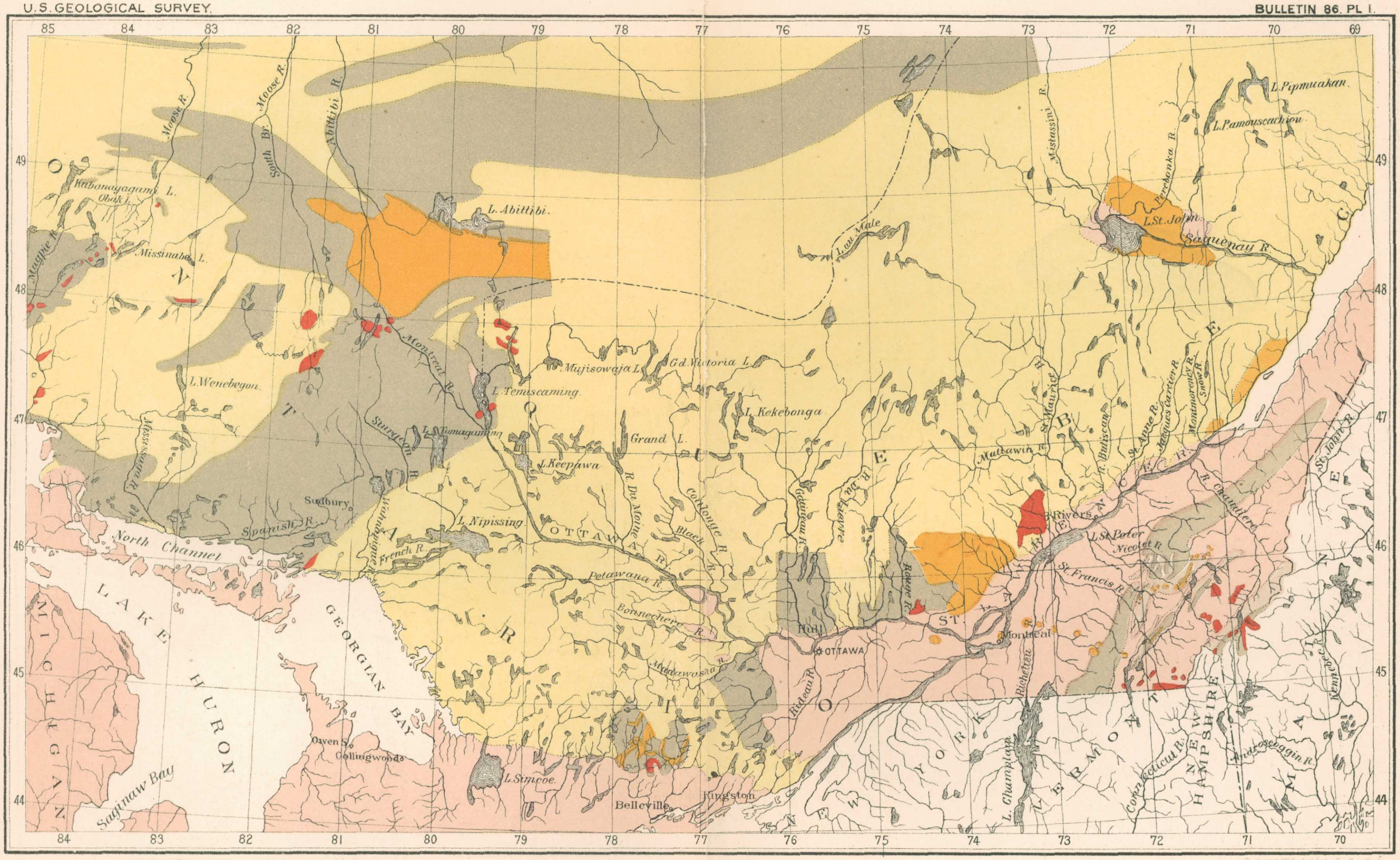
LOGAN,[4] in 1854, applies to the series before called "metamorphic" underlying the fossiliferous formations of Canada the name Laurentian series, because metamorphic is applicable to any series of altered rocks. The proposed name is founded on that given by Mr. Garneau to the chain of hills which they compose. Above the Laurentian series is the Potsdam sandstone.

MURRAY,[5] in 1854, remarks that south of the Laurentian series are the more recent fossiliferous rocks. The Laurentian series consists of masses of micaceous and hornblende-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 of 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,[6] in 1857, describes the Laurentian formation for some distance north of the 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, on account of the repetition of layers by folding and lack of fossils, the work is very difficult. 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.

MURRAY,[7] in 1857, finds Laurentian rocks largely exposed between Georgian bay and the 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 the Maskanongi and Sturgeon rivers, its course being in a northeasterly direction.

HUNT,[8] 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.



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UNCLASSIFIED PRE-CAMB. | ALGONKIAN | ALGONKIAN? | POST-ALGONKIAN | ERUPTIVES: GRANITIC, BASIC

GEOLOGICAL MAP OF A PORTION OF CANADA

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from Official Maps of the Canadian Geol. Survey

Scale 1/5,449,000.

LOGAN,[9] in 1858, in describing the Laurentian of Ottawa thinks it probable that it can be divided into two great groups: that characterized by the presence of limestone and that without, and 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 range of mountains 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 the Rouge river. There are found to be two belts which are 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 over 22,000 feet, of which over 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 rocks and quartz rocks 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, 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 one a thickness of 400 and the other a thickness 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 schists are more abundant near the interstratified bands of limestone than elsewhere, and in the same neighborhood there usually occurs a more frequent repetition of beds of quartzite than in other parts. Garnet is sometimes disseminated in the micaceous and hornblendic gneiss and quartzite and are 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 conglomeritic 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 possesses a 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, and 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; Proctor's 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 uncomformably. It is remarked that if the two inferior limestone bands of the Grenville series disappear on reaching the margin of the anorthosite, it 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 isles, 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. As proofs of life are the occurrence of limestone, carbon, phosphorus, sulphur, and iron ore. 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, horneblende, 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 1866, further describes the distribution and structure of the Ottawa Laurentian limestone. There are here three great conformable bands, which are termed the Grenville, Green lake, and Trembling lake bands. In these limestones Eozoon is found.

LOGAN,[16] in 1867, states that the Hastings series is arranged in the form of a trough, and that to the eastward, 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,[17] in 1867, gives the ascending section of Laurentian rocks in Hastings county as follows: Red feldspathic gneiss, 5,000 feet thick; 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[18] (Sir William), in 1869, states that the graphite of the Laurentian is scattered through 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 corresponds with that of micaceous and bituminous matter in marine formations of modern date; third, if of metamorphic origin, it has only undergone the metamorphosis 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,[19] 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,[20] 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 lowest, and it is probable that the middle group is unconformably below the upper and unconformably above the lower group.

VENNOR,[21] 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, quartzites, and limestone are cut by a network of veins.

VENNOR,[22] in 1873, gives an additional report upon 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 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 one-fifth of an inch broad have a length of from 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, graduating 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,[23] 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,[24] 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 have many subordinate phases of rocks; they occupy distinct and separate positions, but it is not known whether they represent one or more formations.

VENNOR,[25] 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. Both Logan's Huronian and Upper Laurentian are 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,[26] 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; and these last have also been shown to be a low portion of the gneiss and limestone series, that is, groups IV, V, and VI; and 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 the 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 the Silurian does in this section of country to both of these together.

There is thus in these old crystalline rocks a great uncalcareous 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 lowest and oldest. As shown by the map, north and northwestward of the line, at the base of the gneiss and limestone series, there 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 is 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 from 50,000 to 60,000 feet. No attempt is made to estimate the thickness of the underlying gneiss and syenite series.

BELL,[27] 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 anticlinals and synclinals. 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.

WILKINS,[28] in 1878, describes near the Grand Trunk station of Shannonville, about three-quarters 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 Gibson's mountain, 6 miles southwest of Belleville, occurs Laurentian porphyritic coarse grained granitoid syenitic gneiss.

SELWYN,[29] in 1879, states 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 quite unconformably upon a massive granitoid, syenitic, or red gneiss series, and are unconformably below the Potsdam or Lower Silurian rocks. The same may be said of the Huronian series of Georgian bay, which at lake Nipissing include 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 thought 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, is 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 stratigraphical relations.

SELWYN,[30] 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.

SUMMARY OF RESULTS.

It is apparent that the great area, roughly bounded by Georgian bay, the Ottawa and St. Lawrence rivers, to which the term Laurentian is applied, is, as a whole, a very crystalline one. This is so far true that no attempt has been made over the greater part of the area to stratigraphically subdivide the rocks. The exceptions to this are a small area in Argenteuil and adjacent counties, and a strip of country running from Ottawa to Madoc. Even in the districts in which the detailed maps are given there is no estimate of the thickness of the layers of the more massive parts of the series.

In discussing the stratigraphical succession, large areas of the rocks, including syenite, granite, porphyry, etc., can be excluded, for it is certain, as was early recognized by Logan and Murray, that many of these rocks are eruptives of later age than the gneissic and schistose rocks with which they are associated.

Logan, Murray, and Vennor in his final comprehensive review, reached the same stratigraphical conclusions. Occupying the inferior position in this region is an immense thickness of syenitic, granitic, and gneissic rocks. For the most part this lower division is intricately folded, and if it has a stratigraphy, it is of so complicated a character that no estimate is made of the thickness. Where a structure is present there is no evidence that it is due to sedimentation. It contains no bedded limestones, no carbonaceous schists, no clastics, either volcanic or water-deposited. It is, then, a complex, devoid of any structure which has been shown to be bedding, devoid of any materials which may not be of other than surface origin. As described by Vennor, this lower non-calcareous Laurentian covers the larger part of the region. That limestones were at one time supposed to be contained in this series is explained by him to be due to the fact that overlying bands of the upper division are included as infolded troughs.

Upon these rocks rests a series of a very different lithological character. It includes great thicknesses of limestones, quartzites, conglomerates, hornblende-schists, mica-schists, and bedded gneisses. If the limestones, quartzites and the regularly bedded character of the gneisses are not sufficient evidence of a clastic origin, the presence of unmistakable conglomerates at numerous points is conclusive. This clastic series, as shown by the descriptions of it in the vicinity of Madoc, is in part clearly volcanic. The very great estimated thickness of this bedded series may be questioned, for evidently the study was not close enough and the structure well enough determined to decide this difficult question. The equivalence of the clastic rocks of the different districts has been assumed, but those more distant from the type area differ considerably from it in lithological character as well as from each other. That they are really equal has not been shown, although this is probable for certain of the districts.

As to the anorthosite series it may be excluded from the bedded succession. It is now believed by most geologists that this rock is an eruptive. The unconformity at its base is an eruptive one, in all probability caused by the outflowing of this rock at a later period than the formation of the underlying series.

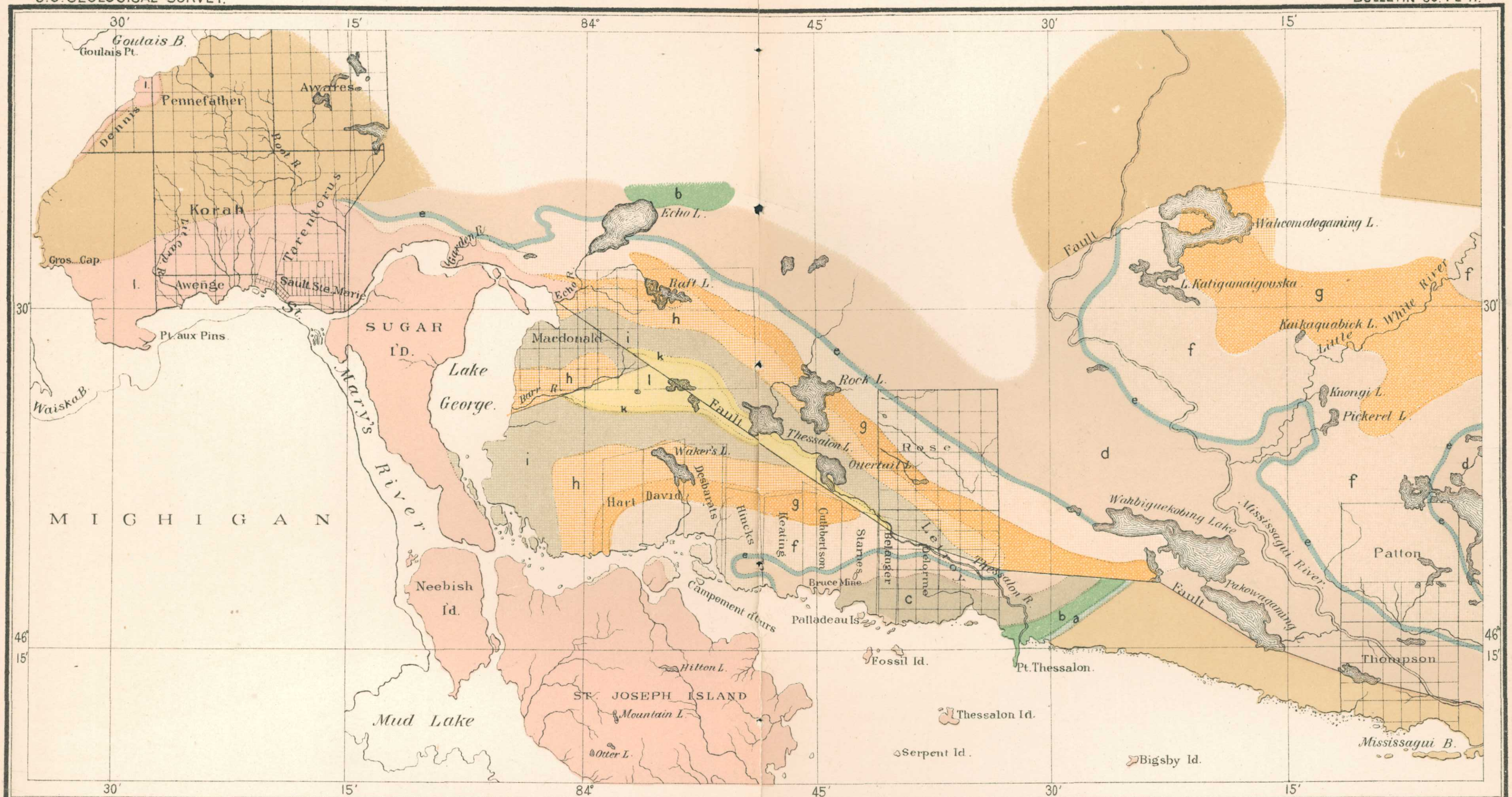
The Laurentian clastic series of the type area resembles, to a remarkable degree, the bedded gneisses, limestones, graphitic schists, and quartzites of the Adirondacks, except that the latter have become more completely crystalline. The core of the Adirondacks is "anorthosite rock," really gabbro, and away from this the bedded series dips in a quaquaversal manner, so that the anorthosites apparently underlie the clastics. This is explicable by regarding the anorthosite as an intrusive which has pushed up the bedded clastics, causing the latter to dip away from it in every direction. In the Ontario area it appears that the "anorthosite" has actually burst through and overflowed the clastics.

Comparing the bedded clastic division of the Laurentian with the Original Huronian, the description of the latter by Bell at Nipissing approaches closely in lithological character that of the Huronian, to which division the series was referred by Selwyn. The clastic series in the vicinity of Madoc, before Vennor realized that it is probably a continuation of that to which the term Laurentian was applied at Ottawa by Logan, was considered as Huronian, and by Logan himself was supposed to be higher than the Grenville series.

These two districts are intermediate in position as in character between the type areas of upper Laurentian and the Huronian.

The clastics of the Laurentian nowhere come in contact with those of the Original Huronian area, so that we have no evidence whatever as to their relative age. The former are underlain by a banded and contorted gneissic and granitic series. The same is true of the Huronian of lake Huron. In this latter area the clastic series rests unconformably upon a lower gneissic one, but in eastern Ontario we have no positive evidence that similar relations obtain; but it is not improbable, as maintained by Vennor, that there is at the base of the clastic series a true unconformity. On the other hand, it is possible that the relations between the clastic series and the underlying completely crystalline series are those of sedimentary rocks and later intrusives.

Bearing in favor of an unconformity between the lower granite-gneiss and at least a part of the clastic series are several lines of evidence: (1) In Leeds, Frontenac, and Lanark counties the granites which cut the Laurentian gneisses in a network of veins never penetrate the series of quartzites, conglomerates, limestones, etc., although sometimes found in Vennor's middle or dioritic division. This indicates that the granite-gneiss not only existed but had been intruded by granitic eruptions before the clastics were deposited. (2) The abundant large pebbles and bowlders of granite and syenite found at many localities in the Laurentian region, and particularly about lake Nipissing and near Shannonville, show that earlier than the clastics existed gneisses and granites identical in character with those now designated as Laurentian. The probability is that these pebbles are, as supposed by Logan and Wilkins, derived directly from the Laurentian. If this is the case, between the two must have existed a great time gap, for these fragments when deposited show that the rocks from which they are derived were then at the surface in their present completely crystalline condition. (3) The rocks of plainly clastic origin are associated and occur in trough-like areas, although having interstratified with them comparatively thin belts of gneiss, which, however, may be meta-



ARCHEAN

ALGONKIAN
HURONIAN

POST-ALGONKIAN

- a Gray Quartzite
- b Green Chlorite Slate
- c Lower White Quartzite
- d Lower Slate Conglomerate
- e Limestone
- f Upper Slate Conglomerate
- g Red Quartzite
- h Red Jasp. Conglomerate
- i Upper White Quartzite
- k Yellow Chert & Limestone
- l White Quartzite, Chert & Limestone

MAP OF THE ORIGINAL HURONIAN ROCKS

(After Logan)

Scale $\frac{1}{506.880}$

Sackett & Wilhelms Litho. Co. New York.

morphosed sedimentaries. That this series is newer than the granite-gneisses, is indicated by the fact that the intricate structure of the lower Laurentian is not simulated by the clastic rocks. Apparently the latter has undergone earlier and more intense orographic movements than the former.

SECTION II. FROM NORTH CHANNEL OF LAKE HURON TO LAKE TEMISCAMANG.

LITERATURE.

BIGSBY,[31] 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,[32] 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,[33] 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 (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,[34] in 1847, having visited Echo lake and the Bruce mine, finds the rocks of the North channel to consist of sandstone, talcose slate, 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,[35] 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, 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,[36] 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 consist, firstly, of a metamorphic series, composed of granitic and syenitic rocks in the forms of gneiss, mica-slate, and hornblende-slate; and, secondly, in 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. The breadth of country this series occupies, and the thickness it attains, there was no opportunity of determining. 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,[37] 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. Upon 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,[38] in 1850, gives the result of a survey of the Spanish river. Upon 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,[39] in 1852, states that on lake Huron the Lower Silurian group rests unconformably upon a siliceous series, containing one band of limestone about 150 feet in thickness, having leaves of chert, but without discovered fossils. The series is 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 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,[7] 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 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 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; and 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 the Spanish river.

LOGAN,[40] 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,[41] 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,[42] 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 Temiscamang 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 degrees. 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,[43] 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,[44] in 1862, concludes that the Huronian is greatly older than the Cambrian because: (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,[12] 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, 200 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, however, also present 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 Missisagui 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 each other. 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,[45] 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.

SELWYN,[30] 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,[46] 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 depth, and therefore has been subjected to great erosion in order that this class of rocks may be found 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 at the vicinity of the mouth of Serpent river. Logan's[2] green, chloritic slate is composed of diabase sheets and a little interleaved fragmental material, perhaps partly volcanic ash.

WINCHELL (N. H.),[47] 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 (ALEX.),[48] in 1888, also gives many 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, with an equal volume of an obscure slaty character. 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, in descending order, is as follows: 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. Joseph's island the Huronian is immediately overlain by a fossiliferous limestone, apparently the Chazy. It thus appears that the Huronian is a system following downward immediately below the Lower Silurian, and 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, 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,[49] 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,[50] in 1890, describes the relations between the Huronian and 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[51], 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, namely, by the direct conversion of the thin bedded or slaty varieties of graywacke, by the alteration of the mixed quartz and feldspar rock derived from other varieties of it, and by the 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 (ALEX.)[52], 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 are close to a vertical attitude, strike nearly east and 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 Doré 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 (ALEX.)[53], 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 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 to the southward of 78°, while 2 miles south of this the slate-conglomerate has a dip of 40° toward 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 of 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 a series, in descending order, of 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° southwesterly, 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 until 1886 as Keewatin by Lawson, the term Kewatian is proposed.

BELL,[54] in 1891, describes the geology of the district of Sudbury. The main outlines of the great Huronian area of this region are given. Within this 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, and 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 two 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 a mile to ten miles in length. Also are associated obscurely stratified varieties of quartz-diorite and of dioritic and hornblendic 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.),[55] 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, with 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 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,[56] 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 is now the original limestone. 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 two 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 debris 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, that this slate conglomerate is the lower one, and, if so, 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 the water was very low, and two islands upon which the contact occurs were then 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 water-worn appearance. However, in any given area the fragments are always of material identical with that of the immediate 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 its 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 to be found 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.

SUMMARY OF RESULTS.

Bigsby's Transition formation is that to which the term Huronian was later applied by Logan and Murray, and his description of this series is hence the earliest. From the first it is plain that Murray does not consider the series as metamorphic, since it is excluded from the rocks to which that term is applied. It is also plain that the true nature of the interbedded greenstones was appreciated. Logan was distinctly a stratigraphical geologist, who believed in extreme metamorphism of sedimentary beds, yet he also clearly saw that the greenstones associated with the fragmental rocks could not be regarded as other than of igneous origin.

As to the relations of the Huronian and Laurentian north of lake Huron, Murray made the distinction in 1857 to rest upon age and upon lithological characteristics, the Laurentian being older and more completely crystalline than the Huronian. While the Huronian and Laurentian by Logan and Murray are not described at any definite locality as having unconformable relations, the former 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. The first to describe an actual contact between the underlying gneissic series and the overlying Huronian was Irving, who in 1887 clearly showed that such an unconformity occurs. The observations of Pumpelly and myself reenforce this conclusion and show that between the lowest member of the Huronian and Laurentian complex is a very great discordance.

The facts given by Barlow, taken in connection with the foregoing, show that he has neglected to differentiate the clastic rocks of the Huronian, from the more ancient underlying crystalline gneisses. Also, he has failed to separate an earlier granite-gneiss from a later intrusive. That a part of the granite is eruptive, of later age than the Huronian, was as well known to Logan and Murray as to Barlow. These early geologists recognized both a later granite and a granite-gneiss basement complex upon which the Huronian was deposited, while the latter failed to make this fundamental discrimination. He saw the former and assumed that this covered the entire ground.

As to the position taken by Alexander Winchell, that the Original Huronian is divisible into two unconformable series, it may be remarked that the locality in which the strongest evidence for this is given, Echo lake, is on the outskirts of the area mapped in detail by Logan and Murray. Before accepting the conclusion that these geologists, in their careful work extending over several years in the area of the Original Huronian, have overlooked a great unconformity and have misunderstood what part of the area is covered by lower slate conglomerate and what by upper slate conglomerate, we ought to have the most decisive evidence. However, the observations of Pumpelly and myself tend toward the correctness of Winchell's first conclusion. At least between the limestone and the upper slate conglomerate, in places, there has been a considerable erosion interval. That with the Huronian in the more general work of later years Logan and Murray placed two discordant series is certain. The same was done by the geologists on the south shore of lake Superior, and in view of this very common reference it is stated in another place that for these two series the terms Upper Huronian and Lower Huronian are used. If it is really the case that in the Original Huronian of the north channel of lake Huron, in the area covered by the detailed map of 1863, two discordant series do exist, this suggestion is eminently appropriate.

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 stratigraphical methods apply, and Logan and Murray were able to subdivide it into formations upon a lithological basis in the same fashion 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 stratigraphical laws and separated both in descriptions and mapping. This is the more creditable because for many years afterwards similar rocks were supposed by many other writers to be parts of the stratified successions in a completely metamorphosed condition 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.

To the person who hypothecates that all pre-Cambrian rocks are wholly crystalline and that all truly detrital rocks are Cambrian or post-Cambrian, these conclusions prove only that inferior to the Potsdam sandstone, and separated from it by a great unconformity, is a series of rocks of great thickness, having a number of persistent members of varying lithological character, which are lower Cambrian. But this position does not lessen the value of the work done; for it would still be true that the Huronian series was the first so low in the geological column in which the above facts were shown.

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.

NOTES.

The following are the titles of papers and works cited in the foregoing chapter, reference marks to which appear in the text:

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[2] On the Geology of the Counties of Beauharnois and the Lake of Two Mountains, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1851–'52.

[3] On the Geology of the Region between the Ottawa, the St. Lawrence, and the Rideau, Alexander Murray. Ibid., pp. 59–65.

[4] W. E. Logan: Rept. of Prog. Geol. Survey of Canada for 1852–'53, pp. 8, 74.

[5] On the Geology of the Region between Kingston and Lake Simcoe, Alexander Murray. Ibid., pp. 75–133.

[6] On the Laurentian rocks of Grenville, Chatham, St. Jerome, etc., and the Economic Materials found in them, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1853–'54–'55–'56, pp. 5–57. Accompanied by a sketch map.

[7] On the Topographical and Geological Features of the Region between the Ottawa river and Georgian Bay, as well as North of Lake Huron, Alexander Murray, Ibid., pp. 59–190. Accompanied by two maps.

[8] Reports of T. Sterry Hunt. Ibid., pp. 397–494.

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[10] On the Distribution of the Laurentian Limestones, and of the Drift in the Grenville Region, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1858, pp. 8–40.

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[15] Summary Report of Geological Investigations, W. E. Logan. *Ibid.*, pp. 10–19.

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[18] On the Graphite of the Laurentian of Canada, J. W. Dawson. Ibid., vol. XXV, 1869, p. 406. See also vol. XXVI, pp. 112–117.

[19] On the Geology of portions of Hastings, Peterborough, and Frontenac Counties, Ontario, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada from 1866 to 1869, pp. 143–171. Accompanied by a geological map.

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[21] Progress Report of Exploration and Survey of Leeds, Frontenac, and Lanark, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1871–'72, pp. 120–140.

[22] On Explorations and Surveys in the Counties of Frontenac, Leeds, and Lanark, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada, 1872–'73, pp. 136–179.

[23] Report of Explorations and Surveys in Frontenac, Leeds, and Lanark Counties, Henry G. Vennor. Rept. of Prog. Geol. Survey of Canada for 1873–'74, pp. 103–146.

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[53] A Last Word with the Huronian, Alexander Winchell. Bull. Geol. Soc. America, vol. II, 1891, pp. 85–124.

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CHAPTER II.

LAKE SUPERIOR REGION.

SECTION I. WORK OF THE OFFICIAL GEOLOGISTS OF THE CANADIAN SURVEY AND ASSOCIATES.

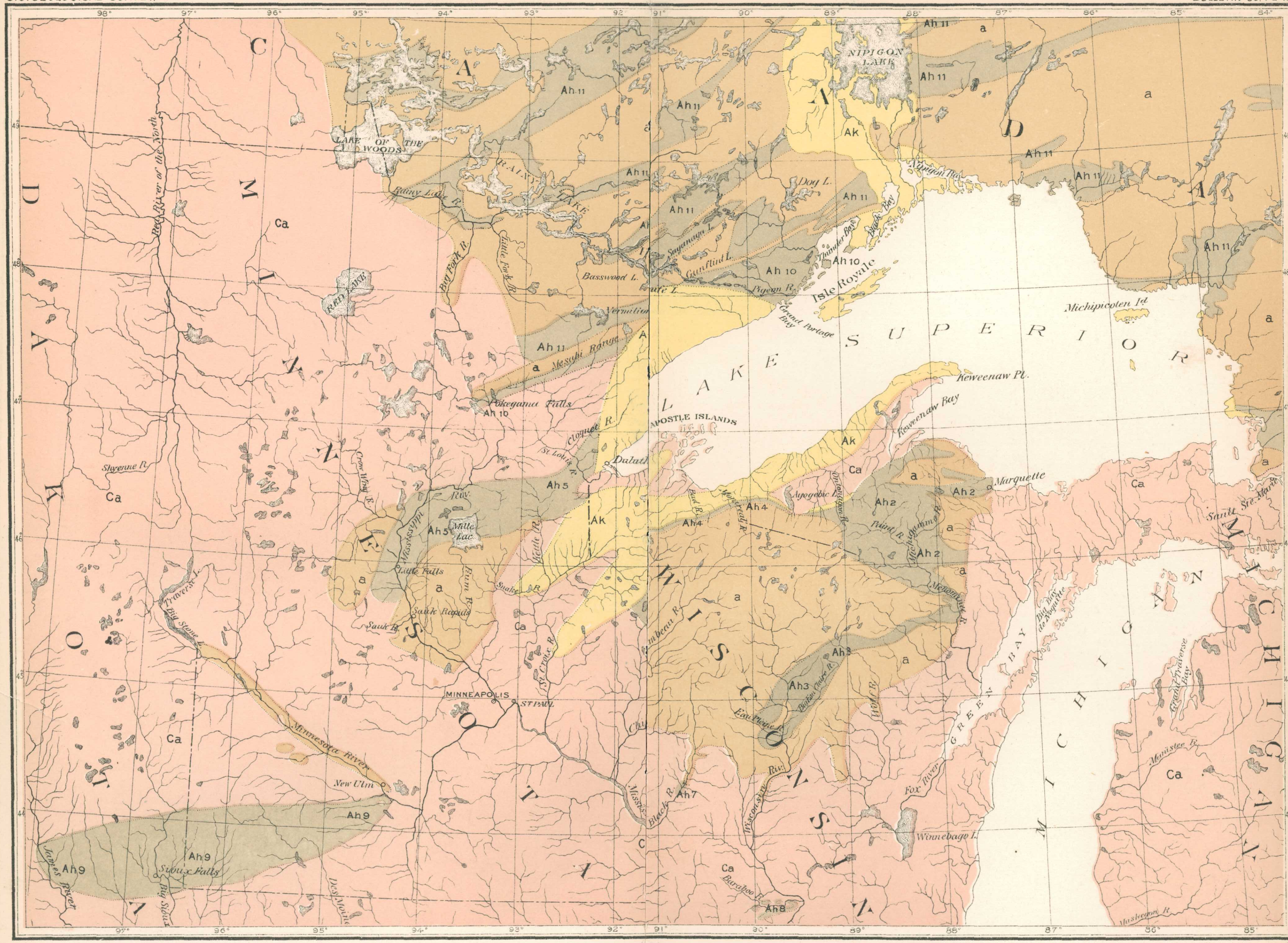
BIGSBY,[1] in 1825, describes in detail the rocks at many points along the north shore of lake Superior, between the falls of St. Mary and Grand Portage, an interval of 445 miles. The varieties of rocks are few in number when compared with a similar extent of country in Europe. Of mica-slate, clay-slate, 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, çaryophylliæ, 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,[2] 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,[3] 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 overlaid by an immense bed of greenstone. It is probable, although not certain, that this sandstone underlies the fossiliferous red sandstone of St. Marys.

LOGAN,[4] 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 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. These slaty beds at times have the quality of a greenstone, at times a mica-slate, and a few are quartz rocks. Higher in the series are conglomerates, the pebbles of which



ARCHEAN	ALGONKIAN		POST-ALKONKIAN
	Huronian	Keweenawan	
a	Ah	Ak	Ca

GEOLOGICAL MAP OF LAKE SUPERIOR REGION
SHOWING PRE-CAMBRIAN CRYSTALLINE ROCKS.
Compiled from Official U.S. and Canadian Surveys.

HURONIAN

- Ah — *The Original Huronian.*
- Ah 2 — *The Marquette-Menominee Iron-Bearing Schists.*
- Ah 3 — *The Wisconsin Valley Slates.*
- Ah 4 — *The Penokee Iron-Bearing Schists.*
- Ah 5 — *The St. Louis Slates.*
- Ah 6 — *The Chippewa Valley Quartzites.*
- Ah 7 — *The Black River Iron-Bearing Schists.*
- Ah 8 — *The Baraboo Quartzites.*
- Ah 9 — *The Sioux Quartzites.*
- Ah 10 — *The Animikie Series.*
- Ah 11 — *Folded Schists of Canada.*

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 Temiscamang. 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,[5] in 1847, in an account of the 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,[6] 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,[7] 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 northeast 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,[8] 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,[9] 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 ENE. strike, and a NNW. 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 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 frequent, and so is the occurrence of veins of porphyritic granite traversing the gneiss in all directions. The chlorite-slate greenstone, gneiss, and mica-slate are conformable with each other.

DAWSON (SIR WILLIAM),[10] 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,[11] 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 are 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. Rising in the series the dark green slates become interstratified with layers holding a sufficient number of pebbles of different kinds to constitute conglomerates. It often happens, unless the pebbles are of white quartz, that they are very obscurely distinguishable on fracturing the rock, 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 being 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 the 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 Royale and Michipicoten, at which latter island the total volume of the formation is at the most moderate estimation 12,000 feet. Upon 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, 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 contrasts 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, [12] in 1866, gives observations on the Laurentian, Huronian, and Upper Copper-bearing rocks of lake Superior. The Laurentian series on lake Superior seems to differ somewhat from 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 this latter 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 Doré 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,[13] in 1868, describes the rocks of the north and east shore 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 conglomerates 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,[14] 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,[15] 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 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 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 appear to be composed of rocks of the Huronian series, consisting of diorites, dioritic conglomerates, hornblendic and fine grained micaceous slates, with some quartzites.

BELL,[16] 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,[17] in 1872, finds in the country between lake Superior and the 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,[18] 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 lake Huron and Superior.

BELL,[19] 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 lake 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, 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,[20] 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 with a few miles to the eastward. 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,[21] in 1874, in the country between the Red river and the South Saskatchewan, finds extensively 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 each other.

DAWSON (G. M.)[22], 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 rest 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 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 an 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 altered Laurentian rocks.

BELL,[23] in 1875, describes on the north 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 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, sandstones, often covered with trappean outflows. For this Upper Copper-bearing series the term Nipigon group is proposed.

BELL,[24] 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,[25] 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 the Goulais river there are again alternations of Laurentian and Huronian rocks.

BELL,[26] 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 tufas, 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,[27] in 1879, in discussing Selwyn's paper on the Quebec group, maintains that there is 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 cap, south shore of Batchawana bay, and cape Gargantua. The conglomerates are full of Huronian débris, and in Batchawana bay bowlders may be observed 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° to the southeast, while the nearest Huronian rocks dip 34° to 55° northward.

BELL,[28] 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 system crosses the 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,[29] 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 unconformability 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 systems 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,[30] 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 in ascending order are (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,[31] 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 the surrounding region.

LAWSON,[32] 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 semi-crystalline 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 Keewatin schists, while in the Huronian of Logan such intrusions, if present at all, are mentioned at only one locality. The slate conglomerate of Doré river appears to resemble the lake of the Woods agglomerates, but this area is distant from the typical Huronian region and appears to differ from it lithologically, as well as being in a nearly vertical attitude. These differences between the Doré and Huron areas, with their geographical separation, may warrant the belief that possibly Logan embraced under one designation two distinct series. As to Prof. 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 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 quite 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 found oftentimes to be apparently interbedded. At other times 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 been in a fluid state intruding 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 merges in the same rock mass 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. Upon 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 they have been laid down and folded within a trough in the Laurentian formation.

HERRICK, TIGHT, and JONES,[33] 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, consisting of fragments of all the varieties 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,[34] 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,[35] in 1888, reports on the geology of the Rainy lake region. The pre-Cambrian rocks are divided into an upper and 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 frequent. The relations between the Keewatin and Laurentian are exactly like those described as maintaining upon 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, Rat-root bay, Keewatin conglomerate rests upon Coutchiching schists, the conglomerates containing water-worn 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 five 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 acid division, the latter being higher in the series than the former. Microscopical study leads to the conclusion that the series has been subjected to 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 may 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 now 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. Calculating the thickness upon this basis, it is found that 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 Laurentian. In the Coutchiching series there are no intercalations of recognizable volcanic rocks such as are found in the Keewatin, the rocks being acid 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,[36] 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 approximately a horizontal position and contrast markedly with the steeply inclined or almost vertical older rocks. The Animikie formation is divisible into an upper and 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,[37] 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. A part of them are of similar origin with characteristic tracks of the Cambrian rocks of the St. John group of New Brunswick.

LAWSON,[38] 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,[39] 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 the 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, there is a large area which gives off arms to the northeast and 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, which has been already alluded to, 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 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 are 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 really concretions of a lenticular form, and differing 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 ores are common in these rocks. Gneiss is not common in the Huronian, and it differs from the ordinary Laurentian gneiss in being imperfect and slightly calcareous.

In the upper division of the Huronian probably the most abundant rock in Ontario is what 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 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 their immediate vicinity, 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 the ascending order, the Animikie, Nipigon, and Potsdam formations.

The Animikie formation, in ascending order, consists of arenaceous conglomerate, with pebbles of quartz, jasper, and slate, seen on the north shore of Thunder bay; of thinly bedded cherts, mostly of dark colors, with argillaceous and dolomitic beds; of 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, tufas, 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,[40] 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 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.),[41] 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 as 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 the 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, in ascending order, are 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 synclinal, a middle anticlinal, and a western synclinal, the latter being faulted. The axes of these folds have a high pitch to the southward, 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 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 monoclinal which, under the action of the cleavage-producing force in a northeast and 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 one another, to great orotechnic forces, which acted—the first in a northeast and southwest direction, and the second in a northwest and 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.

SECTION II. WORK OF THE EARLY UNITED STATES GEOLOGISTS AND ASSOCIATES.

SCHOOLCRAFT,[42] in 1821, in his Narrative Journal of Travels in the Northwest, 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 the Montreal river and for a few miles beyond it toward Chequamegon bay. On the St. Louis river, after passing red sandrock 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.

CATLIN,[43] 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.

LOCKE,[44] 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 semifusion with a corresponding degree of induration, while others seem scarcely to have been altered.

CUNNINGHAM,[45] in 1845, SANDERS,[46] in 1845, CAMPBELL,[47] SANDERS,[48] GRAY,[49] in 1845, GRAY,[50] in 1846, give various detailed observations as to the mineral regions of lake Superior, but give little or nothing of structural interest.

ROGERS,[51] in 1846, describes the red sandstones and conglomerates of lake Superior as resting unconformably upon highly inclined slate rocks undoubtedly Primal, and the Potsdam sandstone of the New York survey at Chocolate and Carp rivers, and therefore of post-Paleozoic age.

OWEN,[52] 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.

LOCKE,[53] in 1847, speaks of the relation of the trap rock and sandstone at Presque isle, and submits a drawing of it.

WHITNEY,[54] in 1847, describes the wide band of trappean rocks commencing at the extremity of Keweenaw point as continuing its course uninterruptedly as far as the 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.

OWEN,[55] 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.

NORWOOD,[56] in 1847, describes various rocks on the St. Louis river in the district between Fond du Lac and the falls of St. Anthony, and from the mouth of the Montreal river to the headwaters of the Wisconsin river by way of lake Flambeau. On the St. Louis river a conglomerate is found to rest unconformably upon the lower slates, the junction of the slates and conglomerates being exposed.

ROGERS,[57] in 1848, remarks that the south shore of lake Superior is outlined by a series of east and west dikes.

WHITNEY,[58] in 1848, finds in the townships near the Anse fossiliferous limestone, which seems to be surrounded by and has been deposited on the lake Superior sandstone.

FOSTER,[59] 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.

Upon the 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.

JACKSON,[60] 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 Royale about one quarter of the area is sandstone and conglomerate and the remainder trap, which formed ridges extending the whole length of the island.

WHITNEY,[61] 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.

AGASSIZ,[62] 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 shores 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, into 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.

JACKSON,[63] DICKENSON, MCINTYRE, BARNES, LOCKE, FOSTER and WHITNEY, GIBBS, HILL, BURT, and HUBBARD, in 1850, report upon the mineral lands south of lake Superior in the state of Michigan.

JACKSON,[64] 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 semi-fused 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 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 the 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[65] 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[66] accompany their synopsis of their explorations by geological maps of the region between Portage lake and the Montreal river, Keweenaw point, isle Royale, and the region between Keweenaw bay and Chocolate river.

WHITNEY[67] 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 granitic 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 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[68] 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 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 is 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 the 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 Royale 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 Bête 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[69] 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 are a series of alternating strata of sandstone and conglomerate.

HUBBARD[70] 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-slate.

BURT[71] finds in the area bounded on the north by the Fifth Correction line and south by the Fourth Correction line and the Brulé 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,[72] 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 labrador 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 Royale dip in opposite directions and form a synclinal trough. Near L'Anse is a limited patch of limestone which has a dip to the eastward from 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[73], in 1851, report on the iron region of lake Superior land district, and give and 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 Royale 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 their 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 Royale, except that the dip of the sedimentary rocks is reversed, thus rendering 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 the 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 done by Logan 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 do 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., is 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 locks are cemented together by a hard ferruginous paste.

The granites belong to two different epochs: That 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, was 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, 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, and 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 the 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,[74] 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,[75] in 1851, farther speak of the age of the lake Superior sandstone. The sandstone of the 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 as 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 resting upon the sandstone effectually completes the chain of evidence.

OWEN,[76] 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,[77] in 1852, discusses the age of the red sandstones of lake Superior. The test of lithological character, if alone applied, is in favor of the view that they are of the same age as the red sandstones of New Jersey and Nova Scotia. On the 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, 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 the adjacent beds, that tilted red sandstones dipping to the south really may never rest conformably under the white and buff sandstones, but merely abut against them and not in fact 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.

NORWOOD,[78] 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 the St. Louis and Black rivers the sandstone rests unconformably upon the underlying argillaceous and siliceous slates.

WHITTLESEY,[79] 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, 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, slaty quartz. (4) Granitic, including syenite and granite. The granites and syenites of the interior are the most ancient rocks of the district. After the protrusion of these granitic masses many changes have occurred. The sandstone deposits of lake Superior must have been subsequent to the granites of the Wisconsin, Chippewa, and Montreal rivers; since 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 away to the 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 stratification, has spread out between the beds, forming alternate strata of trap and sandstone without any visible conglomerate.

SHUMARD,[80] 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.

JACKSON,[81] 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 Royale is a vesicular rock formed by the interfusion of sandstone and trap rock.

MARCOU,[82] 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,[83] 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,[84] in 1855, states that the granitic 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 straits of St. Mary's 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 granitic series, which continues to Gros cap on lake Superior. The red sandrock 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 Royale, and the long peninsula of Keweenaw. The sandstone of the southern 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 the second is at Grand island.

WHITNEY,[85] 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,[86] 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 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 are 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,[87] 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.

JACKSON,[88] 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 upon isle Royale such as are 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 Royale.

ROGERS,[89] 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.

WILLIAMS and BLANDY,[90] 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 nearer horizontal toward the northwest, until finally the sandstone which succeeds it becomes absolutely so.

KIMBALL,[91] 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 stratigraphical 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,[92] in 1867, finds at two ravines near Torch lake—one the Douglass Houghton—that the sandstone rests unconformably upon the trap. The trap dips N. 42°, while the sandstone, 100 feet distant, lies nearly horizontal, with no trace of an anticlinal axis between. The sandstone contains water-worn 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.

WHITTLESEY,[93] 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, Wisconsin.

WADSWORTH,[94] 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 only from the hard ore and jasper 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; 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 and were successively laid down one upon the other, are 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 has been maintained to rest against the trap and sandstone series unconformably, is found interlaminated with the melaphyres, and therefore 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 gradually declines in steepness, although still to the northwest, 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.

WADSWORTH,[95] 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 cephalapods. The interior of the specimen is in all respects that of an ordinary volcanic rock.

SECTION III. WORK OF THE MICHIGAN GEOLOGISTS AND ASSOCIATES.

HOUGHTON,[96] 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,[97] 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, (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 northwesterly sides are invariably tilted to a high angle near the range of hills. The sedimentary rocks on the north are traversed by frequent dikes, varying in thickness from 50 to 400 or 500 feet. The 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 these 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 deposited around the conical knobs of trap 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 sandrock. This mixed rock occurs upon isle Royale and was seen to be very widespread upon 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 sandrock. The material of this sandrock 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 sandrock 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 sandrock conforms to the limestone above it, and rests conformably upon the uptilted edges of the red sandrock below.

WINCHELL (ALEXANDER),[98] 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. Joseph's and Sulphur islands suggests the idea of its being Azoic; but the gradual transition from the unaltered sandstone of the Sault to the altered sandstone of Neebish rapids and jasper conglomerates of the western shore of Campement d'Ours, favors the idea of the equivalency of the sandstone and quartzite, as it is also the fact that the fossiliferous Chazy limestone is found directly upon the quartzite at Sulphur island.

CREDNER,[99] in 1869, describes in the upper peninsula of Michigan the Laurentian and Huronian systems. 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; chlorites-chist, 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 the 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 Huronian. The Potsdam sandstone rests upon the Huronian and Laurentian unconformably.

BROOKS and PUMPELLY,[100] 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 from 60° to 40°. Also for a long distance between the 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 from 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 have been detected a lack of conformity between the Laurentian and Huronian in the upper peninsula of Michigan, but when the Huronian and Cupriferous are seen in contact there seems to be a well marked concordance between them.

BROOKS,[101] 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 total thickness of the whole Marquette series may have an aggregate of 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 or 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 aphanite) 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 a 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 degrees west of north. The non-conformability 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,[102] 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 Bête 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 from 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 Maj. Brooks and the author are in the country between the 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 from 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 the 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° southeast. The nearest outcrop of the cupriferous series is about 4 miles distant, and it strikes nearly east and west and dips 50° to the north. 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 are given at Portage lake, and one cross section at the Central mine describing the thickness and character of the alternating rocks in great detail.

MARVINE,[103] 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 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 over 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 acid rocks among the conglomerates was noted, and opposite Calumet the former presence of predominant quartz-porphyry was inferred.

ROMINGER,[104] 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 under 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,[105] 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,[106] 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 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 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 series is best exposed, the name Keweenawian is suggested for this period.

BROOKS[107], in 1876, gives a list of the rocks of the Huronian series in 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, both in the Marquette and 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 dike-like 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,[108] 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,[109] 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° to the south, while the plainly bedded Huronian strata in direct contact have a dip of 65° to the north. At the Macomber mine, near Negaunee, is found a bed of manganiferous hematitic shale bearing the impression of some fossil which Profs. 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.

ROMINGER,[110] in 1881, gives a general account of the Marquette and Menominee iron region, with very voluminous details as to particular localities.

The Marquette region.—In general remarks on the geology of the Marquette district the succession is (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 part 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 subsequently to the rocks cut.

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 non-stratified 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 fault. 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 quite often differ considerably. The rocks of this group are incumbent on the quartzite formation, but also sometimes rest upon the ore-bearing rocks, and quite 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 sandrock 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.

The 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-bearing 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.

WINCHELL (N. H.),[111] in 1888, describes in the Marquette district the conglomerate overlying the ore and jasper formation at several mines, 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 role 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 (ALEX.),[112] 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 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 is 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 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.

WADSWORTH,[113] 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.

WADSWORTH,[114] in 1891, modifies somewhat the foregoing account of the Azoic system. A portion of the jaspilites and associated iron ores are still held to be eruptive, but it is suggested that even for these supposed nonfragmental jaspilites of Ishpeming and Negaunee, their present relations 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 water-worn 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,[115] 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,[116] 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 from 5° to 14°, while in the vicinity of Torch lake it has a dip of from 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.

ROMINGER,[117] in unpublished manuscript of the Michigan Survey for 1881 to 1884, further reports upon 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 quite 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-bearing group, except in the country north of the Penokee range in Wisconsin, and in the vicinity of Duluth, Minnesota, 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 dike-like-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-ore group of the Marquette and Menominee districts before described is found at many localities important deposits of iron in both these regions 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 creek 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 the 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.

SECTION IV. WORK OF THE WISCONSIN GEOLOGISTS AND ASSOCIATES.

PERCIVAL,[118] 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, 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.

DANIEL,[119] 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.

LAPHAM,[120] 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 dip to the north.

HALL (JAMES),[121] 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 and west direction and had become uplifted and metamorphosed before the commencement of the Potsdam era. 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),[122] in 1862, describes the central and northern areas of Wisconsin as consisting of the Azoic rocks. These are hard and crystalline, are often destitute of lines of bedding, though they are in reality as regularly stratified as the more modern formations. Notwithstanding their crystalline character, their 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, 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 that we know that these 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 the Huronian system of the Canadian survey.

WHITTLESEY,[123] in 1863, describes the copper-bearing strata of Keweenaw point as extending southward across the boundary of the state 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 the Bad and Montreal rivers are found no masses of crystalline limestone.

IRVING,[124] 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.

MURRISH,[125] in 1873, describes the quartzite ranges of Baraboo as a metamorphic sandstone of the Potsdam age. On the Black and Yellow rivers are found granitic and hornblendic Azoic and plutonic rocks. 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 the Wisconsin river, Azoic rocks similar to those on Black river are found. A quartzite mound at Necedah occupies a geological position similar to the iron ores at Black river falls.

EATON,[126] in 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 Devil's 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 has suffered enormous erosion before washed by the waves of the Potsdam sea.

IRVING,[127] 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.

IRVING,[128] 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 of 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 are near their junction 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 dipping, whenever it is observable, always to the southward, and having no tilted sandstones and conglomerates associated with them. 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 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 synclinal of Copper-bearing rocks is found to extend west into northern Wisconsin.

SWEET,[129] 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 to the northward at an angle of 66°, while 100 feet to the south is a ledge of gneissoid granite showing a well defined dip of 77° to the south. There can be no doubt of the unconformability of these formations. The Penokee series is found to be about 5,000 feet thick, to be everywhere conformable, and to dip about 66° to the north.

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 the 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 synclinal is traced westward across the state of Wisconsin and enters the state of Minnesota. It is then over 300 miles in length and from 30 to 50 miles in width.

IRVING,[130] in 1877, summarizes the facts proved as to the older rock series of Wisconsin. There are here four series: The oldest (1) are 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 unconformability is to be seen at the Dalles of the St. Croix between the Potsdam and Copper series.

WIGHT,[131] 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. Almost in contact with the trap the sandstone contains numerous well preserved fossils. 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.

CHAMBERLIN,[132] in 1877, describes the Archean rocks which in the eastern part of Wisconsin protrude but are not intrusive in the Paleozoic formations. These are the Mukwa granite, the Berlin porphyry, the Pine bluff quartz-porphry, 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 deposit of the neighboring horizontal rocks, and which have been tilted and eroded before the stratified rocks were deposited. These quartzites are regarded as a portion of the Baraboo quartzite series.

IRVING,[133] 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, the quartzites of Chippewa and Barron counties on the west, and 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 unconformability, 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 by a prevailing gneissoid and schistose character, but also by 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, and a small area only on the south of the district is doubtfully Huronian.

Very numerous details are given as to particular localities, showing the manner of occurrence and relations of the different varieties of rocks and the unconformities which exist between them and the Silurian. On Mosinee and Rib hills are found 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 here found.

Isolated from the main Archean area are quite numerous exposures of crystalline rocks which protrude in mound-like forms from beneath the horizontal strata. The largest of these are the quartzite ranges of Baraboo. About many of these areas are 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,[134] in 1878, describes at Potato river the siliceous slate, 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,[135] in 1878, describes on the Gogogashugun, in the Penokee district, the exact junction between the Laurentian and Huronian series. 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 a hand specimen was obtained, one portion of which 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 is presented the greatest probabilities of the existence of workable ore.

IRVING,[136] 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, all of which are unconformable with each other. 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 have certainly an enormous thickness. It is evident that these rocks 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, 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, the strikes are oblique to the underlying Laurentian gneiss, proving the unconformability 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 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 the 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 Keweenawan rocks; (3) 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 the 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 much of the phenomena. That the sandstone formation rests unconformably upon th 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,[137] in 1880, describes the Huronian series west of Penokee gap. The succession here found is limestone, chloro-silicious schists, quartzites, magnetic schists, Keweenawan; the magnetic schists being occasionally interstratified with greenstone. At Penokee gap is found a dolomitic limestone overlain with quartzite and chloro-siliceous schists, which rest unconformably upon the Laurentian rocks. The Huronian rocks here have a dip of 66° to the north, while the Laurentian rocks have a southern inclination from 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,[138] 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 synclinal. In northern Wisconsin, below the Keweenawan, no southward dipping rocks are found referred to the Huronian, but in

Minnesota, along the 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. They are hence 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 over 36,000 feet. The quartzites, siliceous schists and chloritic slates along the 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 quite 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 be only said that they are older than the lake Superior red sandstone; 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 the 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,[139] 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 trough-like 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 the Potsdam is found directly superimposed in a small gorge upon the melaphyre. The melaphyre is cut by vertical planes of division which are quite smooth and uniform; but there is another persistent set which is much less smooth, but persistent and constant in direction. These planes are usually in detail slightly uneven and undulatory, and 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 made. Outside of the district the northward dipping diabase is found on one side of the Numakagon river, while upon the other is seen the Laurentian granite.

BROOKS,[140] 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 magnetic, 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 resemblance 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 always being much metamorphosed and often 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 dike-like masses of granite and greenstone. The abundant greenstone dikes of the Laurentian are much more common than in 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,[141] 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,[142] in 1882, further describe the quartzites of Barron 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,[143] 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,[144] 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,[145] 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, syneites, 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 investigations in the future 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 are taken as the evidence of life. After the deposition of the Huronian it was upheaved, metamorphosed and eroded before the beginning of Keewenawan 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 those 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,[146] 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 regarded as unsatisfactory. 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,[147] in 1884, describes, upon the 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.

FULTON,[148] 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.

SECTION V. WORK OF THE MINNESOTA GEOLOGISTS AND ASSOCIATES.

EAMES,[149] in 1866, mentions different crystalline rocks as occurring at many points in northeastern Minnesota.

EAMES,[150] 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),[151] in 1869, finds in the vicinity of New Ulm, on the 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,[152] 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),[153] in 1873, states that the granitic and metamorphic rocks occupy a great portion of the state 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.),[154] in 1874, gives details as to the geology of the Minnesota valley. The quartzites in the vicinity of New Ulm and R[illegible] stone, referred to the Potsdam, are conglomeratic in places. In the valley there are quite numerous outcrops of granite which are sometimes cut by trap dikes. At Granite falls there are sudden changes from real granite to hornblende-schist.

STRENG and KLOOS,[155] in 1877, describe in the Upper Mississippi a set of granitic, syenitic, dioritic, and gabbro-like rocks which 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 the 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 the 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.),[156] 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 the 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.),[157] in 1879, gives the geological results of an examination of the northeastern part of the state 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 seems to overlie several formations unconformably, and is interstratified with some of the later, and especially with Nos. 1 and 2.

WINCHELL (N. H),[158] 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,[159] in 1880, describes granites and gneisses at numerous localities in the Minnesota valley. In the conglomerate opposite New Ulm and in the quartzite at Red stone are found numerous pebbles of quartz and jasper, but no granite pebbles are seen, although it outcrops close to the west.

HALL (C. W.),[160] in 1880, describes the rocks between the mouths of Poplar and Devil's 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.),[161] 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 monoclinals 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 milky quartz is found in nearly a 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 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.),[162] 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 a 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 limestones, 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.),[163] 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 unconformability 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. As to 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 water-worn 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,[164] in 1884, describes the crystalline rock outcrops in central Minnesota.

CHESTER,[165] 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 jasper and quartzite and is intimately bedded with the country rock, chiefly sericite-schist, standing in nearly a 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.),[166] 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 the 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,[167] 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 the Mississippi and Minnesota rivers, the slates of the Upper Mississippi, 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),[168] in 1885, finds between Two harbors and Vermilion lake two rock ranges, the first being Mesabi proper and the second the Giant's range. Resting unconformably upon the syenites of Giant's 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.),[169] 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, as well as the associated red gneisses, felsites, and felsite-porphyries, are all Primordial.

UPHAM,[170] in 1885, gives descriptions of the quartzites of Minnehaha county, Dakota. 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.

WINCHELL (N. H),[171] 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. Below the granite and gabbro is (2) a mica-schist group. This is penetrated by biotite-granite. (3) Is the black mica-slate group, which often contains graphitic schists, in which are such ore deposits as the Commonwealth mine of Wisconsin. (4) Is 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) Is the great quartzite and marble group. It includes the marble of Menominee and marble and lower quartzite of Marquette, the great conglomerate of Ogishki Manissi lake and the lower slate-conglomerates of Canada. In (6) are 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.

WINCHELL (ALEX.),[172] in 1887, gives detailed observations made on an extensive 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° to the north to 80° to the south. 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 each other. 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 hornblendic 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.),[175] 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 micaschist. The Vermilion group is defined as including the lower portion of the complex series of schists designated as 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 Mayhew Iron range, and is found from this range at many points all the way to Duluth. The nontitaniferous magnetic 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, and in its relations to the jasperoid rocks it fills all their cavities, overlying them unconformably, and holding fragments of the jasper; 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 and 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 Giant's 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 each other.

There is reason for believing that the Animikie rocks overlie the greenstone No. 2 and underlie the gabbro, No. 1, of the above succession.

WINCHELL (N. H.),[174] 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 to the north grade conformably into the crystalline schists of the Vermilion group, and these still farther to the north by transition pass into the gneisses and syenites of the Laurentian. The Animikie rocks are found resting unconformably 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 Giant's range and belong in the same stratigraphical position near the beds 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 Kékékabik 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 (ALEX.),[175] 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 quite 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 cause of 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 as far as Duluth and still beyond to the 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, in descending order, then as follows: (1) Huronian system, over 4,082 feet thick, including the magnetic 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, over 1,500 feet thick, and the gneissic group, over 88,000 feet thick. Total, more than 121,082 feet.

WINCHELL (H. V.),[176] 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.

WINCHELL (N. H.),[177] 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 sandrock of Vermont, and the granular quartz of the Taconic.

WINCHELL (N. H.),[178] 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 ejectimenta 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 a 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 acid 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	Quartzite, 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.),[179] in 1889, gives further observations on the iron regions of Minnesota. On the Giant's 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 are found to contain fragments of the Animikie slates and quartzites, and is, therefore, of later origin. At Gunflint lake the Animikie rests uncomformably 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,[180] in 1889, gives geological observations made in northeastern Minnesota. North of Gunflint lake the vertical Keewatin and crystalline schists, with an east and 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 indicate 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 (ALEX.),[181] 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.),[182] in 1889, in a general discussion of the origin of the eruptive rocks, maintains that there are four epochs of basic eruption in Minnesota: first, the Vermilion group; second, those succeeding the graywackes; third, those succeeding the Animikie; and fourth, those of the Cupriferous formation.

MEADS,[183] in 1889, describes the Stillwater, Minnesota, deep well. The well, after passing through about 700 feet of St. Croix and Potsdam sandstone, passes into 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, and 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.),[184] 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 (ALEX.),[185] in 1890, repeats his general conclusions as to the stratigraphy in northeastern Minnesota and gives in descending order a succession, as follows:

V. The Uncrystalline schists (Animikie, Huronian).
IV. The Semi-crystalline schists (Keewatin).
III. The Crystalline schists (Vermilion).
II. The Gneissoid rocks.
I. The Granitoid rocks (Laurentian).

WINCHELL (N. H. and H. V.),[186] in 1890, state that the iron ores of Minnesota are at five different geological horizons, in descending order, as follows: (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.)[187], 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 al three of the known agencies for rock-forming were intermittently at work and concerned in the formation of 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 Giant 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),[188] 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 in descending order, as follows: 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, red felsite; Pewabic quartzite (Granular quartz, Potsdam?); Keewatin—sericitic schists, graywackes, greenstones, agglomerates, 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 found to occur sometimes minutely interlaminated; at other times the jasper is in irregular layers, which never have any great extent and always finally pinch out; at other times 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 sometimes such relations with each other 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 which is 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 that on Stuntz island, at Vermilion lake and 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.)[189], in 1891, states that the syenite of Saganaga lake is conglomeratic in places and contains pebbles which are similar to each other, 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.

SECTION VI. WORK OF THE LATER UNITED STATES GEOLOGISTS AND ASSOCIATES.

HAYDEN,[190] in 1867, in his sketch of the geology of northeastern Dakota, describes quartzites along the James river, Vermilion river, and at Sioux falls. These quartzites are sometimes conglomeratic. On the 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.

IRVING,[191] 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 the 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 acid kinds, but there is no such chronological relations 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. Acid flows are superimposed upon basic flows, flows of intermediate acidity immediately overlie acid flows, flows of intermediate acidity overlie porphyritic conglomerates, flows of intermediate acidity are superimposed upon basic flows, basic rocks are intersected by acid rocks, basic flows overlie acid rocks, basic flows overlie those of intermediate acidity, acid 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 acid rocks of the series—that is, such material as porphyry, both non-quartziferous 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 acid.

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 acid original rocks include quartzless porphyry, quartziferous porphyry, and felsite, augite-syenite, granite-porphyry, and granite. Here is 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, while 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 acid 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 acid 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 the 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 acid 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, that 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 acid 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 thickness of the lower division is placed in round numbers at 25,000 to 30,000 feet, while at the 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 the Ontonagon river, of the South range, of the region between the Ontonagon river and Numakagon lake including the Porcupine mountains, of northwestern Wisconsin and the adjoining part of Minnesota, of the Minnesota coast, of isle Royale and Nipigon bay, 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 part 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 the 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 Prof. 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 are described at Bête Grise bay, along the Hungarian river and Douglass Houghton ravine, and sections 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 the Ontonagon river, as at Bête Grise bay, the sandstone dips away from the north-dipping Keweenawan diabases at quite a high angle near the contact, which rapidly flattens as it is receded from. 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 rest 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 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 the 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 iron-bearing rocks of Marquette and Menominee appear then to belong together and may hence 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 now is 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 acid 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 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 synclinal 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,[192] in 1883, gives a summary of the arguments for regarding the copper-bearing series of lake Superior as pre-Potsdam: (1) The weakest argument of all, the general stratigraphical relations, 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 rarely reaches 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 the upper St. Croix river, the 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 lying near the upturned igneous and detrital rocks of the Keweenaw series. (5) The foregoing facts are all consistent with each other. (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,[193] 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 include 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 and CHAMBERLIN,[194] in 1885, give a systematic account of the junction between the Eastern sandstone and Keweenaw series on Keweenaw point. Detailed descriptions are given of the relations of the two series at Bête Grise bay, at the Wall ravine, at the St. Louis ravine, at the Douglass Houghton ravine, at Torch lake quarry, at Hungarian ravine, and at 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 Bête 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 Torch lake quarry the sandstone is found to be in a horizontal position, there being no evidence whatever found 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 Keneenaw 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 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 debris; the irregular and broken contact faces 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.

IRVING,[195] 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 séries 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; 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 trough-like 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 occurring at points where the quartzites come in contact with the basement rocks.

The Archean in these regions is then divisible unless the upper series are called Cambrian, for which there is no ground until in them fossils have been discovered. 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 [196], 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' 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 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 the 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 the Black River, the Baraboo quartzites, and the quartzite series of southwestern Minnesota and southeastern Dakota.

At New Ulm and Redstone in Minnesota the quartzites and conglomerates plainly uncomformably overlie the gneiss. 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, South Dakota, having a thickness of not less than 3,000 to 4,000 feet. The tilted position of these quartzites, their great thickness, 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 are regarded in part as having been once continuous with the Animikie series and are 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. It is also the case that 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,[197] 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 'iscovered in the case of the ordinary quartzites and graywackes, and therefore of chemical origin. Associated with the iron-bearing beds often a considerable quantity of carbonaceous or graphitic schists. concluded, (1) That the original form of the iron-bearing beds of Lake Superior region was that of a series of thinly bedded carbon- 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) 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 afterwards, and to the latter period belong probably the larger bodies of crystalline ore.

WILLIS,[198] 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, 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 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, 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 Vermilion range. In section 28 huge masses of jasper form the crown of the arch and are imbedded 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.

IRVING,[109] in 1887, discusses the separability of a Huronian group from an underlying series. The character of the Original Huronia area is again fully discussed. When two series of rocks are in conta one of which is crystalline in character and the other unquestiona of sedimentary origin, there is presumptive evidence of a discorda between them, as, whatever the origin of the crystalline schists, tl present condition indicates the action of long-continued and deep-seat 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 also 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 the 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, as proof of distinctness of the newer series, is 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 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.

In passing southward from Marquette great areas underlain by the granites; gneisses and schists of the older formation are passed, but before the Menominee river is reached at least four distinct belts are crossed occupied by the newer iron-bearing series. These belts of newer rocks are more closely folded than the Marquette district, but the relations between the newer and older series are identical with that district.

Passing now to 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 (1) by 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; (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 unconformities 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 district, where the folding is so close that the discordances are no longer distinct; to the Vermilion lake district, where extreme pressure has produced a general community of inclination between the two groups of rocks. There is then in all these regions 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 rest 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.

IRVING,[200] 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, the relations of the Potsdam to the Keweenaw series, the relations 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, theAnimikie 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 ikenesses of the rocks in the different districts referred to the same grand division, and 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,[201] 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.

HALL[202] (C. W.), 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.

WILLIAMS,[203] 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 from 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.

IRVING,[204] 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 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, when in contact with the greenstone schists, fragments of 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., Mich.; in Secs. 21 and 22, T. 47 N., R. 26 W., Mich.; in Sec.

29, T. 48 N., R. 25 W., Mich.; in Sec. 20, T. 48 N., R. 27 W., Mich.; in Sec. 17, T. 48 N., R. 26 W., Mich.; in Sec. 21, T. 48 N., R. 27 W., Mich.; and at various points in T. 49 N., R. 28 W., Mich.

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 different 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 have perhaps 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 Prof. 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,[205] 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-Bearing, 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 shows no evidence as a whole of mechanical origin, although occasionally a small amount of detrital material is found in it. It is regarded either as a chemical or 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 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 kind 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 over 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 and 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 quite 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 water-worn 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, that the underlying complex had nearly reached a base level before the overlying series was deposited.

Above the Penokee series are the Keweenawan rocks, which are found at Tyler's fork 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 there lapsed a sufficient time for erosion to remove at least this thickness of sediments, and consequently that between the Keweenawan and Penokee series 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 in a horizontal position to rest 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 are found equally characteristic of the Keweenaw series, and it is therefore concluded that after the deposition of the Penokee and Keweenawan series, before the Eastern sandstone was laid down, that 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 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 character of the ore-bearing member is identical 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 that 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 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.

VAN HISE,[206] 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 formation as well as the chief iron-bearing formation containing the hard ores, 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 has 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 is 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 in the future 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, the Dakota, Iowa, Minnesota, and Wisconsin quartzites surrounded by the fossiliferous series. In the Lower Huronian is the Keewatin (in part at least), the Lower Kaministiquia, Lower Vermilion, Lower Marquttte, Felch mountain iron-bearing series, Menominee proper, and the Cherty limestone at the base of the Penokee series, and the Black river falls iron-bearing schists.

BAYLEY, [207] in 1892, concludes, after a microscopical 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 of Chauvenet reached in 1883 and 1884. This iron-bearing silicified gabbro has been traced by this geologist southwest through secs. 25, 35, 34, T. 65 N., R. 5 W., to Mitchigamme lake. The same silicified gabbro belt has been found by Merriam at lake Gobbemichigomog.

MERRIAM,[208] 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,[209] 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.

PUMPELLY and VAN HISE,[210] in 1891 and 1892, find that in places the ore formation of the Menominee and Felch mountain districts passes down into the limestone. This gradation may be well seen in the Menominee district at a quarry east of the Chapin mine. Also 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.

SECTION VII. SUMMARY OF RESULTS.

The lake Superior region is the one in America about which most has been written and which has furnished the most definite knowledge of the structural relations of the pre-Cambrian rocks. Contained in the foregoing summary of literature is potentially much that follows, but it seems desirable to put together the conclusions which may be considered as determined and see how far the various positions taken by the different writers are really in harmony. Unless otherwise stated, the cited positions of the various authors are their later expressions; oftentimes earlier and different views have been held. For the sources from which the conclusions are drawn it will be necessary to turn to the literature, from which, by means of the footnotes, the material may be traced to the originals.

The four series to be arranged are those known as the lake Superior sandstone, the Keweenawan, the Huronian, and the Laurentian. The last two have by certain later writers been again subdivided.

LAKE SUPERIOR SANDSTONE.

The horizontal red sandstone of lake Superior was recognized as the most extensive formation of the lake by the earliest geological voyageurs, 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 overlapped 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 sandstone at Granite point, and that between the latter and the slates on the 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 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 in northern Wisconsin like unconformable relations between the horizontal sandstone referred to the Potsdam and the crystalline rocks. Norwood, in 1847, again saw the unconformity between the lake Superior sandstone and St. Louis slates at Fond du Lac, described by Schoolcraft many years before. Foster, in 1848, saw the same unconformable relations between the sandstones and 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 in which there is not yet entire unanimity, although the weight of the evidence is so strongly in favor of the inferior position of the Keweenaw series that this conclusion is doubted 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, and Winchell (N. H.), 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 Keweenaw series is older than the lake Superior sandstone. Agassiz at first regarded all the sandstones of the same age, but came to the conclusion afterwards that the sandstone was deposited against the upturned Keweenaw series. Agassiz, Brooks, Chamberlin, Dawson, Irving, Owen, Pumpelly, Rominger, Strong, Sweet, and Wooster maintain a great unconformity between the two. Macfarlane held that there was a doubtful unconformity between the Keweenaw series and the lake Superior sandstone, the former occupying an inferior position. Houghton's, Logan's, and Selwyn's position is that the Keweenaw 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 Keweenaw 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 is placed above the Potsdam. The true position of this sandstone another will discuss, but 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 Keweenaw series, and it is even yet a debatable question as to just where at certain places the lake Superior sandstone begins and the Keweenaw series ends; 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.

In considering the question whether the lake Superior sandstone is a part of the Keweenawan, the general field relations are more significant than all else. Wherever the Keweenaw series appears in its characteristic development about lake Superior, from Michipicoten on the east to Duluth on the west, from Thunder bay on the north to Keweenaw point on the south, it is a titled series, the inclinations rarely being less than 30°, never less on the south shore, while more commonly they are much higher, running often to 80°. The lake Superior sandstone, on the other hand, wherever found, is horizontal, except along lines of contact with Keweenawan or other rocks, and here the tilting has been explained to be due to faulting. The only locality remote from a contact at which the sandstone is said not to be horizontal is Traverse island, aud at this place the facts upon which the statement is based have not been published. The lake Superior sandstone runs as a long tongue for a distance of more than 50 miles, always in horizontal attitude, gradually narrowing to the west; between the north and south highly inclined Keweenawan trap ranges to near the Montreal river. Nowhere is it interlaminated with or cut by a single eruptive rock of any kind. The finding of detrital rocks between the lava flows of the South range of the Keweenawan has no bearing against this assertion any more than does the existence of such rocks in the main trap range. Before it can be concluded that such tilted interlaminated detritals are a part of the horizontal Eastern sandstone the two must be traced together in continuous exposure.

These broad field relations and the absence of trap point with irresistible force to the conclusion that the lake Superior sandstone is a far later formation, laid down since the Keweenawan was deposited, uptilted, and eroded. If this is not the case, that it in broad areas should have wholly escaped the dynamic movements which upturned the Keweenaw series everywhere about lake Superior is absolutely inexplicable. Equally strange is the fact that it has everywhere escaped intrusive material. It is not a common thing for eruptive activity which extends over distances of 300 miles east and west and 100 miles north and south to continue in full force up to and stop along a ruled line 100 miles long. That this occurred must be believed if the lake Superior sandstone is regarded as belonging to that part of the Keweenaw series, interbedded with the traps, as advocated by Wadsworth. The absence of eruptive material in the horizontal sandstone on the theory that it is a part of the Keweenawan can be explained only by regarding it as the equivalent of the upper members of the Keweenawan, and even this hypothesis would leave wholly unexplained the strange field relations. The amount of positive evidence, based upon contact relations, necessary to establish the conclusion that the lake Superior sandstone is interstratified with the Keweenaw series, considering these general relations (mentioned by Logan as early as 1863), would need to be very great indeed.

However, the great mass of the evidence of contacts bears toward the later age of the sandstone. At the very numerous localities in Wisconsin in which the contacts are not obscured by faulting, all who have examined the district are agreed that the sandstone there found does rest unconformably upon melaphyres and traps in every respect identical with those of the Keweenawan. Also the order of superposition of the Potsdam sandstone and the Keweenawan are shown by the deep well at Stillwater, Minnesota, described by Meads. This well passed through 700 feet of St. Croix and Potsdam sandstone and then went into the characteristic interbedded sandstones and eruptives of the Keweenaw series. This occurrence alone would seem to demonstrate the inferior position of the Keweenawan, although from the nature of the case it can not determine whether there is an unconformity between the two. The only district in which anyone has maintained that the lake Superior sandstone does pass in continuous exposure between the traps is along the southern border of the Keweenawan of Keweenaw point, and, as already said, it is now not denied that there has been faulting here both before and since the deposition of the Eastern sandstone. Moreover, the fault is probably an overthrust. It is, then, a district in which the contacts and relations are particularly liable to be confusing and misleading. Even here, however, examinations by Agassiz, Chamberlin, Irving, Rominger and Pumpelly, have led them all to the conclusion that the Eastern sandstone is newer than and overlies the trap, while only Foster and Whitney and Wadsworth maintain the contrary.

Nearly all of the positive evidence as to the relations of what is known to be the lake Superior sandstone to the Keweenaw series is that the former is far later than and was deposited upon and against the upturned edges of the Keweenawan; that between them is a great unconformity; and, as has been seen, this conclusion is the one reached by the greater number who have studied the question critically. As the lake Superior Sandstone is Potsdam, it follows that the Keweenawan is pre-Potsdam; and since the unconformity separating the two is so great, the latter is probably pre-Cambrian.

THE CHARACTER OF THE KEWEENAW 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 detrital rocks on the south shore was reached by Pumpelly and Marvine. Their work was much fuller on this series of rocks than any that had gone before, and as a consequence of this the rocks were recognized as a distinct system 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 uncomformably underlying Animikie. He however recognized that the two have a very different lithological character. The felsites, quartz-porphyries, and other acid rocks—in the earlier reports frequently called jaspers—and amygdaloids were by many of the earlier authors supposed to be metamorphosed sandstones. This position is, I believe, for the acid 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.

RELATIONS OF KEWEENAW AND UNDERLYING SERIES.

Coming now to the relations of the Keweenaw 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 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 to say, the base of the Keweenawan is now in contact with one member of the underlying series and now with another. Selwyn finds at Thunder bay no evidence of this erosion interval, but this testimony is negative and stands alone. The great mass of evidence from many localities agrees that there is a physical break at the base of the Keweenawan.

The last point to consider 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, and 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 area of gabbro, the thickness and magnitude of which is incomparably greater than the so-called crowning overflow of Thunder bay. This great mass of gabbro extends from Duluth northeast to the National boundary, a distance of 100 miles or more, and is at its maximum outcrop more than 20 miles in width. There is no question, unless it be considered a subsequent intrusion, that this great gabbro is the base of the Keweenawan, for it now comes in contact with one member of the Animikie and now with another. At other times it is in contact with the crystalline schists of the Lower Huronian, and again with the granite and gneiss of the Laurentian, so that it is evident, if it is a part of the regular succession, that all of these rocks have been deeply eroded before its appearance. This gabbro has been, however, too little studied to venture an opinion as to whether it is a great surface flow or succession of flows, or, as suggested by Bayley, an immense reservoir in the nature of an early laccolite or batholite which furnished material for the subsequent diabase dikes and sheets of the Animikie and for basic surface flows of the Keweenawan. Recently N. H. Winchell, contrary to all previous work, places this gabbro as older than the Animikie. Little evidence is given to support this change of view. No section is given illustrating the supposed structure. To the writer there appears to be great if not insuperable difficulties in the way of the correctness of this conclusion.

GENERAL SUCCESSION ACCORDING TO DIFFERENT WRITERS.

In taking the next step downward, we come to the complex about which there has been great diversity of opinion and about which 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 any one. Also it is doubtful if any would deny that the rocks below the Keweenaw series are divisible on a structural basis, if the Animikie series is here 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 Keweenaw 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 series.

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 upon lithological grounds and the superior position of the second. These are the Laurentian and 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 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 formations. 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 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. The existence of granite and gneiss prior to the deposition of, and which have yielded débris to, the lowest members of the Huronian, is recognized, although contacts are said to be not often sufficiently frequent to enable a discrimination to be made 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 an identical conclusion 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 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, have 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.

Lawson recognizes a physical break at the base of the Keweenawan and a great break at the base of the Animikie, and divides 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 on the north shore and Foster and Whitney, Wadsworth, Irving, and Williams on 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 there is believed to be a considerable geological break. The upper is the equivalent of the schistose series of the lake of the Woods. To cover the two series is 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 interstratified 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.

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. 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.

Alexander Winchell's succession below the Keweenawan is Huronian, Keewatin, Vermilion and Laurentian. At the base of the Huronian is a great structural break. The three lower series are in conformity and grade into each other. This is much the same as this part of the succession given by N. H. Winchell, except that one great series, 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.

Doubtless to the minds of many the great thickness of the combined Keewatin and Coutchiching of Profs. Winchells and Lawson will be presumptive evidence against the structure which they have worked out. This thickness as given by Alexander Winchell is more than 30,000 feet, while Lawson gives the Keewatin a thickness of 5 miles and the Coutchiching a thickness of 4 or 5 miles, or in the neighborhood of 50,000 feet. The manner in which the structure of the Keewatin and Coutchiching schists always strike parallel to and encircle the adjacent granite masses suggests that these intrusives have developed slaty cleavage or schistose structure which has been mistaken for bedding. Lawson supposes the intruding granite has upthrust the beds until they now stand on end. That both schistose structure and bedding, with marked discordance to each other, exist east of Rainy lake is positively maintained by Pumpelly and Smyth.

If the objection of great thickness for the Keewatin and Coutchiching has weight, the enormous thickness of over 120,000 feet given for the conformable system in northeastern Minnesota, on the theory that the Keewatin and Coutchiching are conformable and grade into the gneissic series, and that all are of sedimentary origin, now folded into a simple synclinal structure, will be still more weighty evidence against the correctness of the conclusion reached. It is notable that Willis's explanation of the structure at the center of this supposed syncline, Vermilion lake, reverses this and makes it an anticline. Lawson does not have to meet this difficulty because he regards the granite and gneiss as irruptive and consequently a series to which the principles of ordinary stratigraphical geology do not apply.

From the foregoing statements it might be concluded that lake Superior stratigraphy below the Keweenawan is in a greater state of confusion than is really the case, 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. 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, 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.

LITHOLOGICAL CHARACTERS OF AZOIC, LAURENTIAN, HURONIAN, ETC.

Before going farther 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 to a certain extent this will repeat the preceding paragraphs. It is here much less easy to make definite statements than in the case of the lake Superior sandstone and Keweenawan.

Azoic, as used by Foster and Whitney and those who followed these authors, was made to include everything below the Keweenawan, with the exception of 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 their character from those which are plainly clastic, as conglomerates, to those which are 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, covers the most of the light colored granites and coarse grained gneisses. 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 a large part of the granite and gneiss from the

Laurentian, believing this part to be of later age and intrusive. Dawson about the lake of the Woods made the same discrimination. 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 taken to be 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 a 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 and the Profs. 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. 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.

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 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 acid 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 he, however, 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, the metamorphic mica-schists, etc. In his Huronian he included the Animikie on the north shore, placed above the Huronian by the Canadian geolgists.

Lawson abandons the term Huronian and divides the schistose rocks included under this term by the earlier Canadian geologists into two series the Coutchiching and Keewatin. The Coutchiching includes the lowest rocks in contact with the Laurentian gneisses and granites and comprises mica-schists and fine grained, evenly laminated gneisses; that is, thoroughly crystalline finely laminated rocks. The Keewatin includes fine grained green schists, both basic and acidic, with volcanic tuffs, agglomerates, peculiar altered conglomerates with intersecting eruptives, and jaspery iron ore beds. It does not include the unaltered slates, graywackes and ferruginous beds of the Animikie. The position of the Profs. Winchell is practically the same as that of Lawson, except that instead of using Coutchiching, Vermilion is used, and both the Keewatin and Coutchiching are held to be inferior to all of the Huronian.

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.

Belonging to the series designated by the foregoing terms are recognized by all writers interbedded and cutting basic and acid eruptives of various sorts, only in the Animikie and in the Huronian of Irving the acid eruptives are insignificant in amount. Many of the fine grained green schists, with some exceptions, in early days regarded as much metamorphosed sedimentary Huronian rocks, are now considered by all to be much altered eruptives, either of surface or deep-seated origin, their present structure being due to secondary causes. That acid eruptive material should be found plentifully cutting the clastics series is not at all surprising. Acid eruptions were abundant and widespread in the lake Superior region as late as Keweenawan time, as is attested by the original acid 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 acid dikes are found in the upper Huronian of the south shore can be explained only by the fact that the acid eruptives of the Keweenawan are mostly remote from the Marquette, Menominee, and Penokee series. A closer study in the future will probably show in these districts a greater abundance of acid 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 may be of Keneewanan or Animikie age. Even if this were the case and there are two epochs of granitic eruptives later than the upper Huronian clastics, this would be no evidence of the absence of an ancient floor composed mainly of granite-gneiss upon which the oldest Huronian has been deposited.

ORIGIN OF THE IRON ORES.

Before taking up the correlation of the pre-Keweenawan lake Superior series, one further point remains to be considered, whether the iron ores and associated rocks are eruptive or are sedimentary, for upon this point depends the correctness of many structural determinations. If, as believed by Wadsworth and Foster and Whitney, the iron ore is partly igneous, and by the first named that a part of the jasper has the same genesis, they may occur at any horizon up to that of their eruption and can not be used as guides in working out the structure. Those who believe the iron-bearing formations are sedimentary have regarded them as persistent members, and the striking and peculiar lithological characters of these belts have furnished key horizons to which to refer the associated clastics.

Foster and Whitney saw that the masses of iron ore and jasper have none of the characteristics of vein deposits, and believed that the supposition that they resulted from the decomposition of pyrites or the metamorphism of bog ore is wholly inadequate to account for the accumulation of such vast masses as occur, or to explain the relations to the associated rocks. If not of this origin, they could only conceive that they are igneous. The frequent association of the ore with eruptives and the fine banding led to the conclusion that these facts can hardly be explained except by igneous action. These writers saw, however, that when the ore is found in beds in clearly metamorphic strata having a common bearing and inclination they must be sedimentary, and such deposits are regarded as having been derived from the destruction of previously formed igneous masses and their present association to have resulted from aqueous deposition, so that even in this case the iron has an igneous source. At the present time few would assert that the iron ores are vein deposits, or the result of decomposition of pyrites, or the metamorphism of bog ores; but there are other explanations overlooked by Foster and Whitney which may apply before being driven to the igneous hypothesis.

The reasons given by Foster and Whitney for an igneous origin of the ore-bearing formations are of a negative character, and the only case in which positive evidence is given the rocks are recognized as detrital. But Wadsworth brings forward positive evidence as to the origin of the ores. Many instances are cited showing the way in which the jasper and ore have eruptive contacts with the associated schists. The facts, however, indicate the eruptive character of the ore and jasper only if the schists are of sedimentary origin. The investigations of Irving, Williams, and the Profs. Winchell, as well as our own later work, have shown that the lower Vermilion and lower Marquette iron-bearing members contain many schistose dikes, and also that in many cases the massive greenstone knobs found in these districts vary by imperceptible stages into the finely laminated schists associated with the iron ore and jasper. The schists are, then, in part at least, of eruptive origin. Brooks noted the dike-like character of certain magnesian schists associated with the ore formation, between which and the dioritic schists, believed to be of sedimentary origin, it was said to be impossible to draw the line. That these well laminated schists should not at first be regarded as eruptive is natural, but the variation of massive igneous rocks into those which are well laminated as a result of dynamic action and metasomatic changes is now so well known that new cases of it excite no surprise. I would by no means assert that all of the schistose rocks associated with the iron ores and jaspers in the Marquette and Vermilion districts are of eruptive origin, but this is certainly the case at many localities. This view reverses Wadsworth's and makes his sedimentary rocks eruptive and his eruptives sedimentary. It will, however, be seen that this position harmonizes Irving's conclusion as to the sedimentary origin of the ores and jaspers and the point upon which Wadsworth places most emphasis, that there are eruptive contacts between these rocks and the associated schists.

It is to be noted that the eruptive theory has been applied only to the Marquette and Vermilion jasper and ore. No one has asserted such an origin for the iron-bearing horizon of the Penokee and Animikie series. This is an independent question, as will be seen by what follows; for these formations probably occupy a higher position than the lower Marquette and lower Vermilion ores. We have, then, to answer two questions: "What is the origin of the iron-ore formations of the Penokee, Animikie, and equivalent iron-bearing formations?" and, second, "What is the origin of the great masses of ore and jasper of somewhat irregular shape, apparently not continuous formations, although probably at rather persistent horizons, in the Lower Vermilion, Lower Marquette, Kaministiquia, and similar areas?"

Upon the first of these questions there is practically no dispute. The iron-ore formation in the Penokee district has been found to extend for many miles as a simple belt of very uniform thickness between two readily recognized detrital formations, all with a common strike and dip varying within very narrow limits. A precisely similar condition of affairs is found in the Animikie district. These formations have been shown by later work to have been originally altogether what they still are largely, thinly laminated impure cherty carbonates of iron, in every way analogous to similar earthy carbonates of later geological periods. The other forms of material now associated with them, such as jasper, actinolitic and magnetitic schists, ore bodies, etc., are the consequence of subsequent changes. The ore bodies, for instance, are secondary concentrations, generally in troughs, due to the action of percolating water. The same facts are apparent as to the Upper Marquette and Upper Menominee ores and jaspers.

In the case of the iron formations of the Lower Marquette, Lower Vermilion, and similar districts the question can not be so decisively answered. The Lower Marquette iron-bearing formation is generally, if not always, the uppermost member found in the lower series, when erosion has not carried it away, and therefore apparently occupies a definite horizon, although as the structure of this district has not been worked out in detail this can not be positively asserted. In the Vermilion lake district the great masses of ore and jasper of immense thickness seem to extend only for a short distance along the strike of the rocks, then disappear and reappear at intervals to the northeastward at Long lake, at Hunter's island, and other points, probably also north of Port Arthur in the Kaministiquia district. This lack of persistence may be due to the fact that the fold or folds are not horizontal, but have a varying pitch. The ore formation at the swells of the pitching folds may have been removed by erosion. While it is not proved, it is probable that the ore formation is at a definite horizon, since the different outcrops appear to be in the same part of the series and along the same general line of strike for considerable distances. These ore and jasper formations contain abundant iron carbonate, are interlaminated with graphitic schists containing iron carbonate, the graphite of which is so abundant and widely disseminated in minute particles that it can hardly be believed to be other than of organic origin, and from these forms there are gradations to the other forms of rock found in the iron-bearing formation. In the deeper workings of some of the larger mines of the Marquette and Menominee districts, the ore bears much residual carbonate of iron and also carbonates of calcium and magnesium. At Iron Mountain and Metropolitan the iron formation grades downward by insensible degrees into the limestone. All of these points, and the remarkable lithological likenesses between the phases of rocks found at these horizons and those occurring in the iron formations of the Penokee and Animikie, demonstrably of detrital origin, are cited as evidence that these ores are derived from an originally impure cherty carbonate of iron. A study of the Vermilion iron formation by N. H. and H. V. Winchell has led them to the conclusion that it is of direct chemical detrital origin rather than derived from an impure cherty carbonate. Which of these views is the correct one does not concern the present question, for if the ore-bearing formation is detrital it may be used for the purposes of stratigraphy. We thus have in favor of an origin for these lower ore formations similar to those of the Penokee and Animikie a large amount of positive evidence, while the only adverse positive facts are those cited by Wadsworth, and these, as has already been said, may be brought into accordance with the sedimentary theory by considering the schistose rocks having eruptive contacts with the ores and jaspers as the intrusives, which in many cases they demonstrably are. In his most recent paper Wadsworth himself suggests that the supposed eruptive jasper and ore may be "truly fragmental, their present relations being due to sedimentary and chemical action and the squeezing together of the jaspilite and schist."

It was suggested by Brooks that the ore deposits of the New England-Saginaw range and of the lake Superior mine in the Marquette district are secondary concentrations due to the removal of silica and the deposition of iron oxide. The same position was taken by Rominger for the entire Marquette district. Later I have shown that it is a general truth for the lake Superior region that the iron ore deposits are secondary concentrations, produced by downward percolating waters along the paths of great water channels, and particularly at places where the waters are converged by tilted impervious basement formations.

THE 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 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 Marquette, Menominee, Penokee, and other series. All now regarding these rocks as intrusives, the facts that they are often in boss-like masses, and when interleaved do not necessarily continue for any considerable 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, lead to the same conclusion.

The intrusions of the diabases, gabbros, and diorites, as suggested by Rominger, Wadsworth, and Merriam, have oftentimes had an important influence upon the structure of the sedimentary beds, although Rominger holds that the folding is primarily due to the intrusive granite. Strong and Rominger also suggested, in the St. Louis river district, that the eruptives were the pipes which furnished the outflows of Keweenawan time. This idea is not only plausible for this district, but is probably true for the entire lake Superior region. A closer study will probably demonstrate that the fresher eruptives in both the upper and lower Huronian, including the great intrusive beds of the Animikie, are really Keweenawan in age. Also the numerous dikes of like character cutting the fundamental complex doubtless represent in other series the same manifestation of igneous activity.

UNCONFORMITY AT BASE OF CLASTIC SERIES.

In attempting to determine how far the different views held as to lake Superior stratigraphy are really in harmony, it is desirable to have, if possible, as starting planes upper and lower horizons. From the preceding pages it is evident that for the first of these we have the base of the Keweenawan. Nearly all are agreed that below this series is a break more or less considerable, and all are agreed that it is a recognizable plane. It appears to the writer that the evidence shows the existence of another general plane for the lake Superior region at the horizon elsewhere defined as separating the Archean from the Algonkian—that is, the plane between the basement granite-gneiss-schist complex and the overlying clastic series with their equivalent crystallines. The failure generally to recognize this plane is due to the fact that the banded and contorted gneiss, which is the most prominent rock of the basal complex, does not differ greatly in lithological character from 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.

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.

There is, however, much evidence that the plane between the Algonkian and Archean is definitely fixed over much of the lake Superior region by a great unconformity.

That below the Cherty Limestone of the Penokee series there is a great physical break would, in the face of the evidence at present known, be hardly doubted by anyone. The cherty limestone, forming a single line of outcrops, although not continuous, now rests upon granite, now upon gneiss, now upon the green crystalline schists. The granite is definitely known to be later than the schists because it intricately intrudes them, but it never intersects the cherty limestone. This basement is clearly a complex upon which the limestone has been deposited.

Turning now to the Marquette district: Unconformable contacts have been found at many localities, but here the clastic series are folded, and certain of the contacts between the clastics and 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 Laurentian, that at Republic mountain is clearly between the lower part of the Marquette 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 Marquette 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. In the Menominee district Brooks, Rominger, and Irving all hold that 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. The actual contact described by Smyth (too late to summarize in the literature) between the lowest formation of the lower Marquette and the granite-gneiss at Republic mountain is the clearest case on the south shore. Here is a basal conglomerate containing numerous water-worn bowlders and pebbles of granite, resting directly upon the granite from which the fragments are derived.

As shown by Irving, the magnitude of the break in the Penokee, Marquette, and Menominee districts is not lessened whether the underlying schist, gneiss, and granite are igneous or sedimentary, for they had reached their present crystalline condition before the overlying rocks were deposited upon them, a condition which a part or all could not have had as surface rocks; and which shows, whether igneous or aqueous, profound induced structures and deep erosion, and therefore a system of rocks which had an intricate history before the clastics were deposited. In this connection the physical break at the base of the Animikie and its equivalents is not cited, because this series occupies a higher position than the series overlying the break just considered.

As further evidence for a great physical break between the basement complex and the lowest overlying clastics are cited by Brooks and Irving (1) the strong contrast in the lithological characters of the two, the fundamental complex being thoroughly crystalline, while the overlying rocks are mainly plainly detrital, or such as may have been derived from detritals; (2) the fact that the complex is cut by very numerous granite dikes, which are but rarely found in the clastics; and (3) their general field relations, the complex having most obscure structures and very great variability in strike and tip, while the clastics are less intricately folded, showing that the older series has been subjected to orographic movements prior to the newer.

As before stated, Brooks, Rominger, and Irving—the three who have 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 of these writers do not agree in every district as to the position at which this plane is found.

Whether the physical break which exists below the clastic series on the south shore is paralleled by a widespread unconformity on the north shore is less certain, although such an unconformity is found locally. Lawson, who has done the most work in this region, maintains that between the Keewatin and Coutchiching a profound physical change took place in the conditions of deposition, consequent upon which are great differences in lithological characters and a prevalent more crystalline condition in the inferior series. He also describes conglomerates in two places at the base of the Keewatin which bear both granitic fragments and fragments from the Coutchiching. From these facts Lawson believes that there is a real unconformity between the two series, although at the present time they have been so squeezed together and secondary structures formed as to be usually in apparent conformity, and the separation in mapping is based for the most part upon lithological grounds. Lawson, however, believes that the Coutchiching is a bedded sedimentary series, rather than a part of the basal complex, as here defined. If this be true, this unconformity does not bear on the question under discussion.

Pumpelly and Smyth, who have recently made a rather extended trip in western Ontario, acquiesce in Lawson's conclusion in so far as the unconformity is concerned, but 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 Profs. Winchell, although recognizing the plane between the clastics and crystallines as a boundary between two groups of rocks, maintain conformity and gradations, although Alexander Winchell suggests that it is a possibility that the apparent conformity is superinduced by subsequent dynamic action.

The probability of an unconformity here follows from the same line of reasoning as that applied to the lake of the Woods and Rainy lake districts, and is further indicated by the descriptions of conglomerates at Saganaga and Epsilon lakes in northeastern Minnesota by Alex. Winchell. In the published note-books these conglomerates are described and figured as sharply separated from the underlying syenite and containing rounded pebbles of it, although it is said the conglomerates were not laid down on the solidified syenite. Later these occurrences are interpreted to mean that the syenite and gneiss are of sedimentary origin, being completely metamorphosed. However, I am not sure that I understand the descriptions well enough to be certain that these so called conglomerates are not really due to the intrusion of the later irruptive syenite, as was suggested by Winchell himself. In the earlier work on the north shore of lake Superior done by Bell, no distinction was made between the fine grained clastics and the crystalline schistose rocks, although it is not improbable that closer work will make it possible to extend the structural subdivisions of Pumpelly and Smyth. Macfarlane noted that the squeezed Huronian slate-conglomerates frequently contain granite fragments, although he did not consider them to be of sedimentary origin. Herrick found in his schistose group on Michipicoten bay basement conglomerates, the pebbles of which are like the granite below, although the relations between the granite and schists are such as to suggest to him that the granite had been intruded beneath the schist. 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. Recent work of Pumpelly and myself 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.

As shown in another place, the gradation described by the Profs. Winchell in northeastern Minnesota, and which appears to occur in other places, is wholly consistent with a real structural break between the basal complex and the clastics. When a clastic series grades down into a crystalline one, this may be caused by progressive metamorphism, by contact action of a subsequent intrusive, or by later folding, which destroys the original bedding of both series and produces a common secondary structure, at the same time causing the newer series to assume a crystalline character. Such induced conformity and transition are the more likely to occur when the materials of the newer series are chiefly derived from the older, and, as shown by Pumpelly, will be particularly likely to be perfect when the earlier series has suffered atmospheric disintegration before the deposition of the later. Future study may show still other causes of gradations between unconformable series.

Evidently north and east of lake Superior we are not without positive evidence that a great physical break occurs at certain points between an ancient granite-gneiss-schist complex and the clastic series, which, however, are often cut by recent intrusive granite-gneisses. Also at many localities in which an unconformity has not been positively shown the evidence at hand points in this direction. When the conditions are considered which are necessary to produce an unconformity it is difficult to see how one can really be of a local nature. Thus while it can not be asserted that a universal structural break north and east of lake Superior exists between the Algonkian and Archean, there is a probability that such is the case.

The foregoing evidence combined gives a strong case of probability for a general structural break in the lake Superior region between the lowest clastic series and a basement crystalline complex. However, it can not be denied that certain of the contacts, cited as showing this unconformity, although unquestionably beneath the lowest clastic series for particular districts, may be at higher stratigraphical positions than the base of the lowest clastic series of the whole lake Superior region. Before the question of a break at this position can be considered as settled beyond all question for the entire lake Superior region much more detailed mapping must be done. However, the existence of this break for many districts is so strongly supported, that it gives for the present the best available guidance as to one fixed horizon for comparisons of the rock series of the different districts. The recognition of this break does not imply that the lowest clastic series at certain localities are not penetrated by, and now rest upon, intrusive granite-gneiss, but in such cases the evidence of this break, if it once existed, has been destroyed.

We have, then, for structural work two starting planes, the base of the Keweenawan and the base of the clastics, included between which are the larger part of the series of rocks placed in the Huronian by the earlier Canadian geologists, the Animikie, Lawson's Keewatin the Profs. Winchell's Keewatin and Animikie, Irving's Huronian, and perhaps in part the Profs. Winchells' Vermilion and Lawson's Coutchiching.

UNCONFORMITY WITHIN CLASTIC SERIES.

It is believed that many of the further difficulties as to correlation in the districts about lake Superior have arisen from the failure to recognize a third physical break which has a very wide, if not universal, extent in this region. The early Canadian geologists found a break at the base of the Animikie, and while this series was first placed with the Huronian, the fact that unconformably below it was another series 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. The Michigan and Wisconsin geologists include in the Huronian the equivalents of both the Animikie and pre-Animikie Huronian, and while facts were clearly contained in their reports pointing 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. But as early as 1883 Irving saw that there is a series of green schists and schist-conglomerates which must rest discordantly below other rocks recognized as Huronian, as shown by their attitude and degree of crystallization, as well as by the fact that they had yielded fragments to the newer formations. As a consequence of this he was led to exclude from the Huronian these lower schists, which had before been everywhere accepted as Huronian. Lawson, in 1886, saw that his Keewatin series is fundamentally different from parts of the original Huronian, and especially from the Animikie series, and was led to refer it to the Huronian series only doubtfully; at the same time he saw that the Keewatin is like the Doré river series at the east end of lake Superior, and suggested that possibly Logan and Murray had placed in the Huronian two discordant 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.

We will now consider the evidence for a physical break within the rocks which have generally been referred to 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 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, over the iron formation at Michigamme mine, a conglomerate, 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. By Rominger the break was noticed 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 water-worn beaches 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. Recently this author has 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. Lately the break was noticed by the Profs. Winchell, and N. H. Winchell regarded it as so great that the rocks above the break were provisionally referred to the Potsdam. The writer has described the break as of universal extent and as representative of a great unconformity, for the banded and contorted jasper and ore are found to abut perpendicularly against a quartzite bearing abundant fragments of the underlying formation, which are in exactly the condition there found. The lower series is a semicrystalline, much folded one, while the upper series has usually not become crystalline nor closely folded. Before the upper series was deposited the lower series was folded and truncated.

It is, then, plain that in the Marquette district, within the rocks which have heretofore been referred to the Huronian, are two series. Below the break which separates them are the lower quartzite of Brooks, the associated novaculite and limestone, and the lower ore-bearing formation, including the hematitic, magnetitic, and actinolitic schists and jaspers, which contain the larger number of great mines. Above the physical break are Brooks's upper quartzite, the base of which is generally the conglomerate already described. Over the upper quartzite follow the black slates, sometimes carbonaceous, graywackes, and mica-schists, together of great thickness, and occupying an area as large as or larger than the Lower Marquette series. In these upper slates, apparently at rather persistent horizons, are locally belts of chert and iron carbonate associated with ore bodies of considerable size. These ores are, however, of a very different character from those which occur in the lower ore formation.

In the Menominee district as evidence in favor of a physical break within the clastic series are the conglomerates described by Brooks at the Pine and Poplar rivers district, and in the Commonwealth section. At the first is found conglomeratic quartz-schists, containing micaceous iron and magnetite; in the second are included conglomeratic quartz-schists, containing pebbles of white quartz (chert) and jasper. Similar jasper conglomerates have been found by Pumpelly and the writer over the ore at certain of the mines. The relations here are, then, exactly like those in the Marquette district. Also, the structural break indicated by these conglomerates is supported by Brooks's major divisions of the Menominee rocks. His inferior Huronian comprises the lower quartzite of great thickness, a great marble formation, and the great iron-ore horizon, consisting of magnetitic, hematitic, and jaspery schists, with deposits of iron ore. In this formation are the Norway, Quinnesec, Ludington, Chapin mines, etc. Brooks's middle Huronian, presumably above the unconformity, includes quartzites, clay-slates, and obscure soft schists. Within these soft slates is the upper iron-bearing horizon, including such mines as the Commonwealth, those at Crystal falls, etc.

In the Penokee district this unconformity is represented by the basal conglomerates of the Quartz-Slate member, containing numerous fragments of chert and a few of jasper, which were in their present condition when derived from the Cherty Limestone and Iron-bearing members. The lower series is now represented by the Cherty Limestone member alone, while the upper series includes the Quartz-Slate, Iron-bearing, and Upper-Slate members.

That there is a similar unconformity within the clastic series between the Lower Vermilion, Hunters island, and Lower Kaministiquia series and the conglomerates at these places bearing abundant material derived both from the ore-bearing formation and from the green schists, is inferred because the water-worn fragments of schist, jasper, and ore are in precisely the same condition in the conglomerates that they are in their original position. In none of these places have actual contacts been described. The unconformity is further indicated in the Vermilion lake district by a strongly developed schistose structure in a nearly vertical position in the Lower Vermilion series, while the overlying conglomerates at places on the islands of Vermilion lake are found to be gently folded.

The work of the Profs. Winchell also gives evidence of this unconformity. N. H. Winchell, in tracing the flat-lying Animikie series to the westward from Gunflint lake, finds that it becomes more steeply inclined and takes on, at times, a slaty cleavage. It is traced as far as Agamok lake, near the great Ogishki conglomerate, and the latter is consequently placed with the Animikie. To these statements Alexander Winchell agrees so far as to Agamok lake, but places the Ogishki conglomerate as a part of the Lower Vermilion series, for he traces this conglomerate all the way to Vermilion lake and he recognizes no break between the Vermilion lake conglomerate and the Lower Vermilion. Taking the positive evidence given by Profs. Winchell and disregarding their partial conclusions, it would seem to indicate that there is a gradation and actual continuity between the flat-lying Animikie and the conglomerates with a vertical superinduced structure at Ogishki and Vermilion lakes. That between the Animikie and the Lower Vermilion there is a great physical break is now denied by no one, and if the foregoing reasoning is true, it shows that this break is a continuation of the one between the Lower Vermilion and the Upper Vermilion which bears fragments of the lower series. The only published detailed succession of the Vermilion series is that by Willis. His chloritic schists and jasper (I, II, and III) belong in the lower series, while his conglomerate and black clay-slate (V and VII) belong in the upper series. The position of the magnetitic quartzite (IV) is uncertain, while the quartz-diorite (VI) is probably an eruptive rock.

It has been long well known that near Port Arthur, Ontario, the Animikie and underlying Kaministiquia series are unconformable. McKellar, who for many years has been familiar with this district, has proved this conclusively. The rock series here unconformably underlying the Animikie are identical with the Vermilion lake iron-bearing series. Considering the foregoing evidence and the complete likeness of this lower series with that bearing iron at Vermilion lake, it can no longer be doubted that there is a great physical break between the Animikie and Lower Vermilion series in northeastern Minnesota, although the equivalence of the Animikie and Upper Vermilion may yet be maintained.

In the last few years the difference of opinion has been sharp as to the equivalence or nonequivalence of the Animikie with the Vermilion lake and equivalent iron-bearing series. Irving has maintained that the Animikie series in its lithological character is like the Penokee and Marquette, these like the Vermilion, and therefore the Animikie in all probability the equivalent of Penokee, Marquette, and Vermilion. Alex. Winchell, having visited the Lower Marquette series and seeing but little of the ground in which the Upper Marquette is found, and consequently not appreciating that in area and in volume this series probably surpasses the Lower Marquette, has maintained that the Marquette rocks are the equivalent of the Vermilion lake iron-bearing series, but that the Animikie series is separated from that at Vermilion lake by a great unconformity. He, however, appreciated that in the Marquette district are certain slates which in lithological character are like, and might be equivalent to, the Animikie. Both Irving's and Winchell's positions probably have an element of truth and an element of error. The Upper Marquette, Upper Vermilion, Upper Hunter's island (Ogishki), in their lithological characters and gentle folding, are closely analogous to the Animikie, and, as maintained by Irving, are its probable equivalent; while the Lower Marquette and Lower Vermilion lake, as maintained by Alex. Winchell, unconformably underlie the Animikie. The physical break within the clastic series in the Marquette, Vermilion, Hunters island, and Kaministiquia districts is, then, provisionally identified with the great physical break recognized by everyone at the base of the Animikie.

It is only fair to say that Lawson considers the unconformity at the base of the Animikie at a higher horizon than the physical break described in these various districts. He regards the Animikie series as separated by another great unconformity from the Upper Marquette, Upper Vermilion, Upper Kaministiquia, etc. To the writer there seem grave difficulties, based on general relations, in the way of accepting this conclusion. On the other hand, the Upper Kaministiquia conglomerates, not far distant from the ordinary phases of the Animikie rocks, have a decidedly different appearance. This may, however, be due to the fact that certain of these conglomerates are of volcanic origin, the chert and jasper of which appear to have been broken from their beds by volcanic action and mingled with lava and volcanic ash. This sudden change in the character of the beds of the same age is parallelized in the Penokee district, where the strata, within a distance of a few miles, rapidly change in character, become immensely thick, and are largely in the nature of agglomerates, greenstone conglomerates, etc. But it must be said that such detailed mapping has not been done adjacent to the National boundary of northeastern Minnesota and Ontario and in the Thunder bay district as will warrant any positive statement as to whether within the clastic series, between the base of the Keweenawan and the Basement Complex, there is another higher physical break, making two unconformities which separate the rocks into three series.

The ore, chert and jasper conglomerates used as evidence of physical breaks within the clastic series are not to be confounded with the purely volcanic conglomerates which may occur at any horizon. Also the occurrence of these conglomerates will have no such meaning as here assigned by those who believe that the ore, chert and jasper in their present condition are igneous rocks. To such they will be no more evidence of two series than that the Keweenawan conglomerates, the fragments of which are derived from contemporaneous traps, are evidence of many series. But to those who think the evidence is sufficient for the belief that the ore, chert and jasper are not only sedimentary rocks, but sedimentary rocks which have gone through a long and complex history, the evidence of a physical break furnished by these conglomerates will be satisfactory.

CORRELATION; GENERAL CONSIDERATIONS.

We pass now to the general correlation of the lake Superior formation lying between the two planes already defined, the base of the Keweenawan and the top of the Archean schist-gneiss-granite complex.

Before it can be decided whether series so far distant from each other as the Dakota quartzites and the Original Huronian (separated by 800 miles) can be parallelized, it ought to be more definitely settled to what extent correlation can be made by unconformities and lithological likenesses. Irving inclined to the belief that such structural breaks as that described in the Marquette district are of great extent, and this accords with the general trend of modern structural work. From what has gone before it appears exceedingly probable that the structural break between the Upper and Lower Marquette is identical with that which separates, even in a more pronounced manner, the Animikie and Kaministiquia series and the upper and lower Vermilion lake series on the other side of the lake Superior basin. The break, being thus so strongly marked at points so far separated, would argue that it extends over a very considerable area of the lake Superior region, not improbably from the most distant rock series before mentioned, the Dakota quartzites and the Original Huronian of the north shore of lake Huron. It would not be expected that a like succession is now recognizable in each of the areas parallelized, even if they all belong to the same geological series. In the first place, the rocks in some districts are not sufficiently tilted to make it certain that all of the layers are exposed. Further, nine-tenths or more of the surface of the country over large areas is heavily covered by the drift, so that it is all but certain that some of the formations which exist at the rock surface have not been discovered. Still further, no satisfactory explanation has yet been made of the subordinate succession of formations in the Marquette, Felch mountain, Menominee and Vermilion lake districts; so it is not yet known how far the order found in one of the districts is equivalent with that of another. From recent work it is probable that future investigations will show that this likeness is greater in the series below correlated than has been suspected. But even supposing the disagreements are as great as the present known facts might lead one to suppose, it would not be any very strong evidence against the correlations; for it is not to be expected that the same conditions of sedimentation have prevailed at all times in a geological basin 800 miles in diameter. While in one part of the basin fragmental sediments were accumulating, it would not be very strange if chemical sediments or organic sediments were accumulating elsewhere. Below, it is seen that the Penokee and Animikie series are the equivalents of each other in the broadest sense of the term. It is not necessarily true that sedimentation began or ended simultaneously in both districts, but only that in the main they stand as time equivalents. How far a correspondence can be made out among the subordinate members of the various districts can be determined only by a detailed investigation of each of the areas.

EQUIVALENTS OF THE ORIGINAL HURONIAN SERIES.

Passing now to the Original Huronian, shall this series be correlated with the Upper or Lower Marquette, or is it the equivalent of both?

Alex. Winchell lately announced that the Lower Slate conglomerate and the underlying formations of the Original Huronian are separated from the Upper Slate conglomerate and the overlying formations by an unconformity. No contacts are described, the conclusion being based upon general relations. No characteristic debris of the Lower Huronian is said to occur in the Upper Huronian. The locality at which the strongest evidence is brought forward is on the outskirts of the Original Huronian, and a part of the formation which Logan and Murray have mapped as Lower Slate conglomerate is placed by Winchell as Upper Slate conglomerate. The observations of Pumpelly and myself at a contact between the limestone formation and the Upper Slate conglomerate tend to confirm Winchell's conclusion, but since limestone fragments are plentiful in the Upper Slate conglomerate, we place the physical break just above this lower limestone, i. e., 300 feet higher than indicated by Winchell.

The term Original Huronian as here used is strictly confined to the areas first described by Logan and Murray on the north shore of lake Huron, and in 1863 mapped in detail. The Original Huronian only is here compared with the series about lake Superior because it is the area to which the term was first applied, and also because it has been more thoroughly described and mapped than any other area in Canada designated by the term Huronian. A careful field and laboratory study of the rocks of the Original Huronian has shown its upper series to consist in great part (1) of fragmental quartzites, the induration of which has been caused by deposition of interstitial silica; (2) of graywackes and graywacke slates (often conglomeratic—Logan's Upper Slate conglomerate), the induration of which is due to the deposition of interstitial silica and metasomatic changes in the feldspar; (3) of cherty limestones, and (4) of eruptives. The Lower Huronian series is more metamorphosed than the Upper.

In its readily recognized fragmental character and in its gentle folding the upper Original Huronian series, i. e., the upper 13,000 feet, is closely analogous to the Penokee, Upper Marquette, and Animikie, while the Lower Huronian may be compared with the Lower Marquette and Lower Vermilion iron-bearing series. In the order of succession of formations it can not be said that either series corresponds very closely with the series about lake Superior, to which they are compared.

It seems to us that in correlation the unmetamorphosed character of the Upper Huronian is a guide of some importance. As pointed out by McKellar, the intense folding to which the Vermilion lake and Kaministiquia series have been subjected must have preceded the much more gentle synclinal movement which formed the basin of lake Superior. That no violent dynamic movement has occurred since the beginning of Animikie time is known to be true of the lake Superior basin, and it seems exceedingly probable that the gently folded upper members of lake Huron belong with those of like character about lake Superior. If this is not the case, the intense dynamic movements which produced the closely folded rocks of northeastern Minnesota and Ontario lost their force before reaching the area about lake Huron, and this region must have escaped any serious folding for a longer time than any other closely studied part of the earth's crust.

Besides the reason already mentioned for placing the upper Original Huronian as the equivalent of the Animikie and Upper Marquette rather than below these series, as advocated by certain geologists, we have one characteristic feature already cited which is of some weight. One of the most peculiar rocks of the Upper Original Huronian is a conglomerate which carries numerous fragments of blood-red jasper. At present the source of these fragments is unknown unless they come from the iron-bearing formation of the Lower Huronian. From what has gone before it is apparent that a jasper conglomerate is the basal member of the Upper Marquette series, and also that similar conglomerates occur in a like position in Ontario and northeastern Minnesota. Considering the widespread character of this jaspery, cherty, and iron-ore conglomerate, its occurrence in the Upper Huronian of lake Huron suggests that this jasper may there be found in the future in the Lower Huronian in large quantity. This series would therefore, in position and in lithological character, be like the Lower Vermilion and Lower Marquette iron-bearing series. The existence of such a jasper-bearing series was inferred by Logan himself. Taking the Original Huronian north of lake Huron as a whole, if Winchell's general conclusion that it consists of two unconformable series be correct, the analogy between this district and the lake Superior region is complete. Above the fundamental complex and below the Keweenawan, as about lake Superior, are two discordant series.

EQUIVALENTS OF THE SIOUX QUARTZITES, ST. LOUIS SLATES, ETC.

Much of what has been said to show that the Upper Huronian series is the equivalent of the Animikie, Upper Vermilion, and Upper Marquette applies with equal force to such rock series as the Chippewa quartzites, the Baraboo quartzites, the Sioux quartzites and the St. Louis slates. None of these series are closely folded, although often dynamic movements have developed slaty cleavages. Also their original fragmental character is always seen under the microscope at a glance. Between these series and the Potsdam is a great unconformity. They present thick beds of fragmental rocks, the induration of which has been caused by the same process which vitrified the quartzites of the upper Original Huronian. The supposed absence of ferruginous rocks in these districts has been used in the past as an argument against the correlation of them with the Penokee and Animikie series below considered, but this absence has no particular weight because such beds, as compared with the mechanical sediments, are insignificant in amount; and further, it is quite possible that these formations may in the future be found in several or all of these districts. This probability is rendered greater by recently developed ferruginous beds between the two quartzite ranges of Baraboo and in the northward extension of the St. Louis slates. The rocks here found are the exact parallel of the iron-bearing beds of the Penokee and other iron-bearing districts. The percentage of iron is so great in certain localities that the material is being mined for an ore. For placing these rock series with the Keweenawan, as has sometimes been done, there is neither lithological nor structural grounds. In the character of the material of which they are composed, in the presence of iron formations in certain localities and in their induration, they differ profoundly from any of the rocks known to belong with the Keweenawan.

No one has placed these series lower in the geological column than Upper Huronian, so perhaps it is not necessary to give evidence that they are not Lower Huronian. The occurrence of chert and jasper fragments in the Chippewa quartzites, mentioned by Sweet, and the presence of abundant identical material in the quartzites of southern Minnesota and southeastern Dakota, at least show that before the formation of these series there was a prior series bearing chert and jasper. Such a series is the Lower Huronian. These series then in degree of induration, amount of folding and in lithological character are like the Upper Huronian.

SUCCESSION AND EQUIVALENTS OF THE PENOKEE AND ANIMIKIE DISTRICTS SERIES.

In the Penokee district of Michigan and Wisconsin is the following succession: At the base is a granite-gneiss-schist complex. The schists are always completely crystalline, although often finely laminated or foliated. The granites, with granite-gneisses, and the fine grained green hornblende-schists, mica-schists, and chlorite-schists occupy large separate areas, with a debatable ground along their borders. The contacts of the granites and granite-gneisses with the crystalline schists are eruptive ones, the former being clearly the intrusives. Above this complex, and separated from it by a great unconformity, is a Cherty Limestone member which in places is 300 feet thick. While it extends east and west many miles, it is not longitudinally continuous. Above this Cherty Limestone, separated by an unconformity, is the Penokee series proper, which consists of a Quartz-Slate member, the upper horizon of which is a vitreous quartzite, an Iron-bearing member, and an Upper Slate member. Above the Penokee series, separated by another very considerable unconformity, is the Keweenawan. The parallelism between this district and the Marquette already described is at once manifest. The Penokee series proper is the equivalent of the Upper Original Huronian, Upper Marquette and their equivalents; the Cherty Limestone member stands as the only known equivalent of the Lower Marquette; for in the Penokee district the upper members of the equivalent of the Lower Marquette have not been found or have been removed by erosion. That the latter is not improbable is indicated by the very considerable thickness in some places of the cherty limestone and its absence in others, while numerous fragments of it are found in the basal member of the Penokee series proper. These fragments are so abundant in places as to constitute a true basal conglomerate. They are well rolled and are mostly of chert, but are sometimes jasper. This chert and jasper, whatever their origin, were in their present condition before the deposition of the Penokee series proper.

Further, the relative geographical positions of the Penokee, the Upper Marquette, and the Chippewa quartzite districts are such as to strongly suggest that they were once connected. The Penokee series at the east is cut off by the unconformably overlying lake Superior sandstone; but east of the south end of Gogebic lake there are here and there outcrops of slate which are like the Upper Slate member of the Penokee district, and a short distance to the east the narrow belt spreads out into the broad area of upper fragmental rocks, of which the Marquette and Menominee districts are arms. At the west the Penokee series has been entirely swept away by erosion, the copper-bearing rocks coming in contact with the underlying gneisses and granites; but to the southwestward appear the fragmental quartzites of the Chippewa valley, which are believed to be its continuation.

The equivalency of the Penokee series with the Animikie is as plain as the equivalency of any two areas of detached rocks in a single geological basin can possibly be in which is lacking clear paleontological evidence. It has been seen that above the cherty limestone of the Penokee series is an erosion interval. In the Animikie series proper we know of no equivalent to this member, and in what follows it is excluded from the discussion. The Penokee and the Animikie rocks have a parallelism in lithological characters which is most remarkable. Not only is there a general likeness between the specimens from the two regions, but almost every phase of rock from the Animikie series can be matched by specimens from the Penokee series. In the Animikie district the formations underlying the iron-bearing belt are not extensively exposed, and consequently little is known of the Animikie equivalent of the Quartz-Slate of the Penokee series. But along the Lower Current river, near port Arthur, Ontario, quartz-slates underlying the iron-bearing member are found which resemble certain phases of the Penokee quartz-slate. Beginning with the iron formations, the parallelism between the two series is almost exact. The irony beds upon Gunflint lake, where are found the best known exposures of the formation, are in their lower parts jasper, magnetite-actinolite-schist, and cherty ferruginous rocks containing more or less iron carbonate. Higher up are thick layers of thinly bedded cherty iron carbonate. All these varieties of rock are found in the iron formation of the Penokee series, and at many places the order of succession is the same. Above the iron-bearing belt in both districts is a great thickness of fragmental clay-slates and graywacke-slates which are again practically identical in character in both districts. It is true that in the western part of the Penokee district mica-schists have developed from these slates, but the original condition of these rocks was essentially like that of the unaltered phases.

Underlying both the Animikie and Penokee series is a complex of granites and schists, the unconformity between which and these series is of the most pronounced character. That the Animikie series is thus separated from the underlying rocks has been seen by all who have studied it. Above both series follows the Keweenawan. In both districts, in passing at any place from the underlying rocks to the Keweenaw series in section, the two are in apparent conformity; but, when the lines of contacts between the iron-bearing and the Keweenaw series are followed for some distance, both with the Animikie and Penokee series, this apparent conformity is found to be illusory. That is, the Keweenaw series is found to come in contact with one member of the underlying series at one place and with another member at another place, until in both districts at one or more places the entire iron-bearing series is cut off, the basal Keweenaw rocks coming directly in contact with the fundamental complex. These relations mean that between the deposition of the Penokee and Animikie series and the outflows of Keweenaw time there intervened a period of erosion which was sufficient in places to remove the whole of the inferior series and to cut in some places quite deeply into the fundamental complex. There is then an immense time gap between these series and the Keweenawan, although this unconformity does not approach in the length of time involved to that separating the Animikie and Penokee series from the underlying schists and granites.

The Animikie series in its most typical development extends from Gunflint lake on the national boundary, between Minnesota and Ontario, to Thunder bay, lake Superior. The Penokee series lies upon the opposite side of lake Superior. The latter is a simple unfolded succession dipping to the northward under the lake; the Animikie is another such succession dipping to the southward under the same body of water. There is then little doubt, considering all the facts, that the two series represent a single period in the history of the synclinal trough which forms the basin of lake Superior. The relations and likeness of the Penokee and the Animikie series have been repeated at length as showing the breadth of the geological basin in which the deposition of like rocks was taking place simultaneously. The equivalency here shown is a long step in understanding the equivalency of other rocks in the lake Superior basin.

SUCCESSION AND EQUIVALENTS OF THE MARQUETTE DISTRICT SERIES.

In the Marquette district, as the succession has already been discussed, it need here be only briefly repeated. It is as follows: At the base is the Archean gneiss-granite-schist complex. In ascending order follow the Lower and Upper Marquette, having the lithological characters and relations above described.

Much work remains to be done in this district which has been studied so closely. From present knowledge it is not even definitely known whether certain of the iron ranges, as for instance that of Teal lake, are Upper or Lower Marquette, although it is very probable that the one mentioned belongs to the Upper. Also it is a serious question what part of the green schists and schist-conglomerates, some of which are cut by granite, belong in the Lower Marquette series. Recent work appears to indicate that much if not all of this surface volcanic material belongs here, although it can not be asserted that surface volcanic material does not occur with the green schists of the Archean.

SUCCESSIONS AND EQUIVALENTS OF THE MENOMINEE AND FELCH MOUNTAIN DISTRICTS SERIES.

Passing now to the Menominee and Felch mountain districts, information is less exact. It is, however, clear that in both of these areas the fundamental complex is found; that is, the granites and gneisses associated with crystalline schists having the usual eruptive contacts. Above this complex, Pumpelly, with whom this whole subject has been discussed and who has great familiarity with the entire lake Superior region, suggests as exceedingly probable that in the Felch mountain iron-bearing series only the equivalent of the Lower Marquette occurs, the upper series, if it once existed, having been removed by erosion; while in the Menominee district both representatives of the Lower and Upper Marquette are present. The Menominee proper—that is, that part of the area which includes the Chapin, Ludington, and Norway mines, those in which a cherty limestone is found—are Lower Marquette, while the western district, including such mines as the Commonwealth, Florence, and many others occurring in the upper black slate, are Upper Marquette. That between these two is a probable unconformity has already been shown.

EQUIVALENTS OF THE BLACK RIVER FALLS SERIES.

The Black river falls iron-bearing schists of Wisconsin have not such observable structural relations as to enable one certainly to determine their position. They are, however, thoroughly crystalline schists, and are in vertical attitude. On these grounds they are provisionally placed as the equivalent of the Lower Marquette.

SUCCESSION AND EQUIVALENTS OF WESTERN ONTARIO AND NORTHEASTERN MINNESOTA SERIES.

Combining the work of Dawson and Lawson about Rainy lake and the lake of the Woods, Smyth about Steep Rock lake, the Winchells and Irving in northeastern Minnesota, the succession appears to be granite-gneiss-schist (Coutchiching ?) complex, unconformity, Keewatin, unconformity, Animikie, unconformity, Keweenawan. There are also in this district great masses of granite-gneiss at least as late as the Keewatin. Included in the granite-gneiss-schist basal complex are only such granite-gneisses as are more ancient than the oldest sedimentaries. This vast area has been too little studied to say definitely what part of the areas referred to Irving's mica-schist group, Winchell's Vermilion series, and Lawson's Coutchiching belongs with the Basement Complex. It is equally difficult to say whether the Keewatin of Lawson and Winchell does not comprise more than one series. It is Lawson's opinion that it does and that the physical break described as occurring in the clastic series on the south shore exists between the Upper and Lower Keewatin. Our knowledge of this part of the lake Superior region is not sufficiently advanced to outline with any accuracy the areas which are to be referred to these main divisions. It is, however, tolerably clear that in this part of the region there are the same great subdivisions of the pre-Cambrian rocks as elsewhere; that a part of what has ordinarily been called Laurentian will be included in the Basement Complex; that a part of Irving's mica-schist group, Lawson's Coutchiching, and the Profs. Winchell's Vermilion also falls within this complex. It is further probable that a part of the Keewatin is the equivalent of the Lower Marquette, Lower Menominee, and equivalent series. It is possible that other parts of the series which have been designated Keewatin belong rather with the Animikie. If, however, the break at the base of the Animikie is higher than that above the Vermilion, Hunter's island, and Kaministiquia iron-bearing series, and the latter break belongs within the Keewatin, as now known, this group will need to be subdivided into two series, and the succession will thus be expanded at this point into Lower Keewatin, unconformity, and Upper Keewatin.

NOMENCLATURE.

There still remains the question of nomenclature. In Chapter VIII, the major taxonomy of the pre-Cambrian is discussed and reasons are given for including under the term Algonkian all the pre-Cambrian clastics, for confining the term Archean to the inferior crystalline complex, for restricting the term Laurentian to the coarser grained light colored granite-gneiss part of this complex, and for proposing for the dark colored fine grained schistose part of this complex the term Mareniscan. These reasons will not be repeated here, but the terms with these definitions will be applied to the rock successions of different districts of the lake Superior region. This will serve to illustrate the usage of these terms and at the same time will be a test of the propriety of the usages proposed, since the lake Superior region is the one in America about which most has been written and which furnishes the fullest pre-Cambrian column.

Belonging to the Archean on the south shore are the Southern Complex of the Penokee districts, the fundamental complex of the Marquette and Menominee districts, and a great expanse of rocks in northern Wisconsin. This complex is more largely of the Laurentian gneiss than of the Mareniscan schists. Between the two are often the peculiar gradations described which are taken to indicate the intrusive character of the granite-gneiss. Between the Archean and the Algonkian, as indicated by evidence fully given in another place, there is a great unconformity.

On the north shore Smyth finds decisive evidence of a thoroughly crystalline fundamental complex below the lowest clastics at Steep Rock lake. As has been seen, evidence pointing in this same direction is to be found in the reports of Logan, Dawson (Sir William), Selwyn, Bell, Macfarlane, Herrick, and Lawson, although several of these authors do not reach this conclusion. The difficult and uncertain point in this connection is in reference to the Coutchiching of Lawson or the Vermilion of Profs. Winchell. If, as believed by Lawson, there is a great time break between the Keewatin and Coutchiching and if the Coutchiching is found to be older than any of the clastics, it belongs to the fundamental complex and the term Coutchiching has priority over Mareniscan, proposed for the dark colored, fine grained schistose part of the Archean. This is the outcome which seems to the writer, according to present published evidence, to be most likely; but it must be stated that this impression does not accord with Lawson's opinion, who regards the Coutchiching as a sedimentary series more nearly connected with the Keewatin than with the Archean, nor with the Profs. Winchell, who regard the equivalent Vermilion as but a more metamorphosed downward extension of the Keewatin.

In restricting the word Laurentian to the granite-gneiss of the Archean, much of what has heretofore been denominated Laurentian will be excluded. This usage will throw out all of the granite-gneisses of an age later than the clastics, and therefore much of the granite-gneiss which Lawson has called Laurentian. It must be recognized that about the lake Superior region there are granite-gneisses of various ages. This is more evident in the main granite-gneiss areas than elsewhere, for not infrequently intruding them are other large bosses of granite or gneiss, which, with the earlier granite-gneiss, may have again been cut by still later material of the same kind. It is believed by some that there are in the lake Superior region granite-gneisses of at at least four different ages. It will not do to conclude that any certain granite-gneiss is Archean unless its structural relations to the Algonkian clastics are determined. However, the granite-gneisses which belong to the Archean on the south shore are pegmatized through and through and banded and contorted in the most intricate manner. Their constituent minerals show that they have undergone repeated dynamic movements. They are cut by eruptives of many kinds and of different ages. Many of the basic eruptives are so ancient that they themselves have become schistose and have passed over into hornblende-gneisses and similar rocks, which now are seen as dark colored intersecting or parallel layers in the pink granite-gneiss. This intricate complex of granite, gneiss, and schist, which has been subjected to repeated dynamic movements in various directions, is very different from the somewhat regular, little altered granite-gneiss which acts as a subsequent intrusive.

The early Canadian geologists used the term Huronian to cover all the fine grained schistose and clastic rocks between the Keweenawan or Upper Copper-bearing rocks and the Laurentian. The same is true of many of the American geologists. It is clear that the fine grained crystalline schists which constitute a part of the Archean can not here be included. Huronian can include only that part of the Algonkian between the Keweenawan and Archean, and, as has been seen, this Huronian is separable into two uncomformable series. On the part of the Canadian geologists of late there has been a tendency to restrict this term to the lower series, as shown by the exclusion of the Animikie from the Huronian, but if this is done the greater part of the Original Huronian must itself be excluded from the Huronian. Upon the other hand, Irving and the Profs. Winchell have advocated restricting Huronian to the upper series alone. The recognition of a general stratigraphical break in the rocks heretofore included by most authorities in the Huronian leads to the natural suggestion that for the superior division Upper Huronian shall be used, and for the inferior Lower Huronian. The fact that it has been recently maintained that in the Original Huronian area itself both of these series exist but renders this suggestion more appropriate. Further in favor of this position is its conservative character, although it is recognized that the rules of good nomenclature point rather to the restriction of Huronian to the upper or lower series. If restricted to one it should clearly be the upper, for it is certain that the greater part of sediments of the Original Huronian mapped in detail here belongs. Hence, as advocated by Alex. Winchell, is placed as an alternative to Lower Huronian in the following tabulation Lawson's term Keewatin. This term was first defined to cover a series of clastics with some crystalline schists about the lake of the Woods. It was later more clearly defined and restricted to the unmistakable clastics and altered volcanics about Rainy lake. By the Profs. Winchell it was applied to the Vermilion lake iron-bearing series, which was believed by them to be the equivalent of the Rainy lake Keewatin. In many respects the greater part of these series is like the Lower Marquette, Felch mountain, Lower Menominee, Hunters island, and Lower Kaministiquia series. If this supposed equivalence were demonstrated it would be preferable to adopt this term to cover all the series included under the Lower Huronian. It is, however, by no means clear that the Keewatin will not prove to be a complex series, just as have the Marquette and Vermilion lake rocks, consequently it is only tentatively placed in the general column. One other term has been proposed for this place, Marquettian; but this term is objectionable because as used it included both Upper and Lower Marquette.

Lawson has proposed the term Ontarian to cover the Keewatin and Coutchiching. It appears to us that the purposes of geology are better subserved by using the term Algonkian to cover all the clastic series between the Fundamental Complex and Cambrian, and to retain Archean as a term of coordinate value with this to cover the basal complex. If it shall turn out that the writer is correct as to the position of the Coutchiching, the base of the Lower Huronian, not the base of the Coutchiching, is the important horizon to mark. More evidence is desirable for the application of stratigraphical methods to the prominent structure of the Coutchiching, since, in many respects this structure has the characters of an induced one. Lawson recognizes a true physical break at the base of the Keewatin, not at the base of the Coutchiching. The break between the Coutchiching and the granite-gneiss is one which is also found between the granite-gneiss and Keewatin. It is not a structural horizon, but an eruptive contact. Upon the other hand, a great mass of evidence goes to show that there is at the base of the Keewatin a persistent structural plane which is recognizable throughout the lake Superior region.

Selwyn and N. H. Winchell maintain that the Keweenawan and Animikie are properly Cambrian. Whether the term Cambrian shall be so extended downward as to cover two great unconformities and two additional rock series of very great thickness is purely a matter of policy and of nomenclature, which is more fully discussed in another place. While it is of primary importance that an agreement shall be reached as to the actual rock successions in the lake Superior region, it is but a secondary matter as to the names which shall be applied to them. That fossils are found in the Huronian is not sufficient reason for extending the Cambrian downward indefinitely. That the evidences of abundant life are here found has been long known. Many of the thick beds of slates heretofore called Huronian, on the south shore of lake Superior, not only contain graphitic material, but a considerable percentage of hydrocarbons, not infrequently becoming graphitic or carbonaceous schists. In the Animikie, on the north shore of lake Superior, Ingall finds abundant carbon, and it is said that in certain mines and openings rock gas forms in considerable amount. Also small quantities of rock may even be obtained which will burn. These substances must result from the ordinary processes which produced rock gas and coal in the rocks of far later age. Also the great beds of iron carbonate are, to many, evidence of abundant life. In the Sioux quartzites one generally accepted fossil has been discovered by N. H. Winchell. A discovery of a fossil has been announced by Selwyn as occurring in the Animikie. It is a hope that in the future numerous other fossils will be found in this series, so that we may have the assistance of paleontology in lake Superior stratigraphy. Until, however, a fauna is known in these regions which is distinctly Cambrian, the discovery of life or of certain fossils in the Keweenawan and Huronian rocks is wholly insufficient evidence for placing them with the Cambrian.

We then have in the lake Superior region the following successions and correlations for the pre-Cambrian rocks:

Pre-Cambrian rocks of the lake Superior region.

		Western Ontario.	Northern Minnesota.	Michigan.			Michigan and Wisconsin.	Wisconsin.	Iowa, South Dakota, and southern Minnesota.
				Marquette.	Felch mountain.	Menominee.	Penokee.		
Algonkian.	Keweenawan.	Nipigon.	Keweenawan.				Keweenawan.	Keweenawan.	
	Unconformity.	Unconformity.	Unconformity.				Unconformity.	Unconformity.	
	Upper Huronian	Animikie and Upper Kaministiquia.	Animikie and Upper Vermilion.	Upper Marquette.		Western Menominee.	Penokee-Gogebic Proper.	Chippewa Quartzites. Baraboo Quartzites.	Minnesota and Dakota quartzites, surrounded by fossiliferous series.
	Unconformity.	Unconformity.	Unconformity.	Unconformity.		Inferred Unconformity.	Erosion interval.	Unconformity.	
	Lower Huronian.	Keewatin in part at least, and Lower Kaministiquia.	Lower Vermilion.	Lower Marquette.	Felch mountain Iron-Bearing series.	Menominee Proper.	Cherty limestone.	Black river falls Iron-Bearing schists (?)	
	Unconformity.	Unconformity ?	Unconformity ?	Unconformity.	Unconformity.	Unconformity.	Unconformity.	Unconformity (?)	
Archean.	Mareniscan.	(Coutchiching ?)	(Coutchiching ?)	Fundamental Complex. (Not yet separated in mapping.)	Fundamental Complex. (Not yet separated in mapping.)	Fundamental Complex. (Not yet separated in mapping.)	Southern Complex. (Separated in mapping into fine-grained schist, Mareniscan, and granites and granite-gneisses, Laurentian, showing characteristic eruptive contact.	Fundamental Complex. (Not yet separated in mapping.)	Minnesota river valley gneiss and granite.
	Eruptive Unconformity.	Eruptive Unconformity.	Eruptive Unconformity.						
	Laurentian.	Laurentian.	Laurentian.						

LAKE SUPERIOR BASIN.

The synclinal structure of the formations about lake Superior was noted as early as 1847 by Logan in his remarkably accurate general account of the lake Superior region. His five general formations were found to recur in reverse order on both sides of the lake, dipping to the center. Rogers and Agassiz, in 1848 and 1850, maintained that the shores of the lake are due to dikes. Owen, in 1851, in his studies north and south of the west part of the lake, saw that the formations occur in reverse order, and reached independently the same conclusion as did Logan. Bigsby and Whitney followed Logan and Owen in describing the lake Superior basin as synclinal. The next exact contributions to the structure of the lake Superior synclinal were by Sweet and Irving, who found it to continue to the southwestward in Wisconsin and Minnesota, the rocks adjacent to the shore on the south side of the west end of the lake being on the north side of the synclinal basin. Sweet, in 1876, spoke of the lake Superior synclinal as over 300 miles in length and 30 to 50 miles in width. That the lake Superior formations are not only a synclinal in an east and west direction, the rocks dipping respectively from the north shore south and the south shore north, but that it is a basin in the exact sense of the term, the rocks on the east shore dipping to the west, while the western termination of the synclinal in Minnesota plunges to the east or northeast, was shown by Irving. This author went further and also showed that the major bays of the lake are due either to faults or subordinate flexures within the Keweenawan. The basin is clearly a product of Keweenawan time. Chamberlin suggests that it began early in the Keweenawan. The Upper Huronian series partakes in several districts in large measure of the basin structure. This is apparent from the fact that the Huronian of the Penokee and Animikie series was so long regarded as conformable with the Keweenawan. It has been seen that there is between these series a great unconformity, although not one so vast as the other physical breaks about the lake. As a consequence of this the Upper Huronian series corresponds only locally with the synclinal structure, and chiefly about the west half of the lake. The structures of the Lower Huronian and Archean have no reference to that of the lake Superior basin.

CONCLUSION.

It appears that in the lake Superior region is a general succession which may be recognized, and that there is really a much greater degree of harmony than has been thought in the conclusions which the various writers have held most steadfastly as to the lake Superior stratigraphy. From the base upward it is as follows: Archean, including Laurentian granite and gneiss, the origin of which is largely unknown, but which were certainly in their present condition earlier than the formation of the Lower Huronian; unconformity; Lower Huronian (a closely folded semicrystalline series); unconformity; Upper Huronian (a gently folded and plainly clastic series, although indurated by cementation and metasomatic changes); unconformity; completely unaltered Keweenawan; unconformity; lake Superior sandstone. In addition to the above are great masses of eruptive rocks in all the series, both basic and acidic, including granite-gneiss, gabbro, porphyry, diabase, etc.

I can not close without comparing this succession of lake Superior formations with that given by Logan in his remarkable paper published in 1847. It is as follows: "(1) Granite and syenite; (2) gneiss; (3) chloritic and partially talcose and conglomeratic slates; (4) bluish slates or shales interstratified with trap; (5) sandstones, limestones, indurated marls, and conglomerates, interstratified with trap." Between 1, 2, 3, and 4, 5 there was said to be an unconformity. The granite, syenite, and gneiss are Archean; the chloritic and partly talcose and conglomeratic slates, Lower Huronian; the bluish slates or shales interstratified with trap, Upper Huronian; and the sandstones, limestones, indurated marls, and conglomerates interstratified with trap, Keweenawan. Of course, Logan at that time did not appreciate all the structural relations which obtain between these various series, although the greatest of the unconformities was discovered, nor did he suppose that they are all pre-Cambrian, and in his mapping in 1863, 1 and 2 are placed together as Lower Laurentian, and 4 and 5 together as a part of the Quebec group above the Potsdam; yet that he appreciated that in this region there are five fundamentally different kinds of rock, that he gave an accurate characterization of the Keweenaw series, comprehending that it is one of great thickness, not less than 10,000 or 12,000 feet, and that this series rests unconformably upon the granite and gneiss, can not be too highly spoken of. Not only was this paper the first announcement of all of the above great conclusions, but it gave the first mention, as has been seen, of the synclinal structure of lake Superior.

Looking toward the future as to the possible modifications of this arrangement by further work, the point of greatest doubt lies as to whether the unconformities here recognized as universal in the lake Superior region are really so. Is it not possible that the unconformity at the base of the Animikie is at a different position from that between the Penokee proper and the Cherty Limestone, and may not these be different horizons from that between the Upper and Lower Marquette? May not the break above the Lower Marquette be at a different position from that above the Lower Vermilion. These questions can not be positively answered in the negative, although all the evidence at hand bears strongly in this direction. It may be found in the lake Superior basin, so extensive in area, that while the folding and erosion producing an unconformity in one part was occurring, at some other distant part deposition was going on. In all probability this is to some extent true. That the rocks in the different districts referred to these periods have the same absolute duration would hardly be expected. Sedimentation in the series correlated probably continued longer in certain parts of the region than in others. A break even if as widespread as believed probably did not begin nor end everywhere at the same time; and certainly it would be true, after a certain movement and erosion had ended, as the sea began to encroach, that sedimentation would begin in one district before it reached another. So that if these correlations are correct and the breaks really general, as is believed, it does not follow that the periods opened or closed simultaneously, but that they stand in a general way as equivalent. The equivalency advocated may be much more strongly asserted of the districts immediately adjacent to lake Superior than of the more remote districts.

The further question arises, whether as work continues new breaks of considerable magnitude, not now recognized, will be found. This is not improbable. In fact, there is already some indication of such a break, although not now capable of being proved at any point. Does the series of great conglomerates which are placed at the base of the Upper Huronian, the debris being derived mostly from the Lower Huronian, grade conformably upward into the Animikie, or is there here a considerable additional break? It is by no means certain that the truth is not with the latter alternative, for the conglomerates certainly seem to have suffered more intense dynamic action than the adjacent Animikie. Their thickness is great, and it may well be that in the Thunder bay district will be found a considerable break which in a part at least of the lake Superior region will subdivide the Upper Huronian.

Also as a problem for the future is the real nature of the Archean schists. Are they clastic or igneous in origin? Are they, as has been supposed, a real fundamental complex, or will this be subdivided upon a structural basis? A few years ago all below the pre-Cambrian was a fundamental complex. Will not the future find our present fundamental complex further divisible and the real fundamental complex at a still lower horizon?

Accepting the general stratigraphy as given above, how far will it be possible to correlate the individual formations of the series? How far are the Quartz-Slate member, the Iron-bearing member, and the Upper Slate member of the Penokee series equivalent to those of the Animikie? When, as in this case, three like formations of great thickness are found in the same order, and the two series as wholes bear identical relations to underlying and overlying series, the correlation may perhaps be made with a considerable degree of probability, and later closer work rather leads to the conclusion that much will be accomplished in the direction of correlating formations; that is, several of the series may be divided into two or three or more members, which may with a considerable degree of probability be correlated with equivalent members in other districts, but that it will be possible to subdivide these various series into fifteen or twenty or more members, as was done by the early authors, and to correlate these small divisions with each other throughout the lake Superior region, there is not the least probability.

While perhaps more has been done in pre-Cambrian stratigraphy in the lake Superior region than in any other region in America, this very fact opens before us numerous and difficult problems.

NOTES.

[1] Notes on the Geography and Geology of Lake Superior, John J. Bigsby. Quart. Jour. Sci., Lit. and Arts, vol. XVIII, pp. 1–34, 222–269; with map.

[2] Outlines of the Geology of Lake Superior, H. W. Bayfield. Trans. Literary and Historical Soc. of Quebec, vol. I, 1829, pp. 1–43.

[3] On the Junction of the Transition and Primary Rocks of Canada and Labrador, Capt. Bayfield. Quart. Jour. Geol. Soc., London, vol. I, 1845, pp. 450–459.

[4] On the Geology and Economic Minerals of Lake Superior, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1846–'47, pp. 8–34.

[5] On the Geology of the Kaministiquia and Michipicoten Rivers, Alexander Murray. Ibid., pp. 47–57.

[6] On the Age of the Copper-Bearing Rocks of Lakes Superior and Huron, and various facts relating to the Physical Structure of Canada, W. E. Logan. Rept. of British Assn. for the Adv. Sci., 1851, 21st meeting, pp. 59–62, Trans.; see also, On the Age of the Copper-Bearing Rocks of Lakes Superior and Huron, William E. Logan. Am. Jour. Sci., 2d ser., vol. XIV, 1852, pp. 224–229.

[7] On the Geology of the Lake of the Woods, South Hudsons Bay, Dr. J. J. Bigsby. Quart. Jour. Geol. Soc., London, vol. VIII, 1852, pp. 400–406. With a geological map of the Lake of the Woods.

[8] On the Physical Geography, Geology, and Commercial Resources of Lake Superior, John J. Bigsby. Edinburgh New Phil. Jour., vol. LIII, 1852, pp. 55–62.

[9] On the Geology of Rainy Lake, South Hudsons Bay, Dr. J. J. Bigsby. Quart. Jour. Geol. Soc., London, vol. X, 1854, pp. 215–222. With a geological map of Rainy Lake.

[10] On the Geological Structure and Mineral Deposits of the Promontory of Mamainse, Lake Superior, John W. Dawson. Can. Nat. and Geol., vol. II, 1857, pp. 1–12. With a section.

[11] Report of Progress of the Geological Survey of Canada from its Commencement to 1863, W. E. Logan; pp. 983. With an atlas.

[12] On the Laurentian, Huronian, and Upper Copper-Bearing Rocks of Lake Superior, Thomas Macfarlane. Rept. of Prog. Geol. Survey of Canada for the year 1863 to 1866, pp. 115–164.

[13] On the Geological Formations of Lake Superior, Thomas Macfarlane. Can. Nat., 2nd ser., vol. III, 1866–'68, pp. 177–202, 241–257.

[14] On the Geology and Silver Ore of Woods Location, Thunder Cape, Lake Superior, Thomas Macfarlane. Can. Nat., 2d series, vol. IV, pp. 37–48, 459–463; with a map.

[15] On the Geology of the Northwest Coast of Lake Superior and the Nipigon District, Robert Bell. Rept. of Prog. Geol. Survey of Canada from 1866 to 1869, pp. 313–364; with a topographical sketch-map.

[16] Report on the Country North of Lake Superior, between the Nipigon and Michipicoten Rivers, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1870–'71, pp. 322–351.

[17] Report on the Country between Lake Superior and the Albany River, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1871–'72, pp. 101–114.

[18] Notes of a Geological Reconnaissance from Lake Superior to Fort Garry, A. R. C. Selwyn. Rept. of Prog. Geol. Survey of Canada for 1872–'73, pp. 8–18.

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[208] Based on unpublished field notes made by W. N. Merriam in the summers of 1888 and 1889.

[209] Based on unpublished field notes made by C. R. Van Hise in the summer of 1890.

[210] Based on unpublished field notes made by Profs. Raphael Pumpelly and C. R. Van Hise in the summers of 1891 and 1892.

CHAPTER III.

THE GREAT NORTHERN AREA.

SECTION I. THE REGION ABOUT HUDSON BAY.

LITERATURE.

BELL,[1] 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 Paul's lake may be Laurentian. In this distance the rocks are limestones, quartzite, diorite, chert-slate-conglomerate, hornblende-schist, pegmatite, syenite, clay-slates, and, at Paul's lake, gneiss. The diorites have a widespread occurrence, and an area of massive syenite continues for several miles in one local, ity. 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 Kenohamissee.

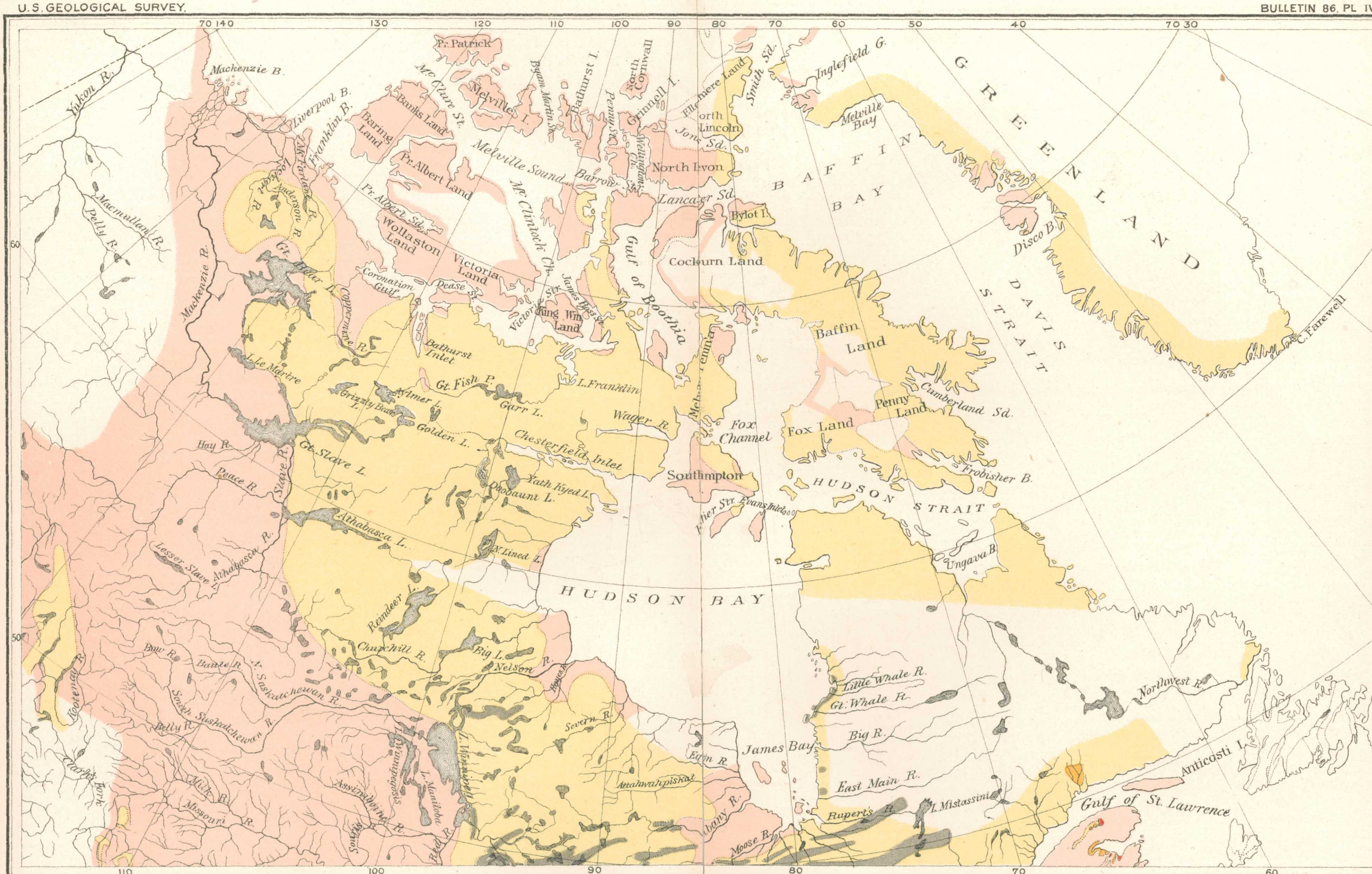
On the return trip the course followed is by the west branch of Moose river, along toward its headwaters, thence to Michipicoten and lake Superior. The rocks are chiefly granite and syenite, gneiss, hornblende-schists and mica-schists and greenish schists. These are in part referred to the Huronian and 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.

BELL,[2] 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 sometimes interstratified with the sandstone.

BELL,[3] 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,[4] in 1880, reports on explorations of the Churchill and Nelson river and around God's 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,[5] in 1881, reports on Hudson bay and some of the lakes and rivers lying to the west of it. Various gneisses and schists are found at different points which are referred respectively to the Laurentian and



Unclassified Pre-Camb.

Algonkian

Post-Algonkian

Eruptives

Granitic

Basic

GEOLOGICAL MAP OF NORTHERN CANADA

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from Official Maps the Canadian Geol. Survey

Scale. 1/21,900,000

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, quartzites and other rocks are found 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,[6] 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,[7] in 1885, describes granite and gneiss at North head, Button islands, Ungava bay, Nunaungok, Ashe's inlet, Nottingham and Digges islands, Stuparts bay, Eskimo inlet, port DeBoucherville, and port Laperriere. 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. Deadman's island consists of white and light-gray quartzites, and glossy mica-schists, striking north 75° west. 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,[8] 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 the 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 Misstassini, in the interior of the Labrador peninsula, bear a strong resemblance to those of the east main coast.

BELL,[9] 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 there is little doubt are more ancient than the regularly stratified gneisses which prevail on 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 Manitounuck series is largely made up of rocks of volcanic origin.

BELL,[10] in 1887, reports on explorations of portions of the Attawapishkat and Albany rivers. Various granites, gneisses, and schists are found upon Pelican lake, lake St. Joseph, and the upper sections of Albany and Boulder rivers, and lake Lansdowne. Upon lake St. Joseph a conglomerate is found. The granites and gneisses are placed with the Laurentian and the schists and conglomerates with the Huronian.

SUMMARY OF RESULTS.

In all of the above works by Bell the rocks are classified as Laurentian or Huronian almost wholly upon lithological grounds, the coarse granites and granitoid gneisses being regarded as Laurentian and the clearly sedimentary rocks and fine grained calcareous gneisses and various green schists with associated rocks being placed as Huronian. Whenever the relations of the two series are spoken of they are said to be in conformity. The Huronian is, however, frequently spoken of as occurring in troughs, which probably implies that this series is taken to be the newer of the two; but in general this is an inference from its lithological character rather than a determination from an ascending succession. The dips are usually high and no structure is worked out, so that from the facts given it would be impossible to determine which is higher and which lower, except by the implication in the words Huronian and Laurentian. While certain of the rocks placed with the Huronian are lithologically like those of the Original Huronian, Bell distinctly states that in the main they are quite different. The likeness apparently goes no further than the fact that occasionally there are found unmistakable clastic rocks, and some of these clastics resemble more closely the fragmentals of the Ottawa series than they do those of the Original Huronian.

The Manitounuck group on Hudson bay, which is described as resembling very closely the Nipigon series, is, from the illustrations, a comparatively flat-lying one and is probably newer than either of the series referred to the Laurentian or Huronian. At least two unconformities are mentioned in it, one between two sedimentary rocks and another between a sedimentary rock and a trap. These unconformities are spoken of as slight, but the cuts illustrative of them represent the first of these unconformities as very considerable.

SECTION II. NORTHERN CANADA.*

LITERATURE.

STEINHAUER,[11] in 1814, gives localities for labradorite on the coast of Labrador.

McCULLOCH,[12] in 1819, describes as coming from Baffin bay, 70° 37′, granite, gneiss, and graywacke-schist.

RICHARDSON,[13] 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 contains more foreign beds in advancing to the 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 eastward of Coppermine river. About Fort Enterprise are numerous hills capped by red granite, around which, on the acclivities, gneiss is wrapped in a 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 with the bases. In the first 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

* This section is largely compiled from Geo. M. Dawson's account of this region accompanying his geological map of it. With a number of exceptions the original reports have not been seen. This unusual plan is here adopted because Dawson's summary of the geological material, widely scattered through the many volumes of Arctic travel, is so complete as to render unnecessary the labor of going through them a second time.

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 Hood's river, the rocks are entirely gneissic or granitic.

PARRY,[14] 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,[15] in 1824, describes the most characteristic rock collected by Capt. 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,[16] 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,[17] in 1826, states that the material collected by Capt. 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,[18] 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 the Mackenzie river, the mountain range consists of graywacke slates which are considered transition rocks.

LESLIE, JAMESON, and MURRAY (HUGH),[19] 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,[20] 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,[21] 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 the Great Fish river to the Arctic coasts are different varieties of granite and gneiss.

BACK,[22] in 1838, describes granite as occurring in two places along the southeastern coast of Southampton island.

SIMPSON,[23] in 1843, applies the name Trap Point to the Kent peninsula. After an interval of low ground to the eastward granite forms the coast line.

RAE,[24] in 1850, finds north of latitude 61° on the west coast of Hudson bay, beyond Nevill's 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, hornblende-slate. Precipitous cliffs of trap were found on Simpson bay, in latitude 68° 27′.

RICHARDSON,[25] 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 the Coppermine river, are series of basaltic cliffs.

SUTHERLAND,[26] 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.

MURCHISON,[27] in 1857, states that cape Granite in the Arctic Archipelago is composed of quartz, feldspar, and chlorite, and is accompanied with gneiss of the same composition.

KANE,[28] 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,[29] 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 M'Clure, 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,[29] 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 Bellot's straits, in latitude 72° north, are found gneissoid granite, graphic granite, and syenite. At Pond's 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. Carey's islands, west of Wolstenholme sound, are composed of a gneissose mica-schist, formed of successive layers of quartz granules, and layers of jet-black mica. The mica-schist passes into white gneiss. Yellow and white sandstones are also found in small quantity upon the islands, reposing upon the granitoid rocks.

LIEBER,[30] in 1860, describes on the coast of Labrador, gneisses, granites, labradorites, etc., at various localities.

DERANCE and FIELDEN,[31] 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, of impure limestones, traversed by veins of quartz and cherts, and of 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,[32] 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,[33] 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,[9] in 1885, describes on the Labrador coast gneiss and granite at Ford's harbor and Mission station, Nain, at Nachvak inlet, at Skynners cove, and other points. The granite sometimes becomes syenitic and the gneiss is sometimes well laminated.

BOAS,[34] in 1885, describes the nucleus of Baffin land as everywhere of gneiss and granite.

GREELY,[35] in 1886, finds toward the head of Chandler fiord high cliffs of schists and slate, and in Ruggles river, at the outlet of lake Hazen, large slabs of slate.

PACKARD,[36] 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,[37] 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 Lewis about 30 miles. This belt of crystalline rocks has a width of somewhat over 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, 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 lithological character.

SUMMARY OF RESULTS FROM DAWSON.

DAWSON,[38] 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, 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.

SECTION III. THE LOWER ST. LAWRENCE RIVER AND WESTWARD TO LAKES ST. JOHN AND MISSTASSINI.

LITERATURE.

BAYFIELD,[39] 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 eastward of Mingan islands and opposite Ste. Geneviève island, where the country for many miles inland is composed of low granite mounds; the coast from Ste. Geneviève east to cape Whittle, longitude 60° W., latitude 50° 10′ N. The granites are in part hornblendic and in part nonhornblendic. At Ste. Geneviève 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. Geneviève 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 southward at angles varying from 30° to 90°.

LOGAN,[40] in 1850, describes a metamorphic group of rocks in the vicinity of bay St. Paul, Murray bay, and White cape on the St. Lawrence river. The predominant rocks are mica-gneisses and hornblende-gneisses. No crystalline limestones were noted.

LOGAN,[41] in 1854, describes the district north of the 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 Mr. Garneau to the chain of hills which the Laurentian series compose. At St. Maurice the Potsdam sandstone rests upon the gneiss.

DAWSON,[42] 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,[43] 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 labradorites are cut by granitic veins.

RICHARDSON,[44] 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.

LAFLAMME,[45] 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.

Low,[46] 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 Abatagomaw, are similar to the epidotic and chloritic slates of the Shickshock mountains and the eastern townships and are referred to the Huronian.

SUMMARY OF RESULTS.

In the very brief and general studies of the area north of the lower St. Lawrence no attempt is made to map the region in detail nor to work out the structure of the rocks. The Labradorite rocks are separated by Richardson from the gneissoid rocks, to which he applies the term Laurentian. The reason for doing this is not given, so that we have no indication as to whether this is an eruptive or a sedimentary series, and if sedimentary, whether it underlies or overlies the gneisses. As in the Ottawa region, the great mass of gneiss is free from limestones. The limestones are local and are associated with other rocks which are presumably of clastic origin, such as quartzites.

The remarks which are made with reference to two series in the Ottawa area would apply equally well to this region. We have no indication as to the relations of the clastic series, described by Richardson, to the Laurentian gneiss which is referred by Low to the Huronian. Richardson, who did the work upon this series, was not able to give an opinion as to its position, and its reference to the Huronian by Low is made wholly upon lithological grounds. It is, however, probable that the great conglomerates in the neighborhood of Lake Abatagomaw, composed almost entirely of rounded fragments of Laurentian gneiss and which in some places closely resemble the gneiss, mark the structural boundary between the two series of rocks. The description of this conglomerate is that of a recomposed rock, the material being derived from the immediately underlying formation.

NOTES.

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[2] Report on an Exploration of the East Coast of Hudson Bay, Robert Bell. Rept. of Prog. of Geol. Survey of Canada for 1877–'78, pp. 1–37 C. With a map.

[3] Report on the country between Lake Winnipeg and Hudson's Bay, Robert Bell. Ibid., pp. 1–31 CC. With 5 plates and 2 maps.

[4] Report on Explorations of the Churchill and Nelson Rivers, and around God's and Island Lakes, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1878–'79, pp. 1–44 C. With a map.

[5] Report on Hudson Bay and some of the Lakes and Rivers lying to the west of it, Robert Bell. Rept. of Prog. Geol. Survey of Canada for 1879–'80, pp. 1–56 C.

[6] Report on the Geology of the Basin of Moose River and adjacent country, Robert

Bell. Rept. of Prog. Geol. and Nat. Hist., Survey of Canada for 1880-'81-'82, pp. 1-9 C. Accompanied by a map.

[7] Observations on Labrador Coast, Hudson Strait and Bay, Robert Bell. Rept. of Prog. Geol. and Nat. Hist. Survey and Museum of Canada for 1882-'83-'84, pp. 3-37 DD.

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[14] Journal of a Second Voyage for the Discovery of a Northwest Passage, etc., 1821-'23, Captain Parry. London, 1824.

[15] Notes on Rock Specimens, Charles Koning. Supplement to the Appendix to Capt. Parry's Voyage for the Discovery of a Northwest Passage in the years 1819-'20, (Natural History). London, 1824, p. CCXLVII.

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[17] Appendix on Geology of Countries discovered during Capt. Parry's Second and Third Expeditions, Prof. Jameson. Journal of a Third Voyage for the discovery of a Northwest Passage, etc., by Capt. W. E. Parry. London and Philadelphia, 1826.

[18] Appendix I, J. Richardson. Narrative of a Second Expedition to the shores of the Polar Sea in the years 1825-'27, by Capt. J. Franklin. London, 1828.

[19] Narrative of Discovery and Adventure in the Polar Seas and Regions, Sir John Leslie, Prof. Jameson, Hugh Murray. Edinburgh, 1830.

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[41] On the Geology of the North Shore of the St. Lawrence, between Montreal and Cape Tourment, W. E. Logan. Rept. of Prog. Geol. Survey of Canada for 1852–'53, pp. 5–40.

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CHAPTER IV.

EASTERN CANADA AND NEWFOUNDLAND.

SECTION I. THE EASTERN TOWNSHIPS.

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.

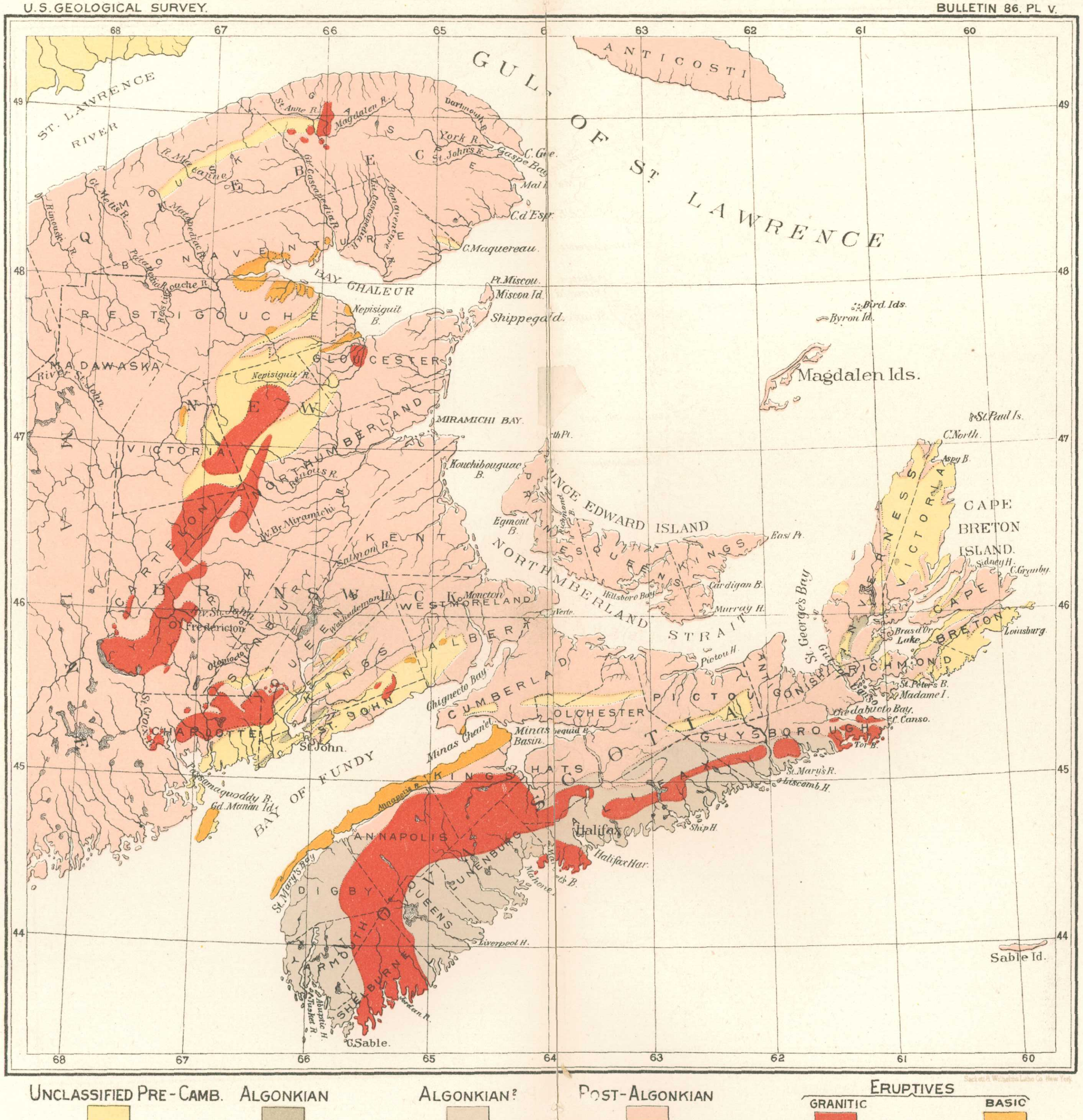
SELWYN,[3] in 1879, gives observations on the stratigraphy of the Quebec group. This group is divided into three distinct groups of strata. First, the lower Silurian group; second, the volcanic group, probably lower Cambrian; and third, the Crystalline schist group (Huronian?). The rocks composing group three 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, 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 further speaking of the Quebec group, asserts of the upper metamorphic or volcanic group that neither a schistose nor a bedded structure can be accepted as a 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 Keeweenian.

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 in a like manner is unconformable 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 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 now considered



GEOLOGICAL MAP OF NEW BRUNSWICK, NOVA SCOTIA, AND PART OF QUEBEC
SHOWING PRECAMBRIAN ROCKS

Compiled from official maps of the Canadian Geol. Survey

Scale $\frac{1}{4000000}$.

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 the 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 anticlinal 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 and west, while the overlying black slate, with which are associated beds of grayish limestone, at times strike nearly north and south. The difference in the character of the Cambrian and pre-Cambrian strata, together with the fact of the occurrence of a line of fault between the crystalline schists of the Sutton mountain anticlinal 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.

ADAMS,[9] in 1889, finds that the massive and stratified varieties of the anorthosite underlying the northwest part of the Eastern Townships 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.

ELLS,[10] in 1890, states that the lowest beds of the Lower Cambrian frequently contain 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 anticlinals, 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 anticlinal 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.

SUMMARY OF RESULTS.

A large number of articles have been written in reference to the Quebec group which are not touched in the above, as their point of view is paleontological, and if the crystallines are referred to at all they are simply placed as the metamorphosed equivalents of the fossiliferous rocks.

While Ells places the middle series found in this region as Cambrian, he is very cautious to say that he has no paleontological evidence for this; so that it is yet to be considered an open question whether it is Algonkian or not. By Selwyn it is compared with the Keweenawan, and by Ells with the Nova Scotia gold-bearing slates. It is certain that the series is uncomformably below the Potsdam, and equally certain that it overlies crystalline schists. While the so-called Cambrian and pre-Cambrian are said to be unconformable, and several localities are cited in which these relations obtain, one wishes that they had been described in more detail. The only one mentioned in which the facts are given upon which the statement of uncomformity is based is the one on the Quebec railway, where it is said that the strike of the Cambrian slates is almost at right angles to that of the pre-Cambrian schists. When it is remembered that there probably are in this region great masses of intrusive granites which have metamorphosed the adjacent strata, and that as a result of such action a schistose structure oftentimes develops independent of the original bedding, the evidence cited at this particular locality is by no means sufficient to establish the conclusion. However, the basal conglomerates of the series referred to the Cambrian, the crystalline character of the pre-Cambrian as contrasted with the clastic character of the Cambrian, and the sharply defined line, either of uncomformable overlap or of fault, between the crystalline series and the slates and quartzites which are styled Lower Cambrian, indicates the probability that a structural break of great magnitude does occur between the two series. The supposed lower series of crystalline chloritic and micaceous schists and gneisses, with their associated quartzites and limestones, seems clearly to be of clastic origin. It is compared with the Huronian by Ells. From present imperfect knowledge it can only be safely placed as Algonkian. If it shall turn out that the nonfossiliferous rocks referred to the Cambrian by Ells are also Algonkian, this system is represented in the Eastern townships by two series which are probably uncomformable.

Selwyn's later position as to the nature of the granite is the opposite of that earlier held. In his reports published in 1879 and 1883 the granites are not only believed to be intrusive, but many of the crystalline schists are believed to be metamorphosed irruptives. In the footnotes accompanying Ells's reports these same granites are said to be metamorphic.

SECTION II. GASPÉ PENINSULA.

LITERATURE.

ELLS,[11] in 1885, describes the pre-Cambrian rocks of the Gaspé 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,[12] in 1885, also describes the pre-Cambrian rocks of the Gaspé 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.

SECTION III. CENTRAL NEW BRUNSWICK.

LITERATURE.

ROBB,[13] 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, (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 the 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 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 each other. 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 imbedded or incorporated in the granite, and vice versa; but no appearance of granite veins cutting the laminated rocks are 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,[14] 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,[15] 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,[16] in 1883, finds crystalline mica-schists, quartzites, etc., which are provisionally referred to the pre-Cambrian system. They are found at two places conformably to underlie the Cambro-Silurian series.

BAILEY,[17] 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 semi-volcanic origin. The granite is filled with imbedded 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,[18] 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,[19] in 1877, 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 character as those which have been previously described as of probable Devonian age.

SUMMARY OF RESULTS.

As a result of the above work in central New Brunswick it is clear that below the Cambro-Silurian rocks is a set of semicrystalline and crystalline schists containing among the former such rocks as slate, quartzite, and limestone. The character of these is such as to show that they are in part of clastic origin. Large masses of intrusive rocks, both basic and acid, cut both these rocks and the fossiliferous sedimentaries. The masses are sometimes so large as to cause important contact metamorphism.

There is little difficulty in separating the intrusives from the fossiliferous rocks, but upon account of the more crystalline character of the older series and its likeness in mineralogical composition to certain of the subsequent intrusives, and further, upon 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.

The maps presented of the pre-Cambrian are purely areal, no attempt whatever being made to subdivide them or to work out their structure.

SECTION IV. SOUTHERN NEW BRUNSWICK.

LITERATURE.

GESNER,[20] 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,[21] in 1840, gives a continuation of his study of the previous year.

GESNER,[22] 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,[23] 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,[24] 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 to near Bathurst, and in them organic remains occur.

JOHNSTON,[25] 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 and mica-slate, and trap rocks.

BAILEY, MATTHEW and HARTT,[26] in 1865, in observations on the geology of southern New Brunswick, give a résumé of the work previously done. Of the 15 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, and 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 conformability 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 on its general lithological character and stratigraphical relations is provisionally referred to the Upper Silurian, although Lower Silurian and Lower Devonian beds may occur.

MATTHEW,[27] 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,[28] 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,[29] 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, (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,[30] in 1872, find the Laurentian system to have a rather widespread distribution. The rocks are placed in the Laurentian because 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 tufaceous 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. Contained 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 grits 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 these 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 here 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,[31] 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,[32] in 1876, place the Mascarene and Kingston series, the latter of which was previously considered Upper Huronian, in the Upper Silurian upon account of fossils discovered in them.

BAILEY and MATTHEW,[33] 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,[34] 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,[35] 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,[36] 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,[37] 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 unconformability of this group with the Silurian is marked in general. 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 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,[38] 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,[39] in 1880, give a general review of their work done upon 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 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 the bulk 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 unconformability is sufficient to prove the fact of any considerable lapse of time. The age and equivalency of the Kingston group, as well as that of the Mascarene peninsula, is somewhat uncertain, owing to the difficulty of obtaining stratigraphical evidence and from 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,[40] in 1881, in summarizing the work of the survey in New Brunswick, concludes that there is a Laurentian and 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, with 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, Maine. On the St. John river, associated with the fossiliferous rocks are amygdaloidal and ash rocks which are indistinguishable lithologically from the Huronian formation, and to which all of these rocks have previously been referred.

BAILEY,[41] 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 in receding from it; the outlines of the granite are irregular and sometimes parallel, at other times are oblique to, and at other times at right angles to 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,[42] 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,[43] in 1890, says the evidences of unconformity between the Primordial and 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,[44] 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 occurs 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.

SUMMARY OF RESULTS.

While the mapping of the province of New Brunswick has been completed by the official survey, the statements of the later papers of those who have taken the most active part in this mapping make it certain that many of the supposed conclusions reached in the early reports are open to doubt. The most noticeable feature is the failure to subdivide the Huronian into two or three series on these maps when the divisions Coldbrook, Coastal, and Kingston have been found in the reports for many years. The reason assigned on the maps for this is that the three series are so intimately intermixed that their separation with any approach to accuracy is impossible.

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 was called upper Huronian; in 1876 was again placed as Silurian; and was not until 1879 finally placed with the upper Huronian. The Coastal group, first placed in the fossiliferous series, in 1872 was placed in the middle Huronian; in 1878 was doubtfully referred to the Laurentian, and in 1879 was again returned to its place as middle Huronian. The Coldbrook group has been reckoned as Huronian since 1865.

At the outset, in discussing the results attained as to the succession of crystalline rocks, the intrusive character of a very large part of the granite at a period later than pre-Cambrian time may be considered as demonstrated. To this conclusion all the official geologists have agreed with the exception of Hind, whose work was done at a time in which the metamorphic theory had extreme power. Announced by Gesner in 1841, the evidence cited by him for the intrusive character of the granite is in a measure the same as that so convincingly given by Bailey over forty years later, in 1884.

The plainly eruptive character of a part of the granite suggests the question as to whether the great mass of syenite, granite, and gneiss making up the lower Laurentian is not also of an igneous character. Even if this be so, it does not follow that it is not the most ancient rock in southern New Brunswick; but the possibility is suggested that it may be an intrusive of a much earlier age than those which cut the Silurian strata, and yet not be earlier than a portion of the crystalline rocks of clastic origin and pre-Cambrian age.

It is evident that among the rocks referred to the Laurentian of southern New Brunswick is a great series of completely crystalline rocks, and an apparently unimportant series composed of slates, quartzites, and limestones. This is shown by the estimated thicknesses given in the report published in 1872. The lower Laurentian is given a thickness of over 13,000 feet, while the upper Laurentian (clastics) have a thickness not to exceed 1,000 feet.

The suggested intrusive character of the lower Laurentian is made more probable by the fact that there is said to be transitions between these plainly clastic rocks and the thoroughly crystalline ones. Upon the other hand, it is also a possibility that there is a physical break between the clastics and crystallines of the Laurentian, but no fragments of the underlying series are found in the clastics nor is any structural unconformity mentioned. One is at once struck with the parallelism between the two parts of the Laurentian of southern New Brunswick and those of the Hastings series. In this latter case Vennor, in his later work, came to the conclusion that the clastic series is a newer unconformable one resting upon an older crystalline series.

The Laurentian and Huronian are in general said to be in conformity. While this is true, Matthew in 1865 states that the Portland series is unconformably overlain by the Huronian, and Ells repeats this statement in 1879. In 1880, however, this position is apparently abandoned; at least it is not alluded to in the general summary of conclusions. As the Huronian and Laurentian are regarded as conformable, the basis for separating the clastic series at the base of the Coldbrooks must be considered wholly lithological. It is somewhat difficult to determine the lithological criteria used in the distinction, but it seems that the appearance of abundant volcanic material is the most important of these. Also connected with this fact is a prevailingly darker color. When it is remembered that volcanic outbreaks are often of a local character, and that it is wholly possible that quartzites and slates are being deposited at the same time volcanic accumulations are occurring, it must be concluded that the criterion of volcanic activity is an uncertain one. It would seem that it would be more reasonable, without reference to other localities, to make the major break above the crystallines of the Lower Laurentian.

The only physical break finally maintained in the whole pre-Cambrian series is between the two divisions of the Huronian, the Coldbrook and Coastal. From the descriptions it seems that this break is a very considerable one; for detritus of the lower series is contained in the upper, and more important than this, the lower series has a steeper inclination. Such a break as this certainly implies not only an erosion interval, but an orographic movement, and this must mean a rather important time break.

Throwing aside all correlations with other regions and considering the pre-Cambrian succession in southern New Brunswick alone, it is as follows: (1) Wholly crystalline granites, gneisses, etc. (2) Quartzites, slates, slate conglomerates, gneisses, and crystalline limestones. (3) Volcanics and clastics of the Coldbrook. Unconformity. (4) Coastal and Kingston groups. While in the reports it is positively stated that the Coldbrook is lower than the Coastal and Kingston, even this conclusion apparently can not be taken without question, since the distinction is abandoned in the mapping. The dropping of the term Huronian for the post-Laurentian groups indicates that this correlation with Huronian, taken for granted for many years, is also considered an open question.

SECTION V. NOVA SCOTIA AND CAPE BRETON.

LITERATURE.

JACKSON and ALGER,[45] 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 in age posterior to the slate.

BROWN,[46] 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 and 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),[47] 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 were not observed.

DAWSON (SIR WILLIAM),[48] 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; 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 the older slate series of Jukes of Newfoundland which contain 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 quartzite consists of grains of flinty sand fused together. The preponderant rocks are thick bands of slate and quartzite having a general northeast and southwest strike and highly inclined. Whether the mica schists and gneiss of cape Canso, and Queen's 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,[49] in 1863, divides the gold-bearing slates into a lower or quartzite group and an upper or clay slate group.

HIND,[50] 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,[51] in 1870, describes the series of gneissic and granitic 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 imbedded 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, and this 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 railroad 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 from 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 Windsor and Halifax 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,[52] (year unknown), 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 and 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, resembling 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.

LOGAN and HARTLEY,[53] in 1870, describe felsites, quartzites, conglomerates, and slates, adjacent to the Pictou coal fields, which are pre-Carboniferous, and are placed as probably of Devonian age.

SELWYN,[54] in 1872, in studying the gold-bearing slates, agrees with Dawson that they belong to the Primordial-Silurian epoch. As evidence of this is given the discovery in the slates of Oven's 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,[55] in 1876, finds that a massive syenite and associated crystalline rocks have a quite widespread distribution in cape Breton. At some points the Carboniferous rocks are brought in contact with the syenite, but generally 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 debris of which is derived from the overlying syenite, limestone, and quartzite.

FLETCHER,[56] in 1877, finds in cape Breton, below the Silurian rocks, 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,[57] in 1878, continues his study of the pre-Cambrian of cape Breton and northern Nova Scotia. The George river limestone is bounded upon both sides by coarse syenitic and granitic rocks and is in apparent conformity with them.

DAWSON[58] (Sir William), in 1878, places the rocks of the Bloisdale 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 Miré. 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,[59] 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 which abounds in Primordial fossils and the second probably of Devonian age. The latter contains masses of granitoid and trappean rocks.

FLETCHER,[60] 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 vein-like 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,[61] 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 the 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,[62] in 1886, describes the pre-Cambrian rocks of cape Breton as including a felsite series and a crystalline limestone series, both of which are referred to the Laurentian, and the latter unconformably overlying the former. 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,[63] 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 Upper Cambrian in cape Breton. Although they are certainly known to rest unconformably below the Cambro-Silurian strata, a part of 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 acid and varying in age from pre-Cambrian to Devonian, or even Carboniferous, are abundantly found.

FARIBAULT,[64] 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. Following Campbell, they are divided 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 are found to 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)[65], 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.

SUMMARY OF RESULTS.

In Nova Scotia and Cape Breton, as in southern New Brunswick, is a great variety of eruptive and intrusive rocks, both basic and acid, and of varying age. It is also plain that there is to be here included considerable masses of rocks which were in early days referred to the Laurentian. The intrusive character of the granites was appreciated by Jackson as early as 1832. Since that time the only observer who has not agreed with this conclusion is Hind, who strongly maintains that they are metamorphosed sediments. His facts, however, clearly distinguishable from his theory, point to an eruptive origin of the granite. The chief fact cited in favor of their being water-deposited rocks is the presence of roundish fragments of slates, quartzites, and schists remote from the contacts with these rocks. All the other facts given by him—i. e., the irregular fashion in which the granite veins intrude the schists, the abundance of large angular fragments of these schists and slates adjacent to the sedimentary rocks—are better explained by regarding the granite as intrusive. The natural explanation of the rounded bowlders remote from the contacts is that they represent partially absorbed pieces of these rocks. The evidence given by Dawson as to the structural relations of the granite and the manner in which the granite fades off into the slates, mentioned by Faribault, is wholly conclusive as to the intrusive origin of a portion of the granites. The relations thus described by Faribault are precisely like those which obtain between the granites and intruded metamorphosed schists in the Black hills and about Rainy lake and lake of the Woods.

While it is thus certain that large areas of granite and felsite are intrusives of later age than the rocks which are certainly of clastic origin, it does not follow that a portion of the felsites, porphyritic gneisses and granites are not of earlier age than any of the plainly clastic rocks.

It is of interest to note that while Dawson insists that all of the granites of Nova Scotia proper are of truly Hypogene origin of later age than the sedimentaries, that he suggests that it is not improbable that they have themselves been produced by the actual fusing of these sedimentaries. This hypothesis is the same as that proposed by Lawson many years later to explain analogous phenomena between the granites and gneisses and the associated schists and clastics of Rainy lake and the lake of the Woods.

In considering the positions and successions of the plainly clastic rocks of cape Breton and Nova Scotia, we have two geological provinces: the first including northern Nova Scotia and cape Breton, which is analogous to southern New Brunswick; and, second, the main part of Nova Scotia, south of the line running from Minas basin to Chedabucto bay.

In the second of these regions, aside from the granites, the only area that is of interest in connection with our study is the gold-bearing Atlantic coast series. Dawson in 1850 places this as Lower Silurian or pre-Silurian. Later, in his Acadian Geology, it is classified as Lower Silurian, although it is stated that no fossils are found in them. Later it was placed by Faribault as Lower Cambrian. The only evidence cited by him for placing it in the fossiliferous series at all is the presence of the obscure fossil Eophyton, discovered by Selwyn. Dawson found no fossil evidence for his reference of this series to the 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 subsequent observers have not repeated it, so that it may be considered very doubtful.

It is then clear that the position of the gold-bearing slates in the Lower Silurian or Lower Cambrian is purely provisional. They can only be considered as certainly belonging here under the premise that we are to place in the Cambrian all rocks which contain well recognized fossils or show the evidence of life. Similar reasoning would place in the Cambrian a large part of the rocks which have heretofore been referred to the Animikie and the Huronian in the lake Superior region. This question is more fully discussed in another place. We know positively only that the gold-bearing series is pre-Carboniferous, as the Carboniferous rocks are the oldest found in contact with the former. Between these two is a great unconformity. How much time this break represents we have at present no means of judging.

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 Windsor and Halifax railway. Not only this, but 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.

In northern Nova Scotia and in cape Breton, among the rocks referred to the pre-Cambrian there is a great variety of rocks both eruptive and sedimentary. The sedimentaries are frequently much more metamorphosed than are the gold-bearing series of Nova Scotia. 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 Lower Laurentian, the lower consisting of various massive and laminated rocks all presumably of igneous origin whatever their age, and the upper series, including all limestones, sandstones, slates, conglomerates—that is, all which are certainly clastic in character. Associated with this upper series 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 conformity, but in 1881 Fletcher describes them as probably unconformable. The detailed evidence for this conclusion it has not been possible fully to give in the foregoing summary, but a close scrutiny of the evidence seems to point more strongly toward the later intrusive character of the so-called Lower Laurentian. The lines of contact between the Lower and Upper Laurentian are very irregular, and in general are found at a lower level than the Upper Laurentian, but both of these would be true if the Lower Laurentian were intrusive. The manner in which the syenite passed into the foliated gneiss, and the foliated gneiss into the ordinary schist associated with the clastics at Dallas brook, appear to indicate the intrusive character of the supposed Lower Laurentian at this place. It is very strange that basal conglomerates have not been found in the upper series which bear fragments of the underlying one, if the former is really newer and unconformable. The interstratified syenites, diorites, etc., placed with the limestone series are, without question, igneous rocks. So that there can be no doubt that many rocks of the same character as the so-called Lower Laurentian are igneous and later than the clastic series, which makes it probable that much of this so-called lower series is of the same age. While all of this is true, as before remarked, 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 Cambrian in southern Nova Scotia are 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. The supposed pre-Cambrian rocks of northern Nova Scotia and cape Breton are known only to be unconformably below the Cambro-Silurian. In this district not only are the igneous rocks apparently more abundant than in southern Nova Scotia, but the folding is of a more intricate character. So far as one can see, there is no evidence that the clastic series to the north is not of the same age as the Atlantic coast gold-bearing series, being, perhaps, more metamorphosed because of the folding and presence of eruptive rocks.

Summing up, it can only be said that all of the clastic rocks of Nova Scotia and cape Breton, so far as we have any positive evidence, may belong as high as Cambrian, as stated by Fletcher in his later work, or may be of pre-Cambrian age and the equivalent of certain one or more of the pre-Cambrian series.

SECTION VI. NEWFOUNDLAND.

LITERATURE.

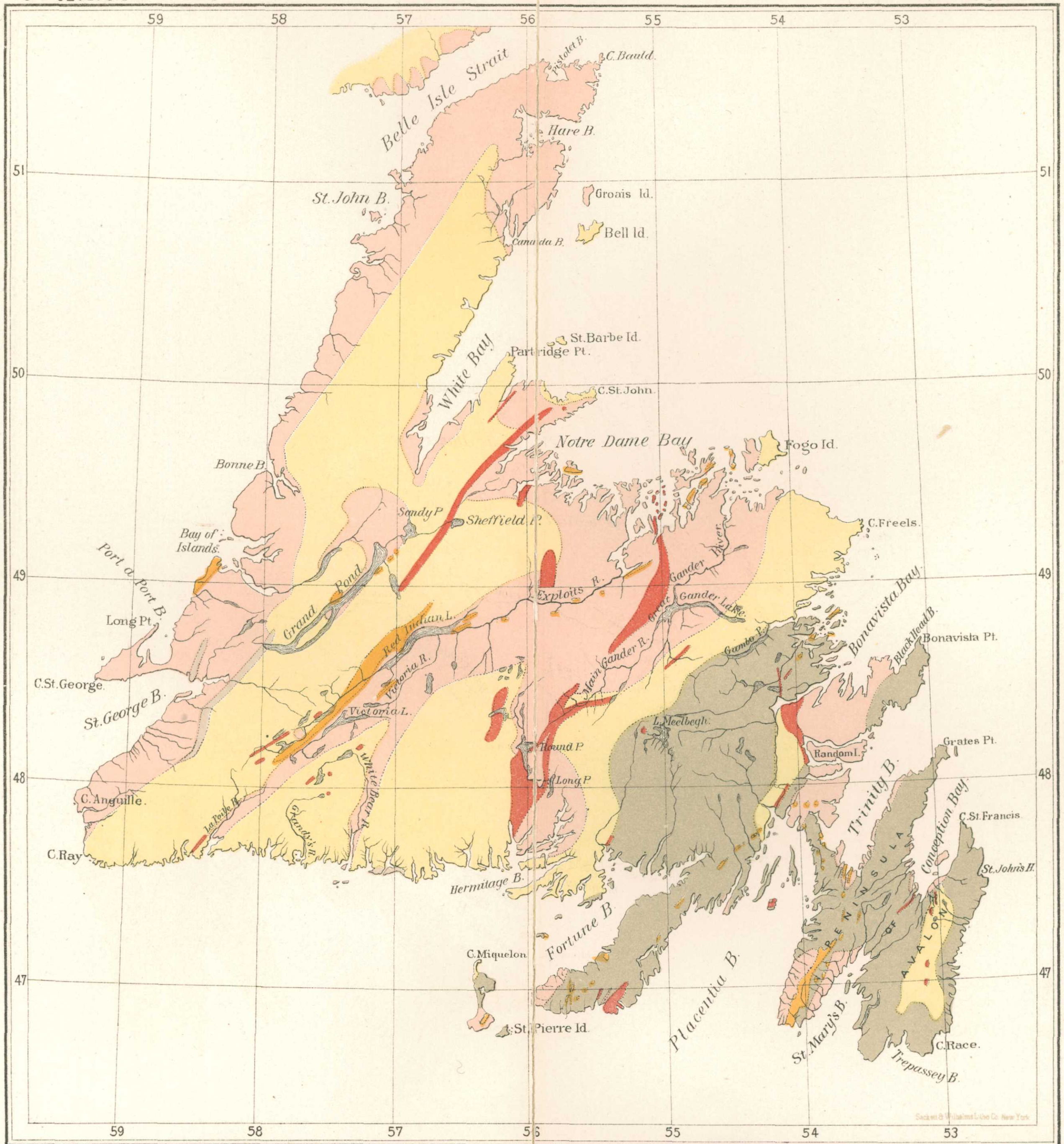
JUKES,[66] in 1843, divides the lower formations of Newfoundland in descending order into an upper slate formation, a lower slate formation, and a gneiss and mica-slate formation. The igneous rocks consist of various kinds of trap, greenstone, serpentine, hypersthene, porphyry, syenite, and granite. 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 Newell's 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 gneiss-like 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 granite becomes more abundant in getting toward the main mass of this rock, the alternations increasing 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 its strike and dip than is the strike and the dip of 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 NNE. and SSW. 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,[67] 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,[68] 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, dolomites, with various eruptives, is referred in part to the Quebec group. Among the intrusives are syenite and diorite. At



Unclassified Pre-Camb. Algonkian Algonkian? Post-Algonkian Eruptives: Granitic, Basic

GEOLOGICAL MAP OF NEWFOUNDLAND

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

Compiled from map by Alex Murray

Scale 1:3,500,000.

Lascie harbor the rocks are mainly gneiss, resting uncomformably upon which is a great mass of unstratified quartzite.

MURRAY,[69] 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 over 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 as 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 to the 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 uncomformably 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,[70] 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,[71] 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. Upon Great Miquelon island is found gneiss, supposed to be of Laurentian age. Greenstones and granite break at various places through the stratified rocks.

MURRAY,[72] 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,[73] 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 the 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,[74] in 1875, finds on Gander lake micaceous slate, fine grained granite, and gneiss, which are correlated with the Laurentian gneiss of Bonavista bay.

HOWLEY,[75] 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. Upon the upper Gambo pond and 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,[76] 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*. This latter 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,[77] in 1889, corroborates the unconformity between the series referred by Murray to the Huronian and the overlying series called Potsdam. This latter is found to contain the *Olenellus* fauna below the Paradoxides and is placed as lower Cambrian.

SUMMARY OF RESULTS.

The reports of Jukes and Murray are far more complete as to the geology of the peninsula of Avalon and the district immediately to the west than they are of the great northern peninsula. The map of this latter area is greatly generalized.

The unconformity described between the Upper and Lower slate of Jukes is evidently the same as that found by Murray between his Potsdam and Huronian. The Potsdam was later determined by Walcott to be basal Cambrian.

It is perfectly clear that in Newfoundland, and particularly in Avalon and southeastern Newfoundland proper, is a great series of fragmental rocks unconformably below a series bearing the *Olenellus* fauna. This series is of great thickness, probably more than 10,000 feet. In certain layers it carries obscure fossils which, according to Walcott, are of an earlier form than those of the Cambrian. It then follows that in this region we have a pre-Cambrian series of rocks bearing a small fauna of a rudimentary type. This result is very important as giving a start toward a fauna which, whatever the series in which it is found shall be called, is greatly older than that now recognized as basal Cambrian. Whether the series shall be called Huronian, as is done by Murray, depends upon the definition of that term. If all pre-Cambrian clastic series are to be placed in the Huronian, this series can be said to belong to that age, but if only those rocks are to be here placed which are the equivalent of those referred to that term on the north shore of lake Huron, we have as yet no means of determining whether the Newfoundland series is Huronian or not.

The relations of the series referred to the Huronian with the granites, gneisses and schists which are placed with the Laurentian are far less satisfactorily known. Nowhere is anything said as to any structural breaks between these two series, and evidently the lines between the so-called Laurentian and Huronian are based upon a very general study. Jukes, Murray and Howley agree that in Avalon and in other parts of Newfoundland are large areas of eruptive rocks, including both basic and acid kinds, which cut the various sedimentaries. Murray does not find that the Cambrian of Avalon is cut by granites and porphyries, but, according to Jukes, in other parts of Newfoundland this is the case. However, both basic and acid eruptives, including granites, syenites and porphyries. are found to cut in the most intricate manner the pre-Cambrian sedimentaries, and as a result of this, this series is found to be more than usually metamorphosed in the area between Trinity and Bonavista bays. The peculiar manner in which the granitic rocks vary into the slates by gradual interlaminations, combined with the occurrence of fragments of the schists within the granite, so well described by Jukes and corroborated by Howley, indicate that a large part of the rocks referred to the Laurentian are certainly intrusive, and that the more crystalline character of the clastic formations adjacent to them are due to metamorphism. It is then by no means clear that within Avalon are any rocks of sedimentary origin older than the series referred to the Huronian, although the fact mentioned by Jukes of a single bowlder of syenite in the older slate series indicates the probability of a pre-Huronian syenitic or gneissic series. At present we have, however, no means of judging what part of the rocks referred to the Laurentian are later intrusives and what part, if any, are older than the pre-Cambrian clastic series.

As to the rocks referred to the Upper Laurentian because of the presence of anorthosite rocks and limestones, the question arises as to whether the crystalline limestones associated with the gneisses are not of later age than supposed, being perhaps more metamorphosed. The associated anorthosite—that is, a probably eruptive rock—may be an explanation of this metamorphism. If the presence in Newfoundland of a Lower Laurentian is doubtful, it is much more doubtful whether here an upper series of fragmental rocks has been shown to exist which are older than the pre-Cambrian series referred to the Huronian.

The observations made by Jukes as to the relations of slaty cleavage and bedding are of the greatest interest and importance. 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 its strike and dip than is the strike and the dip of the beds. The dip of cleavage is never at a less angle than 45°, while in the majority of instances it is nearly perpendicular.

NOTES.

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Wolfe, R. W. Ells. Rept. of Prog. Geol. and Nat. Hist. Survey of Canada for 1886, new series, vol. II, pp. 1–70 J. With a colored geological map.

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CHAPTER V.

ISOLATED AREAS OF THE MISSISSIPPI VALLEY.

SECTION I. THE BLACK HILLS.

LITERATURE.

HAYDEN,[1] 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,[2] 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, quartzose and calcareous rocks.

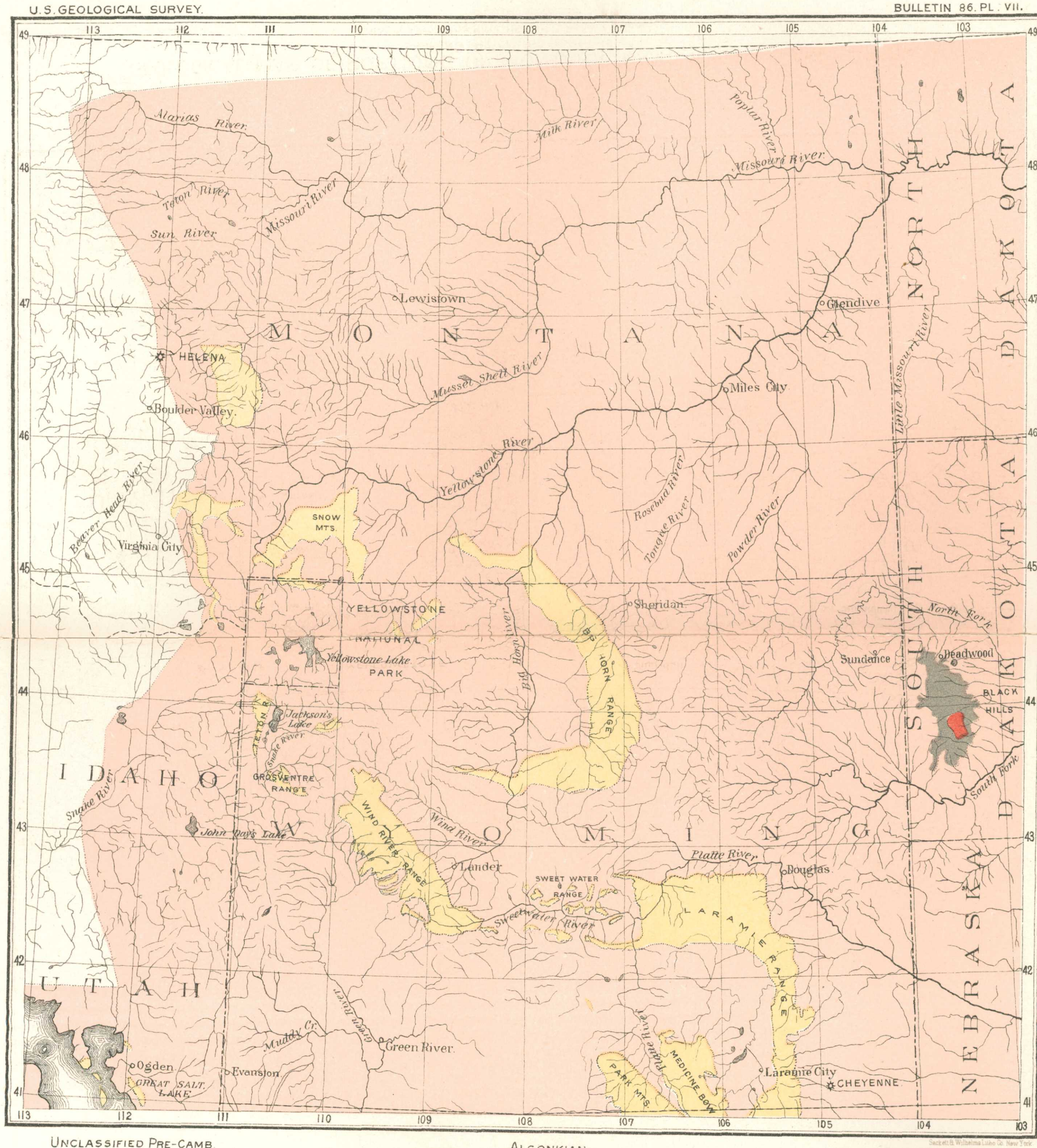
HAYDEN,[3] in 1872, describes the Black hills as being the most complete illustration of an anticline not complicated by any other influences that he has found in the west. The nucleus is a massive feldspathic granite with a series of gneissic beds outside of it, which incline in every direction from 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,[4] in 1875, describes in the Black hills, below the Primordial sandstones and quartzites, a series of mica-slates and mica-schists which contain intercalated beds of quartz. 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,[5] in 1880, gives a systematic account of the Black hills of Dakota. The Black hills is 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 of an age probably coincident 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 and resembles 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 and 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 east and northeast.

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 one than chemical, being probably due to a difference in metamorphism. The apparent discordance discovered by Jenney, and this lithological difference, gives strong support to the view that the slate and schist periods were separated by an interval of



Unclassified Pre-Camb.

Algonkian: Slates & Schists; Granite

Post-Algonkian

GEOLOGICAL MAP OF PORTIONS OF MONTANA, IDAHO, WYOMING AND DAKOTA

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the King, Hayden & Powell Reports.

Scale $\frac{1}{4752.000}$

time between 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 are 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,[6] 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,[7] in 1888, finds that the two groups of Archean as mapped by Newton are quite sharply defined from each other. It is said that in the eastern series of slates are pebbles which have been quite 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,[8] in 1888, states that the unconformity supposed to exist by Newton between the eastern slate and 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,[9] 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 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 and 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 newer foliation produced. Also, in the northern part of the slates is a considerable area about Deadwood 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 which 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.

SUMMARY OF RESULTS.

The summary of Newton's work is altogether unsatisfactory because of the very large amount of material contained in this report. The descriptions in the original are condensed, and to include all which bears upon structural relations would greatly extend the digest given. In the light of the present facts it would seem that we have in the Black hills a set of slates and schists as yet of unknown thickness and undivided into series, although perhaps capable of subdivision by closer work. These slates and schists have a prominent cleavage which is independent of the structure. The different parts of the area vary in degree of crystallization, and this crystalline character is due to the intrusion of igneous rocks; but, unlike ordinary contact metamorphism, has extended from the granitic areas for a distance of several miles. For the present we are obliged to consider the whole as a single series. In the alternating slaty and quartzose characters of the rocks, in the presence of siliceous hematite and a much folded condition, the present structures being in a vertical attitude, they more nearly resemble the Lower Huronian of the lake Superior region than any other rock series, but this is not sufficient warrant for the positive conclusion that the two are time equivalents. The correlation of the Black hills rocks with the Taconic on slight lithological evidence as is done by Crosby, or a part of them with the Coos group on account of the presence of staurolite, can be considered as no more than guesses.

SECTION II. MISSOURI.

LITERATURE.

KING, (H.),[10] 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 cone-like elevations or detached ridges to the height often of 1,000 or 1,200 feet above the level of the Mississippi river. Its sides and valleys are frequently 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 imbedded 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 of 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. 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,[11] 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,[12] 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,[13] in 1859, states that in one locality in Laclede and in one or two in Crawford county are granite dikes or ridges which rise above the stratified rocks.

HARRISON,[14] 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,[15] in 1873, states that the Archean (Azoic) rocks of southeastern Missouri form an archipelago of islands in the Lower Silurian strata which surrounds them as a whole and separates them from each other. 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 frequent 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-Hekla conglomerate of lake Superior.

SCHMIDT,[16] 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,[17] in 1873, states that granite is found in Laclede, Crawford, and Ste. Genevieve counties.

BROADHEAD and NORWOOD,[18] in 1874, describe granite and porphyry at numerous points in Madison county. On the west side of St. François river in the NW. ¼ of NE. ¼ Sec. 33, T. 34 N., R. 5 E., there is an exposure of sandstone and conglomerate resting directly on the granite.

HAWORTH,[19] 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. François and Ste. Genevieve; 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.

HAWORTH,[20] in 1891, describes the crystalline rocks in the vicinity of Pilot knob, Missouri. 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.

PUMPELLY and VAN HISE,[21] 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 in order that this quantity should accumulate 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 the 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 not only been very long, but complex.

SUMMARY OF RESULTS.

As the crystalline rocks of central Missouri are islands surrounded by Cambrian sediments, we have no definite means of determining their age except that they were in their present condition and deeply eroded before the overlying rocks were deposited. With a considerable degree of probability they may therefore be referred to the pre-Cambrian. The series is mainly an eruptive, porphyritic one, but the lavas are oftentimes bedded. The clastics are sometimes porphyry-conglomerates, the materials of which have evidently been derived from the underlying porphyry flows. At Pilot knob the iron ores are associated with the conglomerates.

There is, then, in central Missouri a pre-Cambrian clastic series, and therefore a member of the Algonkian system. Whether any of the crystalline rocks are older than the Algonkian there is no certain means of judging. There are also no certain data upon which to parallelize this Algonkian series with the Algonkian series of the nearest pre-Cambrian region, that of lake Superior. Upon the whole, the lithological character of the series more nearly resembles that of the Keweenawan than any other, although it has a very considerable likeness to the Upper Huronian. This is indicated by the porphyries and porphyry-conglomerates, while the analogy with the Upper Huronian is indicated by the beds of iron ore. This comparison is rather strengthened by the fact that the Upper Huronian quartzite outcrops of southern Wisconsin are associated with and cut by porphyries. But a reference of the Missouri rocks either to the Keweenawan or Upper Huronian has a very uncertain value, and it is not impossible that it rather represents the period of erosion which separates the Keweenawan and Upper Huronian, since in lithological characters it combines to a considerable extent those of these two series.

SECTION III. TEXAS.

LITERATURE.

ROEMER,[22] 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 the Piedernales and San Saba rivers. These granitic rocks are surrounded by Paleozoic strata.

SHUMARD,[23] in 1860, describes in Burnet county rocks upon which rest directly the fossiliferous Potsdam.

SHUMARD,[24] 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,[25] in 1866, states that the known Azoic rocks of the state 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 and southwest direction, being on the same line of upheaval as the Ozark mountains of Arkansas and the Iron mountains of Missouri.

BUCKLEY,[26] 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,[27] in 1876, describes Azoic granitic rocks in many of the mountain ranges west of the 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,[28] 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 from 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,[29] 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[30], 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[31], in 1890, divides the Archean rocks of central Texas into a Burnetan (Laurentian?) system and 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 graduate upon the one hand into quartzose mica-schists, and upon the other into friable sandy gneisses and fine-grained binary granites and graphic granite. Stratigraphically the group is divided into three series 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 the Fernandan and Burnetan strata, metamorphism has caused a close resemblance in many exposures. The general succession from above downward is 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 lithologic series.

Above the Fernandan system is an Eparchean group of rocks, the stratigraphical 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 schists 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 lithologic 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, to the Grand canyon, and the Mason sandy shales and schists to 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,[32] 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 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 nonconformability 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.

SUMMARY OF RESULTS.

It appears that in central Texas there are two thick series, of clastic origin which are of pre-Cambrian age. The upper is Walcott's Llano or Comstock's Texian, and the lower Comstock's Fernandian. The first of these is but little altered, the second is considerably metamorphosed and has associated with it a greater quantity of eruptive rocks. Between these series it is asserted by Comstock that there is a great unconformity, as shown by numerous contacts, by Fernandian debris in the Texian, and by the fact that the Texian rocks are never involved in the earlier uplifts which have affected the Fernandian.

The Archean is represented by the Burnetian. Between the Burnetian and the Fernandian an unconformity is maintained by Comstock upon essentially the same grounds as between the Texian and Fernandian; that is, there are unconformable contacts between the series; the Fernandian bears debris from the Burnetian, and the Burnetian has been affected by orographic movements which are earlier than the Fernandian.

NOTES.

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[13] Geological Report of the country along the line of the Southwestern Branch of the Pacific Railroad, State of Missouri, G. C. Swallow. St. Louis, 1859, pp. 93, with map.

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[15] Geology of Pilot Knob and its vicinity, Raphael Pumpelly. Preliminary Report on the Iron Ores and Coal Fields from the field work of 1872. Part 1, pp. 3-28.

[16] Iron Ores of Missouri, Adolph Schmidt. Ibid., Part 1, pp. 45-214.

[17] Reports on the Geological Survey of the State of Missouri, 1855-1871, B. F. Shumard. Jefferson City, 1873, pp. 189-323.

[18] Madison County, G. C. Broadhead and J. G. Norwood. Report of the Geological Survey of the State of Missouri, including field work of 1873-'74, pp. 342-379, with an atlas.

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CHAPTER VI.

THE CORDILLERAS.

SECTION I. LARAMIE, MEDICINE BOW, AND PARK RANGES IN SOUTHERN WYOMING.

LITERATURE.

STANSBURY,[1] 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,[2] in 1863, describes the Laramie hills as consisting of numerous centers of uplifted granite upon the sides of which the Carboniferous limestones are scattered or unconformably overlie. There is 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, 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,[3] 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,[4] 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,[5] 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,[6] 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 and 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, 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 nonconformity 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 north 20° east, which appears to be the strike of the rocks. The dip is to the eastward 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 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,[6] in 1877, describes Rawlings peak as an outlying area of Archean granite-gneiss which shows distinct lines of bedding, having an inclination of 45° to the west, while the overlying quartzites and sandstones dip 10° to the east.

KING,[7] 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 a great thickness of mica-gneisses, the estimated thickness of which is

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 Clark's 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 only left traces of the easterly dips. The rocks are granite, gneiss, hornblende-schists, and dioritoid 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,[8] in 1879, describes Rawlings peak as consisting of a metamorphic granite nucleus about which the sedimentary strata are qua quaversally arranged.

VAN HISE,[9] in 1889, made observations upon 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. In passing 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. In continuing to pass from east to 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 and interstratified with quartzite. Schistose and massive basic rocks, much altered, in dike-like forms, are found in the clastic series precisely as in the gneissic series. They oftentimes 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° to the southeast. Therefore the Medicine peak series appears to underlie the gneissoid series. The dip of the Medicine peak series in going north of west beyond the mountain 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 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 passing 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.

SUMMARY OF RESULTS.

It is plain that in the Medicine bow range are two classes of rocks: those which are thoroughly crystalline and are mostly of the acid type, and those which are unmistakable clastics, such as quartzites, conglomerates, marbles, cherts, etc., while in the Laramie and Park ranges is only the first class, if the white quartzite, which seems to be in the nature of a vein in the latter, is excluded. The granites and gneisses were regarded by Hayden as eruptive, and they were believed to have intruded and metamorphosed the overlying Paleozoic limestones. King and Hague, on the other hand, regard all of the material of the three ranges as metamorphic, with the exception of the basic dikes and possibly some small areas and dikes of a later granite. That the horizontal sedimentary rocks were deposited unconformably upon and against these ranges is now admitted by all; so that the truth of the observations of Hayden must be considered doubtful, unless he found some place where there is actually present later important masses of intrusive granite.

At the present time many would doubt the conclusions of King and Hague, that because the structureless granite of the center of the ridges vary gradually in passing outward into well laminated gneisses and schists, therefore the whole is of sedimentary origin, the interior parts being more completely metamorphosed than the exteriors. These relations might equally well be produced by the increasing effects of dynamic action upon the outer borders of once massive ranges. The variation of massive or nearly massive core rocks into laminated gneisses and crystalline schists on the outer borders, which occur in many other mountain regions, are thus explained by numerous later observers, the whole being regarded as igneous. The lamination is explained equally as well by one theory as by the other; for in either case the central axes are the parts which are most deeply buried, and which, even if composed of material originally sedimentary, have become recrystallized. On either hypothesis it is probable that in the region under discussion are two fundamentally different series, the very ancient crystallines and the pre-Cambrian clastics. The presence of abundant granite débris in the lower members of the Medicine peak series certainly shows the existence of a granite earlier than this time. That the clastics are later than the crystallines is perhaps further indicated by the numerous dikes of granite which are found in the main granite area, but have not been noted as cutting the clastics. It can not be said whether many of the mica-schists and other intermediate kinds of rocks such as occur in the Medicine bow and Park ranges belong with the Archean or the Algonkian. It is wholly among the possibilities that schist series exist which are older than the granite; these together forming a basement complex upon which the readily recognizable clastics were deposited.

SECTION II. CENTRAL AND WESTERN WYOMING.

LITERATURE OF THE BIG HORN MOUNTAINS.

HAYDEN,[10] in 1861, states that red feldspathic granites, with metamorphic slates and schists, constitute the nucleus of the Big Horn mountains. As these are surrounded by strata as recent as the Cretaceous, this uplift is subsequent to this time.

HAYDEN,[11] in 1868, states that the unconformity between the crystalline and unmetamorphosed strata at the Big Horn mountains is very apparent.

CARPENTER,[12] in 1878, describes the Big Horn 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 various patches of mica-schist. The Owl creek mountains are composed of porphyritic granite rich in feldspar, which give place at higher elevations to a gneissoid granite. They connect the southern end of the Big Horn mountains with the northern part of the Wind river range.

LITERATURE OF THE RATTLESNAKE MOUNTAINS.

ENGELMANN,[5] in 1876, states that granites and granitic syenites which are regarded as igneous rocks form a large part of the Rattlesnake mountains.

LITERATURE OF THE SWEETWATER AND ADJACENT MOUNTAINS.

BALL,[13] in 1835, notes granitic rocks along the Sweetwater.

HAYDEN,[11] in 1868, mentions granites and syenites as occurring in the Sweetwater mountains.

ENGELMANN,[5] 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,[8] in 1879, describes in the Sweetwater valley and in adjacent regions Prozoic and metamorphic rocks. In the Sweetwater hills are Prozoic rocks, coarse grained, structureless granite, like those west of the Wind river mountains which are cut by basaltic dikes, but which 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.

LITERATURE OF THE WIND RIVER MOUNTAINS.

HAYDEN,[10] in 1861, states that the Wind river mountains have a nucleus of red and gray feldspathic granite.

HAYDEN,[11] in 1868, states that the stratified rocks rest unconformably upon the granites and syenites of the Wind river mountains along the eastern slope.

HAYDEN,[4] 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 is found for a distance of 10 miles metamorphic slates.

COMSTOCK,[14] 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 here occur, and there appears to be a gradation from the structureless granites to the pre-Potsdam metamorphics.

ENDLICH,[8] in 1879, describes the geology of the Wind river mountains and 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. Going 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. Passing to the 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 sandstones 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 metamorphosis of the entire mass took place, unless the change in the sandstone is caused by a 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,[15] 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 Fremont's butte.

ST. JOHN,[16] 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.

LITERATURE OF THE GROS VENTRE AND WYOMING RANGES.

ST. JOHN,[17] 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,[16] 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, as in the Gros Ventre range, the Archean is unconformably below the stratified rocks.

LITERATURE OF THE TETON RANGE.

BRADLEY,[16] 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 and west direction. Trap-like rocks are interlaminated with the gneiss and granite, which suggest that they may be dikes, but they are evidently conformable with the layers and were either contemporaneous sheets or else subsequent intrusives.

ST. JOHN,[17] 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, 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 southwest part of the Teton district is a narrow tongue of quartzites which are placed with the Primordial, but may be Huronian.

SUMMARY OF RESULTS.

The rocks referred to the Archean by the various authors can, with considerable certainty, be considered pre-Cambrian, as the region is one in which no folding has taken place since the beginning of Paleozoic time, and the various members of the Paleozoic are found in unconformable contact with the underlying crystallines at many points. It is not necessary to assume, as was done by Endlich, that a portion of the metamorphism of the Archean took place subsequent to Paleozoic time, for the indurated quartzites so often found in direct contact with the crystalline strata have probably been thus hardened by the now well known process of cementation. The quartzites which so closely resemble the unaltered granite are doubtless recomposed rocks which have been cemented in the same manner.

Whether among the pre-Cambrian rocks in these various ranges of mountains there are any which are now of a distinctly clastic character is uncertain. Those between fort Stambaugh and the central Wind river mass spoken of as metamorphic slates, and the rocks described by St. John in the southwestern part of the Teton district as consisting of quartzites, micaceous and chloritic slates, may very likely be of this character, but it is not certain that the latter do not belong to the Cambrian, for nothing is said of their relations to the recognizable Paleozoics.

The separation of the rocks into Laurentian and Huronian, or into Prozoic, Laurentian and Huronian, as is done by Endlich, is purely lithological. They are all thoroughly crystalline, and have been assumed by the various authors to be metamorphic because having a lamination or foliation, and the more massive rocks are regarded as being older because more metamorphic, and also because they are usually core rocks. As has been seen in the case of the Laramie hills and other regions, these facts may be equally well explained by regarding the rocks as all ancient igneous rocks, parts of which have been given a laminated structure by dynamic action.

Nowhere is anything said as to any unconformable relations between any parts of the various series referred respectively to the Huronian, Laurentian, or Prozoic, as the case may be. Consequently the only sure structural conclusion reached is that there is in these mountain ranges a great complex of granites, gneisses, and schists, thoroughly crystalline, and as yet undivided, which are of pre-Cambrian age.

SECTION III. CENTRAL AND SOUTHWESTERN MONTANA, WITH ADJACENT PARTS OF WYOMING AND IDAHO.

LITERATURE.

HAYDEN,[10] 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,[19] in 1872, describes Archean rocks at many points in southwestern Montana. Among the localities mentioned, the following are worthy of note: Upon 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 the Madison canyon is found granite. The rocks adjacent to Virginia City are clearly stratified, wholly metamorphic, and are regarded as below the Paleozoic. Upon 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 is 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,[20] 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,[21] 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 Henrys 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 a 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,[22] 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. Upon one of the head waters 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 angle 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,[23] in 1876, describes some geological sections about the headwaters of the Missouri and Yellowstone rivers. There is an anticlinal axis between the Madison and Jefferson which has a granitic nucleus, and on the east side of the Gallatin the Silurian rocks rest upon granitic hills.

HOLMES,[24] 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, but 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,[25] 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,[26] since 1884, has been working on the "Three Forks Sheet" of Montana (the square degree included between 111° and 112° of longitude and 45° and 46° of latitude). In the northern part, in the Bridger range, of this area is found Archean gneisses.

Other Archean areas are the one extending north of Virginia city some 28 miles, in which a body of eruptive granite occurs, and the one bordering the canyon of the Madison. The gneiss of the Madison canyon extends across to the Gallatin canyon, a distance of 24 miles. This latter belt is about 12 miles in width. There are also two smaller gneissic areas bordering the southern edge of the Gallatin valley. The beds of Lower Cambrian age at a number of localities in the range include angular fragments and masses of gray and red gneiss, evidently derived from these Archean beds.

In the vicinity of the Three forks and in the northern portion of the Bridger range, lying between the basal quartzite of Lower Cambrian age and the Archean gneisses referred to above, is another series of beds that are considered pre-Cambrian. This group, referred to the Algonkian, has a thickness of 5,000 or 6,000 feet in the Bridger range and is correlated with the Lower Cambrian barren slates of much greater thickness found by Davis farther to the north. The beds are made up of alternations of coarse micaceous sandstones and fine conglomerates with beds of hard argillaceous slates and bands of very hard thin-bedded dark blue limestones. These are the beds seen by Hayden in 1861 which were mistaken for eruptives, and which were described by Peale in 1873. Where the lowest exposures were noted, pebbles and angular masses of the Archean gneisses are numerous in these sandstones, indicating that Archean land masses existed not far to the southward. In fact the ancient shore line crossed the area from 12 to 15 miles south of the northern limit of the Three forks sheet. As to age, this series is probably pre-Cambrian as it lies below beds containing Lower Cambrian fossils, being nonfossiliferous themselves so far as examined. So far as observed no evident unconformity exists between the series and the overlying Cambrian beds, but there is certainly an unconformity by subsidence, for after the series was deposited there was an orographic movement by which the Archean area of nearly the entire district of the sheet south of the Three forks was submerged just prior to the beginning of the Cambrian, as is shown by the great southward extent of the lower or basal quartzite over this area which was not before submerged and which therefore shows no rocks of this Algonkian series. Whether the movement occurred immediately after the laying down of the Algonkian beds just described or after an interval can not be decided with the meager data now at hand.

South of the old shore line the Algonkian group is absent, the lower quartzite of the undoubted Cambrian everywhere lying unconformably upon the Archean gneisses, with the exception of two localities, where it rests upon a series of beds considered to be a lower division of the Algonkian. The main area is on the west side of the Madison river, about 20 miles south of Meadow creek, and is about 8 miles in length by about 4 in width. A limited area of these beds occur on the east side of the Madison valley at the west edge of the Madison range between Bear and Indian creeks. The series consists of crystalline limestones, mica-schists, quartzites, and gneisses, very highly inclined and conformable so far as seen with the stratification or bedding of the gneisses. Without more detailed examination and search for obscure folds it is impossible to estimate the total thickness, but it is certainly very great.

SUMMARY OF RESULTS.

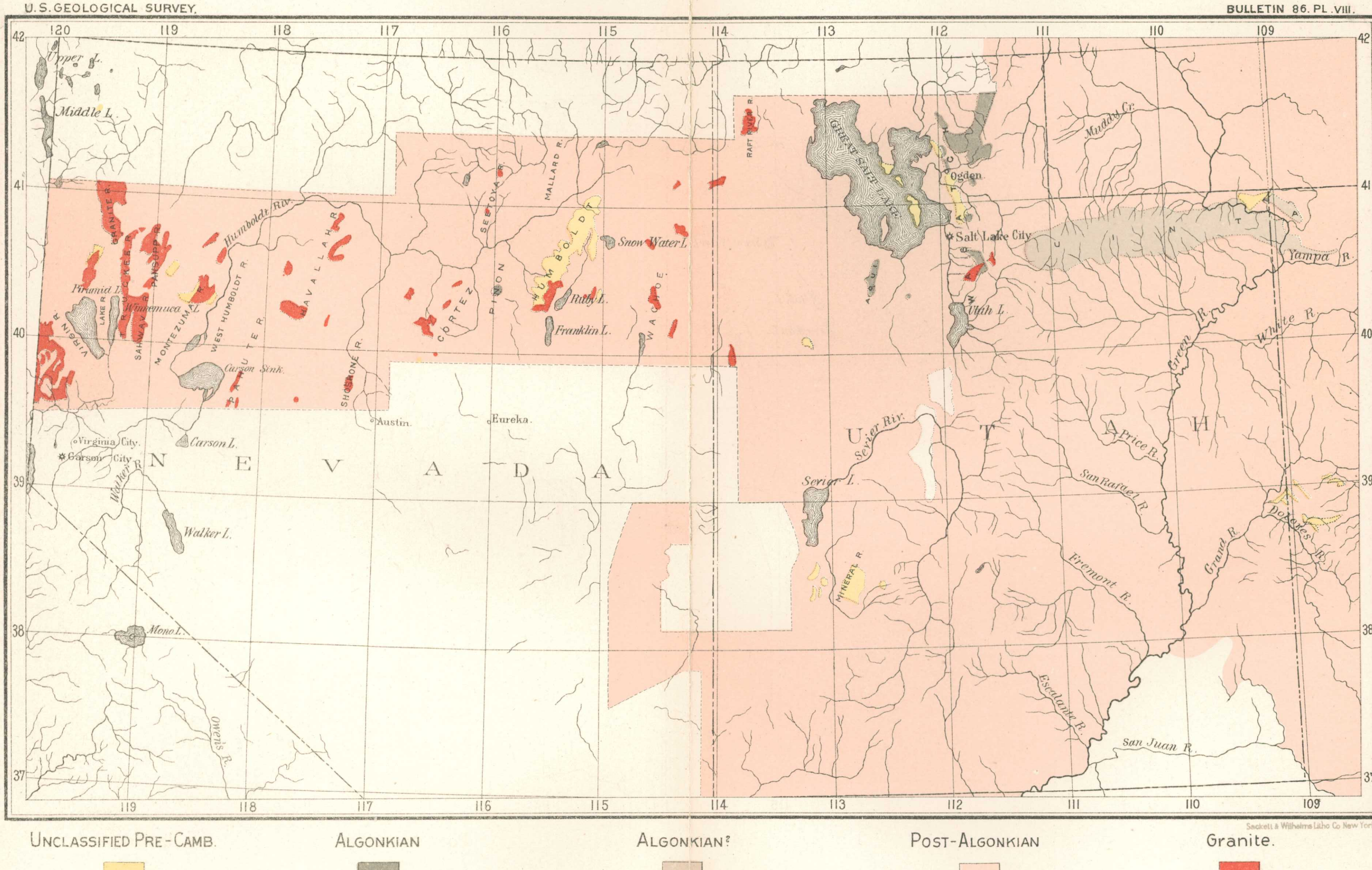
It is evident from the literature, as well as from Hayden's own statement, that no systematic work has been done among the pre-Cambrian rocks, with the exception of that by Peale on the Three forks sheet. The information at hand makes it clear that this region will yield results of extreme interest when considerable areas are mapped. In the region are great areas of intricately mingled granitic and gneissic rocks which certainly belong to the Archean. Associated with this class of rocks are immense thicknesses of regularly bedded gneisses, mica-schists, chlorite-schists, quartz-schists, quartzites, and limestones. Whether the regular lamination of the gneiss is due to sedimentation or to other forces is uncertain, but the great belts of interstratified crystalline limestone, quartz-schists, and quartzites are evidence that here is a series of clastic origin, although at the present time it has become thoroughly crystalline. The relations of this series to the granites and gneisses doubtfully referred to the Archean have not been worked out.

There is also in this region, as shown by the work of Davis and Peale, a great series of unaltered strata which are probably Algonkian. This series is a downward succession of barren slates below the fossiliferous Cambrian, and if Algonkian, is the uppermost division and equivalent to the upper Algonkian of the Wasatch. Peale's results indicate that while there is no actual unconformity, there is a change of physical conditions, a subsidence, and perhaps a real time break between the Cambrian and Algonkian. Nowhere yet have the unaltered barren slates and the more crystalline series of clastic origin been found in contact. Between the slates and the Archean gneisses is a great unconformity, and there is little doubt, when the unaltered series is carried over to the vertical limestones, quartzites, and quartz-schists, that it will be found to rest upon them unconformably. There is, then, in this region probably two series of Algonkian rocks, one almost completely unaltered, the other thoroughly crystalline, and both of great thickness.

SECTION IV. UTAH AND SOUTHEASTERN NEVADA.

LITERATURE OF THE UINTA MOUNTAINS.

MARSH,[27] 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 them are limestones bearing Carboniferous fossils.



GEOLOGICAL MAP OF UTAH AND NEVADA

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the Powell, King and Wheeler Reports

Scale $\frac{1}{4.308.000}$.

HAYDEN,[4] 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 the 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.

Passing upward to the crest of the mountains, but downward in a geological sense, we find a series of purplish sandstones and slates, conformable with the limestones and apparently unchanged, which gradually pass into thick beds of gray and purple quartzite, which are exceedingly brittle and plainly metamorphosed by heat. The later formations once passed over the older ones in the Uintas, and therefore there has been in this region tremendous erosive forces. On Red creek, the only place where such a rock is found, is the largest display of white quartz that the author has seen in the West. This is associated with outbursts of old trap and some beds of true gneiss and mica-schist. The igneous matter has protruded itself in every opening or fissure in every possible direction, sometimes between the strata and sometimes across them, in thin layers or in huge branching masses. It is believed that this igneous material was protruded among the quartz beds prior to their upheaval. It is difficult to account for this development of quartz with gneiss, which rises abruptly above the quartzite, occupying a belt 5 to 9 miles in width and ending as abruptly as it commences. The upper quartzites and white quartz beds seem to conform. It is remarked that the geology of the eastern portion of the Uinta range is very complicated and interesting, but to have solved the problem to entire satisfaction would have required a week or two.

POWELL,[28] in 1874, describes in the Uinta mountains crystalline schists upon which rest unconformable Carboniferous rocks.

POWELL,[29] 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 O-wi-yu-kuts 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 and 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.),[6] 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 before the 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,[7] in 1878, describes the Archean rocks of the Uinta range as a group of pure white quartzites, hornblende schists, 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 are obtained.

PEALE,[15] 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 inclines 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,[9] 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 rather with the granites than 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.

LITERATURE OF THE WASATCH MOUNTAINS.

HAYDEN,[19] in 1872, describes in the Wasatch mountains and on the canyon of the Weber a nucleus of granite. In Box Elder canyon are gneisses, quartzites, and slates. In the 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,[30] in 1872, regards the granite of Big and Little Cottonwood canyons as probably metamorphic from conglomerates, because of the conspicuous patches of dark colored material which they have 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,[21] in 1873, describes syenite in the 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,[22] 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,[18] in 1873, regards the core of the Wasatch as metamorphic. The occurrence ot angular and rounded patches of dark material in the granite of the Little Cottonwood canyon is taken as evidence that these were pebbles of a conglomerate before its metamorphism. The rocks are chiefly hornblendic gneiss and syenite, with quartz veins.

HOWELL[31], in 1875, states that in Rock canyon, near Provo, pebbly chlorite-schist is unconformably below hard quartzite.

EMMONS, (S. F.)[6], in 1877, describes the Wasatch range as a sharp north and 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 widely-spread 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 a thickness of 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. 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° to the westward. 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° to the westward. At the mouth of the 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 the 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 is 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 with the later outbursts of granite-porphyries and diorites which intersect the sedimentary beds of this region. These dikes are very frequent, 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,[6] 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 southward, but the Archean rocks are less abundant. In the lower canyon of the 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 the 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,[7] 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's 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 the Cottonwood canyon there is no sharp division between the structureless granite and the bedded gneissoid form. In the neighborhood of Clayton's 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 the 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 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 seems to be two distinct series. The later series consists of conformable beds of gneiss, quartzite, and hornblende-schist, which dip west at angles from 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 dome-like 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+ feet 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 thick; 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 the Big Cottonwood canyon, in passing upward, comprises 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; 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 of 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,[32] 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,[33] 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 finding 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.),[34] 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 exists in changing the sandstone to quartzite and 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 over 500 cubic miles of sedimentary rocks. If it has done this it has left no trace of fusion in the adjoining rock, and without showing in its own structure and position any marked variation from that of a normal rock. It is further difficult to understand where the great supply of heat is to be obtained to do this work.

WALCOTT,[35] in 1889, places the Olenellus horizon at the base of the Cambrian and the great series of conformable siliceous rocks, 11,000 feet thick, below this zone as pre-Cambrian or Algonkian rocks.

VAN HISE,[9] 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. The main Cottonwood mass and Clayton peak granite are identical in character. 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 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 mentioned 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 the Weber canyon 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 failed to find evidence of unconformity between two series of Archean rocks. 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.

LITERATURE OF THE PROMONTORY RIDGE, FREMONT ISLAND AND ANTELOPE ISLAND RANGES.

STANSBURY,[1] 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,[6] 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. That of 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.

LITERATURE OF THE OQUIRRH MOUNTAINS.

HAYDEN,[21] in 1873, describes regularly stratified quartzites as resting upon a series of granitoid strata in the Oquirrh mountains at the south end of Salt lake. The quartzites pass up into micaceous clays or shales, then into limestones. The lower beds of quartzite and limestone are probably of Silurian age, and it is known that the second limestone is of Carboniferous age.

EMMONS, (S. F.),[6] in 1877, finds granite-porphyry in the foot-hills of the Oquirrh mountains, and in the same range, at the head of Bingham canyon, are diorite dikes which resemble those of the main Wasatch range.

LITERATURE OF THE AQUI MOUNTAINS.

EMMONS, (S. F.),[6] in 1877, describes at Bonneville peak a body of white quartzite not less than 6,000 feet in thickness dipping to the westward. In this quartzite are beds of conglomerate strata, the pebbles of which are flattened and of argillaceous rock, containing mica and becoming imperfect mica-schists like those east of Farmington. This series is regarded as equivalent to the Cambrian of the Wasatch on lithological grounds, because it rests below a great limestone formation and because it is thicker than any of the higher quartzite series of the Wasatch. On Grantville peak a similar series is found.

KING,[7] in 1878, describes in the ridge east of Egan canyon as occurring directly over the granite several thousand feet of quartzitic schists, capped by about 50 feet of highly laminated fissile argillites, which are quite similar to the quartzitic schists of the Wasatch

LITERATURE OF THE RAFT RIVER RANGE.

HAGUE,[6] in 1877, describes in the Raft river range a considerable body of structureless medium grained granite, forming the central mass.

LITERATURE OF SOUTHERN UTAH AND SOUTHEASTERN NEVADA.

GILBERT,[36] 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,[37] in 1875, states that crystalline rocks are found on the Salt lake road in the Virgin mountains.

HOWELL,[31] 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.

SUMMARY OF RESULTS.

In the Uinta mountains the much folded, banded, and contorted granitic rock (so-called quartzite) of Red creek canyon, in its crystalline character, in the intricate way in which it is folded and is cut by ancient metamorphosed basic eruptives, is more nearly analogous to the fundamental complex of other areas in the West than to the Huronian, as has been before suggested.

The lithological analogy between the overlying Uinta series and the Huronian Sioux quartzites, mentioned by Hayden, is very close indeed, but can be considered as a guide of no great importance. This great series of sandstones, quartzites, and shales, unconformably below the Carboniferous and separated by a great unconformity from the fundamental complex, may, so far as present certain knowledge goes, belong anywhere from the Devonian to the Algonkian.

That it is the equivalent of the Weber conglomerate of the Wasatch and belongs to the Carboniferous, as tentatively placed by the Fortieth Parallel survey, is not likely. Its great thickness, its separation by a very considerable unconformity from the fossiliferous Carboniferous, and its lithological character, combined with the fact that a careful search by different observers has revealed no fossils, make it probable that it belongs as low in the geological column as the great basal quartzite series of the Wasatch, in which case it is Upper Algonkian. It is not certain that the series does not occupy a still lower position, perhaps being equivalent to the Huronian, as already suggested.

The general structure of the Wasatch, as explained by the Fortieth Parallel surveyors, stands untouched by later work; that is to say, there is here a great series of pre-Cambrian rocks, against which was deposited unconformably an immense thickness of clastic deposits, and the abrupt western face of the Wasatch is due to a great fault.

Passing to details, it is plain that Geikie's objections to the pre-Cambrian character of the Cottonwood granite mass have great weight. However, it is to be said that while the difficulties involved in the explanation of the Fortieth Parallel surveyors is considerable enough, they do not appear to the writer to be so great as indicated by Geikie. The pre-Cambrian mountain represented in the sections, instead of being 12 miles high, is but half of that height, since its height is not ascertained by measuring its horizontal base, but by the perpendicular distance between the extension of the Cambrian basal beds and the topmost granite. Also, if the stratified beds are supposed to be deposited about the mountain with a slope away from it, as is common along a steep shore line, the altitude of the mountain would be even less than this. This estimate does not provide for the increased altitude which the mountains must have had before being buried. If the section is turned back so as to represent the stratified rocks as horizontal, the average steepness of the granite to its culminating point is found to be in the neighborhood of 45°, the lower reaches being less than this, but the steepness increasing to more than this amount in the upper slopes of the mountains. If the strata are considered as originally deposited with a dip of 10° away from the mountains, this would reduce the average slope of the mountain to 35°. Even with these allowances it is to be said that a buried slope of this degree of steepness, which is covered by the debris of an advancing shore line with the additional altitude of the mountains required in order to furnish the surrounding debris, seems highly improbable.

So far as facts were observed by the writer bearing upon the question of the character of the Cottonwood granite, they tend in the same direction as Geikie's conclusion. If this granite is supposed to be a later intrusive, the metamorphism of the sedimentary beds noted by the Fortieth Parallel surveyors, the presence in them of the granite-porphyry dikes, the sharp contacts and manner in which this eruptive mass cuts across the Archean crystalline schists at the foot of Little Cottonwood canyon, are all explained. In this connection it is to be said that so far as known the zonal character of the feldspars so well displayed by this rock is nowhere found in such perfection in such, ancient rocks as the pre-Cambrian, although this point may not be one of much weight. If the granite is an eruptive, the contained round black areas described by nearly all observers, and early taken as evidence that the granite is metamorphic, must either be partially absorbed fragments caught by the eruptive mass, or else segregations of hornblende which formed at the time of the crystallization of the rocks. If the post-Cambrian eruptive origin of the granite be accepted, there is no necessity for considering the Wasatch fault of such great magnitude and the pre-Cambrian mountains of almost incredible steepness and height.

Upon the other side, it must be said that if the estimate given by Emmons of the amount of sedimentary material of necessity absorbed by the eruptive theory—500 cubic miles—be correct, it is almost an equal strain upon belief. In this connection the question arises whether a closer study of the region will not show that the Cambrian strata have a quaquaversal arrangement about the Cottonwood granite as do the Silurian, Devonian, and Carboniferous strata, the edges of the Cambrian being uptilted, and, like them, the structure as a whole being batholitic. While it may be found that the entering granite has absorbed a portion of the Cambrian quartzite, the amount thus assimilated would be comparatively small. On this hypothesis the present distribution of the rocks would be explained by intrusion and erosion.

The relations of the clastics to the much larger Farmington and northern Archean areas, unquestionably older than the sedimentaries, are such as to require comparatively low and relatively gentle slopes and pre-Cambrian mountains not higher than from 12,000 to 18,000 feet; that is, mountains not higher than those at present existing adjacent to the ocean.

In the Wasatch, among the rocks which the Fortieth Parallel survey placed as pre-Cambrian, the writer was able to find no rocks which are not completely crystalline. An examination of the specimens collected by that survey showed no clastic rocks. In the Farmington area the crystalline schists and gneisses are cut by coarse, intrusive granites; hence, so far as at present known, aside from the usual fundamental crystalline complex, there is no evidence of any rocks below the conformable succession placed in the Paleozoic, excepting the small area of quartzites and quartzose mica-schists at the foot of the Cottonwood canyons. The reference of the basement complex of the Wasatch to the Huronian on lithological grounds by the Fortieth Parallel survey could have been made only by a mistaken conception of the real character of that series. This complex is lithologically much more nearly like the crystalline complex of rocks usually referred to the Laurentian.

The calcareous argillites, limestone, and the quartzites occurring on Antelope island and Promontory ridge are of a different lithological character from the main area of Wasatch Archean and may represent a later series of rocks. To this series the Lower Cottonwood schists may also belong. There is no decisive structural evidence in the nature of known contacts showing that these rocks are older than the lower part of the succession which was referred to the Paleozoic, but the latter series is nowhere so crystalline, and the fact that these rocks were placed in the Archean rather than the Paleozoic by the Fortieth Parallel survey shows that the affinities of these rocks were thought to be with the former. Since part of the rocks here included are certainly of clastic origin, it appears that there is in this region representatives of the Algonkian system.

Below the Olenellus fauna in the great succession of rocks referred to the Paleozoic by the Fortieth Parallel survey is a conformable inferior series of quartzites and schists about 12,000 feet in thickness. There is no evidence that these are not pre-Olenellus, and they are therefore doubtfully mapped as pre-Cambrian or Algonkian. The descriptions of this series show that it is a considerably altered one. The sandstones have been indurated to quartzites, and the mica-schist of Twin peak is quite crystalline. If this reference of the Wasatch lower quartzite to the Algonkian proves correct, it stands as the uppermost series of this system, in a position equivalent to the great series of barren slates of Montana, described by Davis and Peale as conformably below the Cambrian.

SECTION V. NEVADA, NORTH OF PARALLEL 39° 30′.

LITERATURE.

SCHIEL,[38] 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.

EMMONS, (S. F.), and HAGUE,[6] 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, Gosi-ute, Peoquob, East Humboldt, White Pine or Pogonip, Wah-weah, Cortez, Seetoya, Shoshone, Toyabe, Augusta, Fish creek, Havallah, Pah-ute, West Humboldt, Montezuma, Pah-tson, Granite, Pah-supp, Sah-wave, 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 its lithological character from the Raft, Ombe, Gosi-ute, 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 Pah-supp range consists of granites which resemble the later granite of the Pah-tson range.

The Cluro hills of the Cortez range are composed of syenite-granite, which is the only true syenite found in the region.

The Peoquob, East Humboldt, Shoshone, West Humboldt, Montezuma, Pah-tson, 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 possesses, at White Cloud peak, 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 contains 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 schists. The range is regarded as an anticlinal fold. In the Montezuma range are slates and schists which rest unconformably upon the granite. The Pah-tsön 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 quartzites show evidence of having been submitted 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 there 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 Wah-weah range, surrounding the granite, occurs a heavy bed of quartzite, which is referred to the Ogden Devonian, although but little examined.

In the Ombe, Gosi-Ute, 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 overlaid 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, Pah-Ute, West Humboldt, and Truckee granites are referred to the Triassic; that overlying the granites of the Pah-supp range is referred to the Jurassic; while the gray slates resting unconformably above the Sah-wave 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 exceeding difficult, if not impossible, definitely to determine their true geological horizons. In many cases lithological and structural resemblances furnish a strong aid, which, 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 upon theoretical grounds, being upon slight evidence, or even personal impressions received in the field.

KING,[7] in 1878, describes many of the Nevada ranges.

In the Gosi-Ute 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 over 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 Gosi-Ute 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, 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, there being no tendency for a passage to occur between the two rocks and dikes of granitic material invading 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 Pah-tson 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 from north 50° to 65° east, 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. On the one hand, 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,[39] 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 and dips away from it in irregular broken masses.

WALCOTT,[33] 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,[35] in 1889, places the lower quartzite of the Eureka and Highland sections as basal Cambrian.

SUMMARY OF RESULTS.

It is evident that west of the Wasatch no such detailed and careful work was done by the Fortieth Parallel Survey as in that range and in the ranges to the east. In the Nevada ranges, which contain granite only, the reference of the rocks to the Archean or to a later period is based upon too little evidence, and it can only certainly be said that in each case the granites are older than the oldest sedimentary rocks with which they are in contact and do not cut. Some of the granite areas are said to be as late as the Jurassic, as for instance that of the Washoe range, which is in eastern Nevada. That this is an intrusive could be determined, because it cuts the pre-Jurassic rocks; but in the numerous cases in western Nevada the undisturbed sedimentary rocks adjacent to the granite ranges are Triassic or Jurassic; so that granites earlier than these periods, but far later than the Archean, would show no structural evidence of their late age.

It is now well settled that granitic-textured rocks vary into porphyritic forms, but to the Fortieth Parallel Survey belongs the credit of an early recognition of this. In the Gosi-Ute and Franklin butte ranges, in which the rocks are referred to the Archean, the granites are said to grade into granite-porphyries, and at Franklin butte into a genuine felsite-porphyry.

In the Gosi-Ute the granite-porphyry is so associated with crystalline limestone, referred to the Archean, as to lead to the conclusion that both the granite and granite-porphyry are metamorphosed sedimentary rocks. It seems far more probable that they are eruptives later than the crystalline limestone and have been the cause of its metamorphism. This explanation was applied by the Fortieth Parallel surveyors to the case of the interstratification of marbles and granitic porphyry in the hills between the Antelope and Schell creek ranges. In the western half of Nevada, especially, are abundantly found late rhyolites, trachytes, porphyries, etc., so that it may be said that this has been a region of great volcanic activity until late time, the chemical composition of many of the rocks being the same as granite. While probably mistakes have been made as to the age of the granites in individual cases, the general point which King makes that the ancient granites have a crushed, irregular, and confused mode of arrangement of the minerals is one of considerable weight, although it would have no bearing upon their origin; for this condition of the minerals would by many geologists be taken as merely evidence of powerful dynamic action which has produced the present confused condition in an eruptive granite, rather than the result of metamorphic processes upon a sedimentary rock. The exhibition of these characters by one mass of granite and their lack in an adjacent one, indicates that the former is of greater age because the other has escaped the effects of dynamic action.

In the cases of the Schell creek, Egan, Pogonip, and Piñon ranges, where below the Olenellus Cambrian there is a great thickness of in ferior conformable nonfossiliferous quartzite and then an unconformity before the rocks are reached referred to the Archean, the conclusion can not be questioned. Also it is probable that where there is a complex of granite, gneiss, and schists (as in many of the mountain ranges), precisely like that found elsewhere in the West, and known to be pre-Cambrian, the lithological evidence for reference to the Archean is sufficient. Among such ranges are the Cortez, Shoshone, Havallah, East and West Humboldt, Montezuma, Pah-tson, Truckee, Pea Vine, and others.

The question as to the separability of the rocks referred to the Archean into two series is hardly touched. In the East Humboldt it is evidently thought that the White Cloud peak granite is older than the schistose series, the former being regarded as Huronian and the latter apparently as post-Huronian. One wishes that more evidence were given that the granite mass in this case does not cut the schists and gneisses as in most of the other ranges. This is especially true because Hague says the White Cloud mass has the characteristics of an eruptive rock. More often the granites cut the overlying schists, as in the Shoshone, Havallah, West Humboldt, Montezuma and Pah-tson ranges, so that all of the rocks referred to the Archean are in these ranges basement complexes.

Whether there is in any of the northern Nevada ranges genuine clastics which are placed among the Archean is not positively determined. The quartz-schists, limestones, and mica-schists of the Humboldt range seem to be such a series, although they have now become very crystalline by dynamic action. In the West Humboldt range in the schists are mentioned fragment-like areas of quartz, which are explained to be aggregations formed by metamorphism. In the Pea Vine range there are quartzites. While from the descriptions there is no definite indication that truly clastic series exist elsewhere, such may hopefully be searched for in the Peoquob, Shoshone, West Humboldt, Montezuma, Pah-tson, Truckee, with perhaps a greater probability of success in the Shoshone, Peoquob, and Truckee.

If the lower 10,000 or 12,000 feet of quartzite in the Wasatch below the lowest fossiliferous horizon belong with the pre-Cambrian rocks, as suggested in the previous section, it is probable that parts of the quartzites below the Primordial fauna in Schell creek, Egan, Pogonip, and Piñon ranges belong in the same series—that is, the Upper Algonkian.

It is possible that several of the quartzites referred to the Ogden and Weber belong much lower in the geological column than supposed, for it is stated that in some cases these are referred to the Weber or Ogden for the sake of convenience, upon the slightest lithological evidence, or the mere personal impression of the observer. Some of these may be as low as Upper Algonkian. The series referred to the Weber, which in its lithological character is most similar to the Algonkian, is that in the Ombe range, where interstratified with the quartzite are seams of mica-schists.

Upon general principles it appears improbable that an equivalent to the Weber quartzite of the Wasatch should so widely be a basal formation. That a quartzite should be the lowest formation adjacent to an earlier mountain range is what one would expect, but that in so large a proportion of the ranges should now be found exposed as the basal series the same division of a single period is contrary to probability.

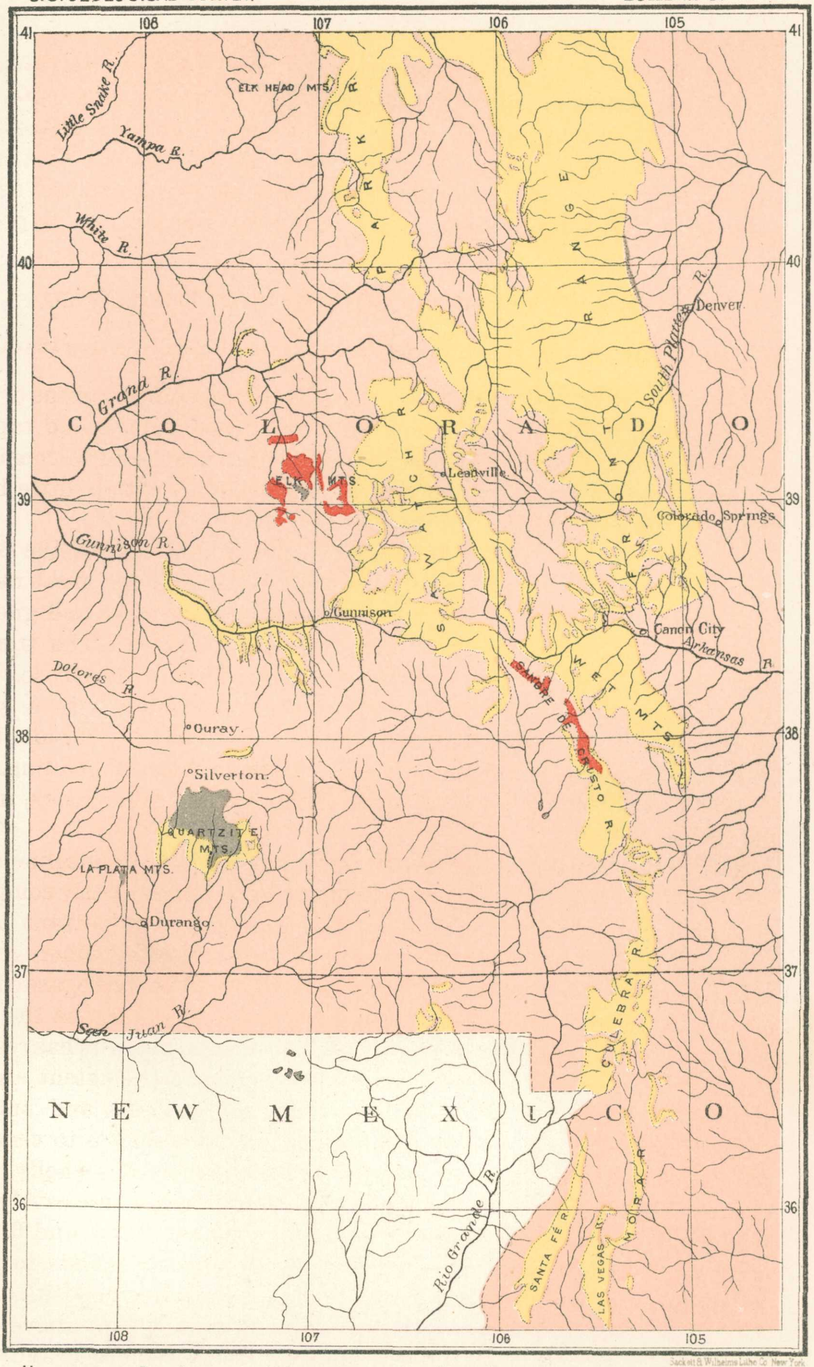
SECTION VI. COLORADO AND NORTHERN NEW MEXICO.

LITERATURE OF THE FRONT RANGE, NORTH AND EAST OF THE ARKANSAS.

LONG,[40] in 1823, describes granite as succeeding pudding-stone or conglomerate on Defile creek. The granite is coarse grained and rapidly disintegrates. A high peak was ascended and was found to consist of an indestructible aggregate of quartz and feldspar, with a little hornblende in small particles.

HAYDEN,[3] 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 and southeast or nearly so. The Azoic rocks have two planes of cleavage, one of them with a strike northeast and southwest, and the other at right angles. Besides these cleavage planes there are in most cases distinct lines of bedding. At Golden city the sandstones lie close to the metamorphic rocks, inclining 30° to 54°.

MARVINE,[41] 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 the 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 with but few remnants of bedding left, but which is apparently conformable with



Unclassified Pre-Camb. | Algonkian | Post-Algonkian | Granite

GEOLOGICAL MAP OF PORTIONS OF COLORADO AND NEW MEXICO

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the King, Hayden & Wheeler Reports

Scale $\frac{1}{3.450.000}$

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 Vrain's, and at the mouth of South Boulder canyon are 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 the 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 metamorphism alone has often left sharp lines of demarkation between differently affected rocks, there are also points where movements of the plastic rock seem to have occurred; while, in tracing a line of schist into a granite area, points may occur where the normal granitoid strata regularly belonging to the series may gradually increase in number and thickness, monopolizing the series and producing a normal metamorphism; or tongues of granite may invade the schists, as if an active metamorphism had proceeded outward from the granites, eating, as it were, into the schists, and absorbing first those beds by nature most readily succumbing to the change, and leaving the intercalated masses less changed. Yet the remnants of structure left in the granites still show that no important movement has taken place in the mass, but that the rocks remain in situ, and are an indigenous granite. But, besides these confusing appearances, lines of the granite sometime appear as if actually injected or intruded among the schists, sometimes on their bedding, and perhaps across them as eruptive veins. Indeed, there seemed cases where, in approaching the same mass of granite from different points, at once all the appearances of a truly exotic and eruptive origin might be found—abrupt lines of demarkation and veins, while at another point nearly all the steps of a gradual metamorphism and transition from the schists beyond might be traced, while the remnants of structure through the mass itself would, in greater part, conform to the surrounding system of folds, showing it as a whole to be an indigenous mass. Two observers thus approaching such a mass would justly render different verdicts as to its nature, one ascribing to it a wholly eruptive origin, the other a clearly metamorphic character. A few minor masses of granite did not show well marked transitions from schists, though in part the ends of the latter gradually, yet abruptly, merged into the granite, as if absorbed by it, the mass as a whole presenting an intrusive character. There is, however, no evidence whatever to show that such masses have traveled far or that they might not have come from a short distance only and have been derived from rocks similar to those in which they are inclosed or others of the same series, for their likeness may be found at other points as true metamorphics. Penetrating various portions of the series are granitic, usually mostly feldspathic, veins, many of which probably extend long distances and appear to be of true eruptive character, while other granitic veins, usually of very coarse bluish quartz and white cleavable feldspar, with sheets and large crystals of white mica, seem to be more naturally referred to infiltration or to be endogenous in character, like many metalliferous veins, some of each kind showing layers of deposition or structure.

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,[42] 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 being between the two slates and quartzites. At several of the sections given the basal layer of the series is a quartzite.

ENDLICH,[43] in 1874, describes granite as forming the heaviest mass of rock north and east of the Arkansas and south of the line running east and west 6 miles south of Pikes peak. Upon Cottonwood creek the rock resembles a gneiss. Resting immediately upon the granite is 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,[44] 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 Baileys 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 marks 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. In every such instance, however, it occasionally changes into gneiss for short distances. Not unfrequently 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 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 Ten-Mile 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 and granite, which gradually assumes a gneissoid structure and contains fragments of gneiss from 6 to 20 inches in diameter which 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, 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 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 it is said the prevailing rock is a micaceous schist passing into gneiss, and containing much granite, which in some localities entirely replaces the others. Not unfrequently 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,[7] 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.),[45] 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,[46] in 1890, made observations upon the district of South Boulder, Coal and Ralston creeks. In the South Boulder and Coal creek 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 upon Coal creek cutting the schists are also pegmatitic granite veins. Nowhere between the clastic and 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.

LITERATURE OF THE WET AND SANGRE DE CRISTO MOUNTAINS.

SCHIEL,[38] in 1885, describes the predominating rock 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,[43] in 1874, describes the region south of the Arkansas as consisting chiefly of granite. That forming the Sangre de Cristo mountains is of different 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 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,[47] 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,[48] 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 the 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,[49] 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,[45] (S. F.), 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.

LITERATURE OF THE FRONT RANGE OF SOUTHERN COLORADO AND NORTHERN NEW MEXICO.

WISLIZENUS,[50] 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,[51] in 1856, describes ridges of metamorphic slate in the Santa Fe mountains, upon the edges of which rest horizontal Carboniferous strata.

LOEW,[52] 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.

ST. JOHN,[53] 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 of which to the Tertiary are not easy to make out. The Vermejo mountains have a nucleus of massive metamorphic rocks.

NEWBERRY,[54] in 1876, states that in the Santa Fe mountains is found coarse red granite, characteristic of the central portion of the Rocky mountain system. It differs from the granite of the Appalachian as well as those of the Sierra and Cascade. 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,[55] 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 the 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,[56] 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 frequent exposures of an exceedingly coarse granite, which resembles a metamorphosed conglomerate, the pebbles being thoroughly distinct. 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 Niño on the 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 nonconformability 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 nonconformability 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 and often conglomerate granite immediately underlying the Carboniferous at many localities may possibly be of somewhat later origin.

LITERATURE OF THE PARK RANGE.

MARVINE,[41] 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° to the southward.

LITERATURE OF THE SAWATCH MOUNTAINS.

HAYDEN,[57] 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,[42] 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,[43] 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.

ENDLICH,[48] in 1877, states that at the southern end of the Sawatch range trachyte is the principal rock.

EMMONS, (S. F.),[58] 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 vein-like 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.

LAKES,[59] 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.

LITERATURE OF THE ELK MOUNTAINS.

HAYDEN,[57] in 1874, describes the Elk mountains as composed of an upthrust of igneous granite, which carries portions of the sedimentary beds on its summits or tilting away from the sides at various angles. The lowest group of sedimentary rocks is Lower Silurian. In some cases there is complete overturn of immense groups of beds, so that for several miles there is a double series from the Silurian up to the Cretaceous, inclusive, as at the head of East river and near Snow Mass peak. Northeast of Snow Mass the sedimentary beds may be seen resting on the granite, on these a great thickness of red beds, and on the top of the latter masses of irregular thickness of eruptive granite from 100 to 400 feet thick, and at both ends the red beds again resting upon the eruptive mass, so that the granite now appears like an interstratified rock. Gothic mountain and Crested butte are regarded as immense dikes, the melted matter being pushed up through the superincumbent matter so as not to disturb to any great extent the thickness of yielding Cretaceous shales and clays. On Eagle river are beds of sandstones and quartzites, the fragments of which indicate that they have been derived from gneissic and granitic rocks.

PEALE,[42] in 1874, describes the entire mass of granite of the Elk mountains as having been either in a plastic or melted condition. The elevation of the range was post-Cretaceous. The mountains are cut by numerous dikes, which are in part trachytic, but which are, however, believed to be connected with the eruptive granite. On the southeast side of Elk mountains are chloritic schists, quartzites, and sandstones, all very much metamorphosed.

HOLMES,[60] in 1876, gives the geology of the northwestern portion of the Elk range and describes in detail the character of the folding, faulting and relations of the crystallines to the sedimentary rocks. On the east side the sedimentary strata lie up against the granite of the Sawatch range, and on the west they have been carried high up on the arch of the Elk mountains, leaving the synclinal depression between the ranges. The axes of the two ranges are not parallel, but approach each other toward the south and separate toward the north, giving an included angle of some 30°. In the vicinity of Italian peak the granites of the two ranges are in contact, or nearly so, being totally distinct in appearance and in reality. The sedimentary beds of Sopris and Rock creeks show a considerable amount of metamorphism and lateral crushing, the Dakota sandstones of the latter being changed to hard, flinty quartzites. A great fault, combined with a fold, runs from the north part of the Elk group, i. e., Snow Mass mountains, to its south part, White Rock mountains. In the sections the granitic rocks are represented in places as being above the sedimentary and in other places as intruding themselves among the layers.

LAKES,[61] in 1885, describes the stratified rocks adjacent to the Elk mountains as riddled with dikes and baked and metamorphosed in places almost past recognition. The huge volcanic masses are some of them dikes, while others may be laccolites.

LAKES,[59] in 1886, describes the Elk mountain eruptions as having occurred under an enormous pressure of superincumbent strata not less than 10,000 feet thick. The Elk mountains are diorite instead of being eruptive granite as called in Hayden's reports.

LITERATURE OF THE GRAND AND GUNNISON RIVERS.

SCHIEL,[38] in 1855, states that along Coochetopa creek and Grand river valleys are granite, gneiss, shale and mica-slate.

PEALE,[42] in 1874, states that adjacent to the Gunnison a section has at its base rust-colored granite, above which is mica-shist, and over this quartzite and sandstone.

STEVENSON,[44] 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,[62] in 1876, describes Archean rocks as occurring along and near the gorges of Eagle and Gunnison rivers. The rocks of the Eagle river are known to be pre-Potsdam, because at the head of the stream such rocks rest upon them. On the 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,[63] in 1877, describes the Archean rocks of the 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 outcrops of quartzitic layers occur 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.

LITERATURE OF THE QUARTZITE MOUNTAINS.

ENDLICH,[64] in 1876, describes the Quartzite mountains. Near the northern border and toward the middle, quartzites and schists predominate, while granite appears toward the east and south. The quartzites are mostly of a white or gray color, gradually becoming filled with mica or chlorite, thus turning into schists. The relations of the quartzites are extremely varied and complicated. Granites change into quartzites between stations 21 and 22. The schists have a less horizontal extent but are just as distinct as the quartzites. They also show great variations in strike and dip. As a rule they seem to be older than the granite, but it was not possible to establish this point beyond doubt. The schists were nowhere found except in the quartzite group. All the granite shows a remarkable regular stratification, not an apparent one only, produced by the main cleavage plane of the feldspar or mica lying in one direction. The dip of the strata is conformable with those of the quartzites and schists and away from the anticlinal axis toward the south. Generally the dip is not very marked but still reaching from 7° to 10°. All along the Animas the junction of the sedimentaries with the granite was not observed. The latter was exposed in the valley, while the former appeared in steep bluffs on both sides. From the dips observed it became evident that the two were conformable.

As to the origin of the metamorphic group of rocks it is said that the Devonian strata were deposited on the granitic strata conformably. Also that from the quartzite into granite the transition is perfect, although often small specimens can be found showing on the one side granite and on the other granular red quartzite. Near the top of a bluff the latter is white or yellowish, becoming red and brown lower down. Finally some mica is observed in it, and the feldspar appears as such, until the coarse grained granite is reached. The metamorphosis is very thorough, and can be admirably studied at this point. So far as could be decided, the granite was formed out of a partly argillaceous sandstone, containing some iron in an oxidized state, while the purer sandstones were turned into quartzites. Probably the process of metamorphosis was a very slow one, and lasted a long time. Throughout the stratification is well preserved in all the rocks of that group, but particularly so in the granite of the locality just described. Even the thicknesses of the various strata which have been altered into granite correspond approximately to those at present exhibited by the superincumbent beds. At a short distance north of station 48, the granite overlies the dark schists, which in turn seem to be younger than the true quartzites forming the main bulk of the mountains still farther north. Taking into consideration, therefore, the observed conformity of the underlying metamorphics with the overlying sedimentaries; taking into consideration, furthermore, the analogous character of stratigraphical relations, the conclusion must be reached that those sedimentary beds, which existed below the Devonian, furnished the material for the metamorphic masses.

COMSTOCK,[65] in 1883, states that in San Juan county there are no rocks which are of Archean age. The granitic and quartzitic series of the Animas river are regarded as metamorphic and said to be of Upper Silurian or Devonian age.

COMSTOCK,[66] 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,[67] 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° to the north. The uplifted crests have been deeply eroded and in the hollows so formed rest the massive volcanic breccias.

EMMONS, (S. F.),[45] in 1890, states that on the north slope of the San Juan mountains, near Ouray, is over 10,000 feet of closely folded quartzites, conglomerates, and slates of the 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.

VAN HISE,[9] 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 dike-like 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°.

The quartzitic area is in places conglomeratic. The rock is for the most part a rather pure white or gray vitreous quartzite, although occasionally it shows more or less of a slaty appearance. Nowhere in the quartzite was found any hornblende-schist in dike-like forms such as occur in the granite, or any layers which could possibly be mistaken for the black or white gneissoid phases of rock which occur so abundantly in the granite area and have such intricate relations with the granite. The dips of the quartzites are also for the most part high, being from 60° to 70°. In the quartzites, as in the granites, there are great local variations in the strike and dip of the rock. Upon both sides of the quartzite area where the change to granite occurs no evidence whatever was seen of a transition between the two classes of rocks. In neither were the quartzites and granites 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.

What is said by Endlich as to the sharp contrast between the sedimentaries and granite may mean the contrast between the black hornblende-schists and gneisses with the coarse granitoid gneisses and granites. If this is the case, the statement is true, for these materials are seen in sharp contact at very numerous places along the Animas. If these hornblende-schists and gneisses are altered eruptives, as they appear to be, the sharp contacts would have no bearing upon the metamorphic origin of the granite.

Some of the quartzites have a color similar to the coarse reddish or grayish gneisses, and also show to some extent a banded appearance. It may be that this fact has led to the statement that there is a transition between them and the granitic rocks.

A study of numerous thin sections of the material collected shows that the rocks composing the area here called granitic are always completely crystalline, giving in the thin section no evidence whatever of clastic characters; on the other hand, all the rocks belonging in the quartzite area, while locally considerably altered by dynamic action, show very clearly their clastic character. However, the evidence of the microscope is not necessary to show the clastic origin of these quartzites, as the conglomeratic phases seen in the field are sufficient to demonstrate this.

As to the conformability described by Endlich between the flat-lying Devonian and these crystalline rocks, no observations were made. It is, however, to be remarked that Endlich states that the crystallines are flat-lying, having a dip of not more than 10° to 15°. This was observed to be the case in one locality, but as before said, the great number of observations along the Animas show the dips to be for the most part very high, i. e., from 60° to verticality, and in various directions. All of the evidence as to the strike and dip show that the area of quartzites and granites is one in which the folding is very complicated.

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 red beds of the Jura-Trias 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. Conformable below the red beds of the Jura-Trias, at Ouray, the Carboniferous rocks appear, but they were not seen in contact with the slates and quartzites. That the quartzite series was an old shore against which the Carboniferous and Jura-Trias were deposited can not be doubted. 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.

As to the relations of the granitic area to the quartzites along the Animas, there is no clear evidence. The fact that the granitic area is an intricate complex of regularly banded gneisses, of granitoid gneiss, and of granites cut by hornblende-schists in dike-like forms, combined with the fact that no such dike-like areas are found near the quartzites, seems to indicate that the quartzite is of later age than this complex. This probability is still further strengthened by the completely crystalline character of one series and the plainly fragmental character of the other. This point would have little weight if the granitic area was a simple massive rock which might be the result of a single eruption. But the varieties of rock of which it is composed and the intricate way in which these lithological phases are mingled indicate that the history of the granite area is a most complex and long-continued one, and was far advanced before the deposition of the fragmental rocks. If it should be held that this granitic area is eruptive as a whole and later than the quartzite, the question arises, Why is it that nowhere do any of the rocks which belong in it cut the quartzites? If, on the other hand, it is maintained that it is metamorphic in origin, the question arises, Why is it that all parts of it have become so completely crystalline while the quartzite is still so near its original condition?

LITERATURE OF THE LA PLATA MOUNTAINS.

HOLMES,[68] in 1877, places the La Plata mountains in the metamorphic belt because the central portion, as exposed in the deep-cut valley of the La Plata river, is composed of uplifted and altered sedimentary rocks; but there are associated with these a very considerable area of eruptive rocks with a resulting great complication of structure. This metamorphic group seems to be a prolongation to that to the northeastward about the Animas. Against attributing any great amount of change in the sedimentary rocks to the presence of the trachyte is the fact that in the neighboring groups of mountains of trachytic origin there is little or no metamorphism apparent. In the central part of the altered area the metamorphic mass proper extends up to and includes the red beds. As one of the best examples of the metamorphism may be mentioned that on the west face of the first mountain south of Hesperus. Here a mass of metamorphic shales abuts or is welded to the trachyte face of the mountain. The exact point of contact can not be determined, as the metamorphism has been so complete that the shales seem to change gradually into trachyte. Away from the trachyte they gradually assume the appearance of a massive grayish yellow quartzite, and in a mile or more from the place of contact assume a shaly character and dark color.

ENDLICH,[49] 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. Large areas are covered by rocks of this group, which occur in almost endless variety. In several instances localities may be observed where the transition from undoubted sedimentary into metamorphic beds is evident. This, however, must be considered as an exception rather than the rule. The gneiss is the oldest of the metamorphic rocks in the district examined. Micaceous, hornblendic and chloritic schists occur as such associated with other metamorphic rocks. Frequently they are due to the substitution of minerals within the gneiss, but they are also found totally independent thereof. If a suggestion may be offered which, however, can not at present be proved, the author would say that argillaceous sandstones form granite. With the decrease or increase of argillaceous matter in the sandstone the quantity of feldspar in the granite stands in direct proportion. Siliceous sandstones form quartzites. Shales, arenaceous in part, are changed into gneisses, and if the quartz in them is predominant they turn into schists. Quartzites can not be generally classed with the metamorphic rocks, but in the Quartzite mountains a complete alteration of the original sandstone has taken place, although stratification has been retained in a measure. Granite is the most representative species of the metamorphic group. It is younger generally than the schistose rocks occurring with or near it. In the Quartzite mountains there is a direct transition from sedimentary beds into typical granite. A large part of the granites in southern Colorado is regarded as metamorphosed Silurian, Devonian, and in rare instances even Carboniferous strata.

SUMMARY OF RESULTS.

The greater parts of the Front, Wet, Sawatch, Park, and Quartzite ranges and the crystalline rocks of the Gunnison and Grand are a completely crystalline complex of rocks which are certainly pre-Cambrian; for, resting upon these ranges unconformably and bearing débris from the older series are the fossiliferous Cambrian. These contacts are found both on the east side of the Front range and in the parks along the Sawatch, as well as at Eagle river in the Gunnison and Grand region. The granite-gneiss-schist complex of the Quartzite mountains also without much question belongs in the same position.

The relations, so excellently described by Marvine and Stevenson, between the nearly structureless granites constituting the core of the ranges and the well laminated schists and gneisses are those between the granites and associated crystallines described in Massachusetts by the elder Hitchcock in 1860, by King along the fortieth parallel, by Lawson about the Rainy lake and the lake of the Woods, and by Winchell in northeastern Minnesota. That is, in passing from a schistose to a granitic area the finely laminated schists become coarser and coarser; then appear thin belts of gneiss, which become more and more prominent until the rock has changed to a gneiss, and this by imperceptible stages passes into a granitoid gneiss, then into a granite. A whole or a part only of the laminated rocks may be cut by granite veins, while oftentimes there are considerable masses of granite in the schists of the same character as the main granite mass, the contacts being exceedingly sharp. In a few cases in the massive granites are found fragment-like areas of the schists. These imperfectly summarized relations are regarded by Stevenson, Marvine, and the other writers to be evidences of the metamorphic character of the whole series, while the intrusives are regarded simply as parts of the main mass which have become perfectly fluid and therefore locally take on eruptive forms. Lawson declines to carry the term metamorphic over to the plastic material and speaks of it as a subcrustal magma. As the real character of such granite-gneiss-schist complexes is a question which concerns not only the Colorado ranges, but almost every other pre-Cambrian region of North America, the discussion of this question is deferred for the general chapter. It is, however, plain that in the mountain ranges of Colorado is a thoroughly crystalline, intricate, fundamental complex like that found in most of the pre-Cambrian areas already considered.

Besides these crystallines there are at least two areas in which unmistakable pre-Cambrian clastics are present. These are the districts of Big and Little Thompson, South Boulder, Coal and Ralston creeks in the Front range, and the district of the Quartzite mountains in the San Juan region. It is also probable that the quartzites and mica-schists of northern New Mexico, described by Stevenson, is a third series, although the relations of these beds to the other rocks are not indicated. The great beds of white quartzite and the granite-conglomerate in the neighborhood of Santa Fe strongly suggests that here is a clastic series, the granite-conglomerate probably being a recomposed rock. A fourth great series which possibly falls among the pre-Cambrian clastics is that seen by Cross in the neighborhood of Salida.

In the Front range the descriptions of Marvine and Lakes agree that there is an apparent gradation from the clastic quartzite and mica-schist series to the gneisses and gneissoid granites, although Lakes states that the transition is somewhat abrupt. Two explanations may be applied here: First, there may be a real physical break which has not been detected between the clastics and the crystallines. In favor of this hypothesis is the fact that quartzites are found nowhere else in the vast area of the Front range, and that nowhere else are there any rocks which are even described as having any evidence of fragmental character, unless foliation be taken as such evidence. If this clastic series and the great complex of granite, gneiss and schist are of the same origin and age, it is certainly strange that nowhere except in this very restricted area do beds of quartzite or quartz-schist occur. Also the presence of genuine granitic pebbles in the conglomerates at least shows that there existed an earlier granite from which débris was derived. Second, those who believe that the fine-grained gneisses, completely crystalline schists and granites are all really of eruptive origin, the foliation being but evidence of powerful dynamic action, will probably maintain that this clastic series is the more ancient one and has been cut and metamorphosed by the intrusion of the igneous rocks.

In the Quartzite mountains the evidence that the fragmental slate and quartzite series is more recent than the granite-gneiss-schist complex is far more weighty. Here an intricate complex of irregularly banded gneisses, granitoid gneisses and granites are cut by foliated dikes of hornblende-schist, which never penetrate the fragmental series. At one of the places along the Animas at which the quartzite is separated by a very short interval from the granite complex there is a sharp discordance in its foliation and a series of sharply folded anticlines and synclines of quartzite, which with considerable certainty indicate the bedding of the latter group. Also, while the quartzite series inclines at a steep angle and is in places sharply folded, it upon the whole has not suffered any such profound and repeated dynamic movements as are exhibited by the granite-gneiss complex. If the latter series be taken as sedimentary its complete metamorphism argues its greater age; and if it be taken as wholly eruptive its present implicated character, with strongly developed schistose structures, denoting profound metamorphism, indicates a history much longer than the one revealed by the quartzites. This great quartzite and slate series can then with a considerable degree of certainty be regarded as much later in age than the granite-gneiss-schist complex. Also it is far more ancient than the Carboniferous, because near Ouray the Trias conformably above the Carboniferous rests in a nearly horizontal position upon the upturned, nearly vertical, truncated edges of the quartzite. On general structural and lithological grounds it may with great probability be referred to the Algonkian. Of the two other areas of clastic rocks too little is known to offer any suggestions as to their age or relations.

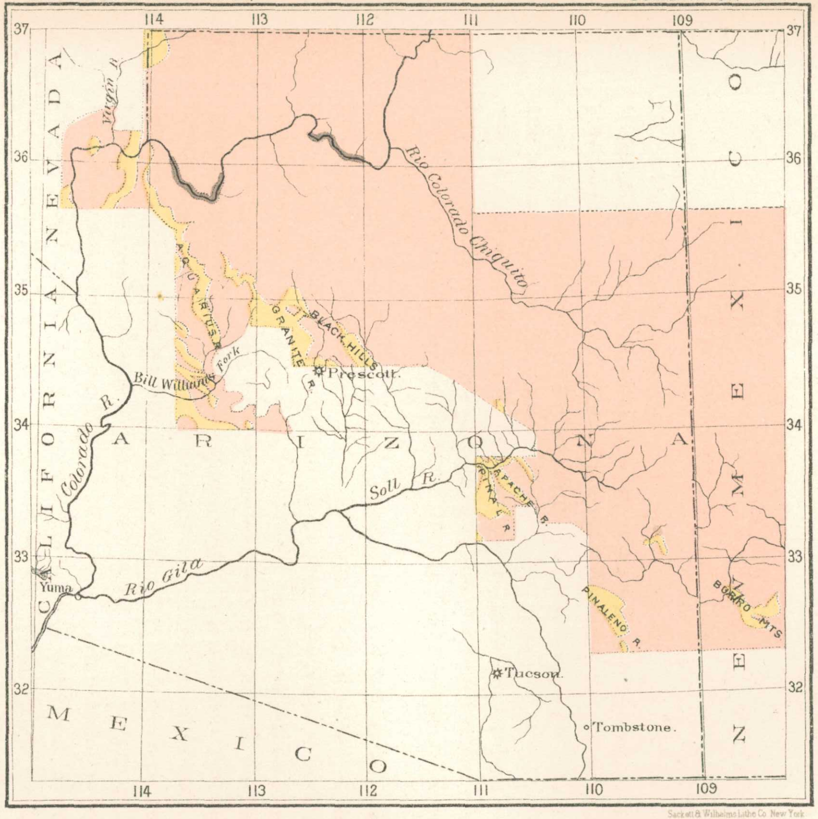
A part of the so-called granite (diorite?) of the Elk mountains and a part of that of the Sangre de Cristo range is plainly an eruptive of later age than the Cambrian, and therefore it does not properly fall within the province of this review.

Whether there are any pre-Cambrian rocks in the La Plata mountains is uncertain. The small area of metamorphosed rock bears such relations to the eruptives as to suggest that their present condition may be due to contact metamorphism.

SECTION VII. ARIZONA AND WESTERN NEW MEXICO.

LITERATURE.

POWELL,[28] in 1874, states that below the Carboniferous is a succession of nonconformable shales, sandstones and limestones, the greatest thickness of the beds being a little more than 10,000 feet. The beds are traversed by dikes of trap or greenstone and irregular layers of the same eruptive material are found in places between these nonconformable rocks and the overlying beds of Carboniferous age. Provisionally these sedimentary rocks are 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



UNCLASSIFIED PRE-CAMB. ALGONKIAN POST-ALGONKIAN

GEOLOGICAL MAP OF ARIZONA AND PART OF NEW MEXICO

SHOWING PRE-CAMBRIAN ROCKS

Compiled from the Wheeler and Dutton Reports

Scale $\frac{1}{6.336.000}$.

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,[69] 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, and the metamorphosed sandstones and shales, with the beds of granite, present evidence of erosion subsequent to the periods just mentioned, yet antedating the deposition of the nonconformable sandstones. Here, then, we have evidences of another and more ancient period of erosion or dry land. Three times has this great region been left high and dry by the ever-shifting sea; three times have the rocks been fractured and faulted; three times have floods of lava been poured up through the crevices, and three times have the clouds gathered over the rocks and carved out valleys with their storms. The first time was after the deposition of the schists; the second was after the deposition of the red sandstones; the third time is the present time.

GILBERT,[36] 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. Following 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 soutwestern 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. Whether a portion of the rocks are altered Paleozoic or whether the Paleozoic has been completely removed in the progress of erosion, or whether the Archean rocks have been covered by no later ocean sediments has not been decided. The purity and great thickness of the Carboniferous limestones up to the very margin of the region would appear to negative the idea of a permanent continent from Archean time, if, indeed, it is not negatived by the survival of acute mountain ridges.

GILBERT,[70] 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. The Zuñi range of the Plateau region has a crystalline nucleus which Howell suspects to be due to the metamorphism of lower Paleozoic strata, as they are conformable with unaltered upper Paleozoic beds. The specimens show a gradation from compact sandstones to gneissic quartzite and quartzose granite. Between the Archean and the Silurian there is, first, a wide unconformity, demonstrating the tilting and erosion of the Archean beds anterior to the deposition of the Silurian; and, second, there is always at the contact a contrast of conditions as regards metamorphism, the Silurian rocks being usually merely indurated and the Archean invariably highly metamorphic. The two characters of the break serve to show that it represents a vast chasm of time, a chasm the duration of which may have been greater than that of the ages which have since elapsed. A third character of the break, one that is supported by less evidence but is negatived by none, is that the lowest of the superposed rocks are conglomerates and coarse sandstones. The conclusion to be drawn from the coarse, fragmental nature of the lower deposits is that the water which spread them was an encroaching ocean, rising to possess land that had long been dry. The recognized interpretation of a widespread sandstone is continental submergence, or, what is the same thing, an advancing coast line.

MARVINE,[37] 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 to the 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 river Verde 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 Pinal mountains extend along Pinal creek to camp Pinal.

POWELL,[29] 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 evidence of this is complete, for the lower sandstones and conglomerates first filled the valleys and then buried the hills of schistic rocks, and these conglomerates at the base of the group are composed of materials derived from the metamorphic hills about; and hence metamorphism was antecedent to the deposition of the conglomerates. The plane of demarkation separating this group from the Tonto group is very great. At least 10,000 feet of beds were flexed and eroded in such a manner as to leave but fragments in the synclinals. Then followed a period of erosion, during which beds of extravasated material were poured over the fragments, and these igneous beds also were eroded into valleys prior to the deposition of the Tonto group. 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,[71] in 1883, describes below the Tonto a great series of unconformable sediments which are divided into two groups, the Chuar and 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 stratigraphical 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,[33] in 1886, states that the Tonto sandstone of the Grand canyon district is Upper Cambrian or Potsdam. Then below a great unconformity occurs 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, the 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 resemble 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, or 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 cannot be considered of Cambrian age.

WALCOTT,[35] 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,[72] 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.

SUMMARY OF RESULTS.

It is evident from the literature that in western New Mexico and in the major part of Arizona is a fundamental, thoroughly crystalline complex, consisting of most intricately mingled and folded granites, gneisses, micaceous and hornblendic schists, etc., precisely as in the previous sections concerned with the Rocky mountain system. This complex occurs at many points, constitutes the axes of many ranges, and its structure is of so intricate a character that no attempt has been made to estimate its thickness or to work out its structure, although in general the laminated rocks have been referred to as metamorphic. The granite in this complex plays the same part with reference to the crystalline schists as in the other areas referred to. Besides this ancient granite, which existed before the next newer series of rocks was formed, there is apparently in certain areas granites of later age, and these are more plentiful as the western part of Arizona is reached.

In eastern New Mexico and western Arizona, so far as the descriptions guide us, there is no certainty that any clastic rocks exist older than the fossiliferous series. In the central part of Arizona, however, in the Colorado canyon district, is the most complete section of rocks older than the Cambrian and newer than the fundamental complex in any known part of the world, with the exception of the lake Superior region.

The Tonto sandstone of the Grand canyon region, called by Powell and Gilbert Silurian in accordance with the nomenclature of the time, by present classification is to be placed as Upper Cambrian. The great unconformity which separates this sandstone from the earlier series makes it very probable that the latter are pre-Cambrian. These inferior series in descending order are the Chuar, Grand canyon, Vishnu series (together the equivalents of Powell's Grand canyon group), and the basal complex. The upper series consists of shales and limestones. Below this, with an erosion interval, is the second, consisting of sandstones, with interbedded and cutting basic eruptives. Inferior to this series, and separated by a great unconformity, is a set of thinly bedded and nearly vertical quartzites of undetermined thickness, broken by intrusive masses of granite. These three are clearly clastic series. The basal complex as described by Powell and Gilbert consists of thoroughly crystalline hornblendic and micaceous schists, gneisses, and granites, like the fundamental complex of the remainder of New Mexico and Arizona. Between this basal complex and the Vishnu series, as shown by Powell, is a vast unconformity. We have then in this region passing from the base upward, a fundamental complex; great unconformity; quartzite series of unknown thickness (Vishnu); great unconformity; Grand canyon series; minor unconformity; Chuar series; great unconformity; Cambrian.

The fundamental complex of Arizona has all the characteristics of the fundamental complex of lake Superior. The next overlying series is a quartzitic one, and quartzite is one of the most abundant and characteristic formations of the Upper Huronian of the Northwest. The next great succession is the Grand canyon and Chuar series, which in their unmetamorphosed condition, and in the character of the sediments are almost identical with the great thickness of sediments of the Keweenawan. Also the eruptives, which are interbedded with the Grand canyon series and cut it, are practically identical with the basic eruptives of the Keweenawan. These interbedded and cutting greenstones are characteristic of the lower, but are not found in the higher series, a still further analogy with the Keweenawan, for the lower Keweenawan contains eruptives and the upper Keweenawan is wholly detrital. The Grand canyon succession is then remarkably like that in the lake Superior region, and the respective series are lithologically alike.

It is exceedingly unsafe to correlate a single series with another series in a different geological basin upon lithological grounds; but when two great series of rocks are found, each of which has respectively similar lithological characteristics in two regions, and they are both separated by a physical break, and both sets of series are in exactly similar positions with reference to the overlying Cambrian and to the basement complex, the likeness suggests that they stand respectively as the time equivalents of each other. Between the two regions is the difference that in the Grand canyon area, a possible equivalent of the Lower Huronian of the lake Superior is not known. The correlation suggested can be considered no more than a conjecture since the parallelism in the two regions may be no more than a remarkable coincidence. It is remarked by Walcott that in the pre-Tonto series are a few obscure fossils, and that this locality is perhaps one of the best in the world in which to search for a pre-Cambrian fauna. Since in the lake Superior region the beginning of a pre-Cambrian fauna is also known, it may not be too much to hope that within a few years we shall have the assistance of fauna of sufficient fullness in these distant regions upon which the correlation above suggested may be tested.

SECTION VIII. CALIFORNIA, WASHINGTON AND BRITISH COLUMBIA.

LITERATURE OF CALIFORNIA, WITH ADJACENT PARTS OF NEVADA AND ARIZONA.

DANA,[73] in 1849, describes various crystalline rocks in the Umpqua and Shasty ranges. These include granite, syenite, porphyry, talcose rocks, serpentine. The hornblendic and talcose rocks are rarely schistose. Associated with the former rocks are conglomerates and sandstones.

TYSON,[74] 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. At the summit of the Sierra, granite is the prevailing rock, and upon its flanks slates. The cleavage of the slates have a uniform course, about north of west. These lines of cleavage are usually taken for those of stratification, but it is frequently difficult to determine the stratification even where extensive excavations have been made. However much the slates have been disturbed during their period of upheaval, they assume the slaty structure in continuous or parallel lines extending over considerable distances—in the present instance for more than 70 miles—the inclination being nearly vertical.

BLAKE,[51] in 1856, states that the contorted gneisses of the Aquarius mountains are metamorphic. In the Aztec mountains the horizontal Carboniferous strata show that it was 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 the Mojave 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,[75] 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,[76] in 1856, states that in the Coast range the igneous rocks that form the axis are of two kinds, granitic and trachytic. While altogether distinct in their extreme types, when they approach each other in position and age they merge these separate differences. The granites of the Sierra Nevada are anterior to the Eocene and posterior to the later Paleozoic. All of the observed sedimentary rocks were post-Cretaceous. 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,[77] 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 are used planes of structure or lamination. 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 limestones of Sussex county, New Jersey. 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 the Mojave river the rocks consist of metamorphic slates, very compact and so much changed as to resemble granite. In the Colorado desert the 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,[78] 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 and at other times 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,[79] 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 Mojave mountains is composed of white granite, traversed by numerous veins of quartz. The Black mountains as a whole are characterized by the prominence of eruptive rocks, such as massive granite, trap, porphyry and trachyte, and the 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,[80] in 1865, describes the Coast range, 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 range 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.

At many localities in the Sierra Nevada are described areas of granite, many of them of great magnitude. With them are associated metamorphic slates, a portion of these being mica-slates. In places granite dikes and veins are seen to intrude the slates. At Dome mountains, near the head of Kern and Kings rivers, a granite has a peculiar concentric dome structure which is not regarded as due to sedimentation, but results from the cooling of igneous material. The few fossils described in the slates of the Sierra are such as to cause them to be referred to the Jurassic.

GILBERT,[36] 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 over 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,[81] 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,[82] 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 River-Side and Half-Way mountains consist of granite and gneiss. At the Mojave 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. Eruptive gneiss is found in the Coahuila valley 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,[54] in 1876, states that in the Aquarius range the Carboniferous strata rest directly upon the granite. In the Cerbat mountains gray granitic rocks are found 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, so far as observed, wholly destitute of fossils. This metamorphic limestone of the Sierra is suspected to be Carboniferous.

CONKLING,[83] in 1877, states that the ridge-like 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,[84] 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,[85] 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, together with 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.

BECKER,[86] in 1891, describes the sierra between the Stanislaus and Truckee rivers as being chiefly granite and diorite overlain in part by andesite and basalt. The granite and other granular rocks are intersected by fissures at short intervals which are believed to be early Cretaceous.

LITERATURE OF WASHINGTON.

GIBBS,[87] in 1855, states that in central Washington, in the valley of the Methow, is found granite, syenite and gneiss, well characterized and blended with each other. 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 the Columbia river was found syenite, granite, gneiss, quartzose rocks, talcose slate and greenstone.

LITERATURE OF BRITISH COLUMBIA.

RICHARDSON,[88] in 1872, mentions crystalline rocks on the east coast of Vancouver which are pre-Carboniferous and may be of Laurentian age.

RICHARDSON,[89] in 1873, finds below the coal-bearing series of Vancouver and Queen Charlotte islands crystalline limestones, diorites, red and green slates, the age of which is uncertain, but are probably Silurian or later.

RICHARDSON,[90] in 1876, finds crystalline rocks throughout a widespread area in British Columbia, extending through 7 degrees of latitude, from New Westminster on the Fraser river to Wrangel on the Stickeen river, and through 6 degrees of longitude, from Vancouver to Cariboo and Tête Jaune cache. While not able to speak authoritatively on the age of this great series of crystalline rocks or to say whether different portions of them will be proved to belong to distinct epochs, they present such a wonderful uniformity in character as to favor the idea that they constitute one great and widespread series. They are doubtless the gold-bearing rocks of British Columbia.

SELWYN,[91] in 1877, in a report on exploration in British Columbia, divides the rocks into five divisions from above downward. Division four consists of semicrystalline 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 five consists of granitic rocks.

MACOUN,[92] in 1877, finds granite-gneiss and gneiss a few miles up the Quatre Fourches river, which are referred to the Laurentian.

DAWSON, (G. M.)[93] 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.),[94] in 1878, states that the crystalline series of Vancouver, described by Richardson in 1872, are found to contain fossils. They have, however, become metamorphosed, and in lithological character resemble the Huronian and altered Quebec groups of eastern Canada.

DAWSON (G. M.),[95] 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 comprises gneisses, greenstones, schists, limestones and granites.

BAUERMAN,[96] 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.),[97] in 1886, in that portion of the Rocky mountains between latitudes 49° and 50° 30′, places the lowest rocks found in the Cambrian. These comprise quartzite, quartzitic shales, argillites, limestones, and conglomerates. One section, between South Kootanie pass and Flathead river, has a maximum thickness or 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 the Colorado river.

DAWSON (G. M.),[98] in 1887, describes Vancouver island and the adjacent coasts. All the stratified rocks are Cretaceous or Triassic, although they are often metamorphic and crystalline. To all the volcanic material underlying the Cretaceous, including the limestones, argillites and quartzites, the term Vancouver series is applied. These rocks, the oldest in the district, were not deposited upon a granitic floor, as the granites are evidently later in date, and nothing is known of the character of the surface upon which the Vancouver beds were deposited. Granitic rocks are very widespread. The granites near the line of junction with the Vancouver series are charged with innumerable darker fragments from that series. In the immediate vicinity of the parent rock they are angular and clearly marked, but at a greater distance are rounded and blurred in outline. The width of the belt in which these fragments occur may exceed half a mile; in other cases it is only a few hundred feet. It was in several instances found impossible to draw a distinct line between the granites and the Vancouver rocks. The Vancouver series for some distance from the contact is very generally shattered and penetrated by granitic spurs or by felsite dikes. If the granite were in limited intrusive masses these would be regarded as ordinary intrusive rocks, but it appears everywhere to be the material upon which the Vancouver series rests, and is nevertheless evidently of later date than these rocks. The only explana tion which appears satisfactorily to account for the appearances met with is that in consequence of upheaval and denudation we now have at the surface a plane which was at one time so deeply buried in the earth's crust that the rocks beneath it had become subject to granitic fusion. It is clear that the granitic rocks beneath were in a plastic condition, not alone from the fact that they are found to penetrate the older series, but also from the evidence everywhere met with of the scattering out of fragments of the stratified rocks into the granites. Both the granites and the rocks of the Vancouver series have been subjected to great pressure in a horizontal direction, causing the fragments in the agglomerates to assume lenticular forms and impressing a more or less distinctly schistose character upon them, while the dark included fragments in the granites have been squeezed out into sheets, giving the portions of these rocks which are characterized by an abundance of such fragments an almost gneissic lamination. At the time at which this effect was produced the granites must still have been in a plastic state. On the inner side of Vancouver island it may further be remarked that for a long stretch the flaggy argillites and quartzites are frequently directly in contact with the granitic rocks, rendering it probable that the refractory character of their materials has proved a sufficient barrier to the progress of the granitic change, which may, locally, have nearly reached its possible limit. Particular occurrences of granite at many localities are described in detail.

McConnell,[99] 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,[100] 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 from 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.)[101], in1891, describes a section in the Selkirk range and compares it with a section of the interior plateau region at Kootanie 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 Kootanie 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. 6. Greenish and gray schists, with limestone .... 2,000 5. Limestone or marble with black, glossy argillites and some gray schists 2,500		*Feet.* Quartzites, with gray schists and some limestone. Black shaly argillites, limestone, and gray schists.		*Feet.* 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).	
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.	Cambrian.
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 their 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 consist of intrusive or vein granite with pegmatitic tendencies. In the Nisconlith series the lamination is often true bedding, but in some cases a slaty cleavage is developed. In the

Castle mountain group and the upper 3,000 feet of the Bow river series of the Rocky 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.

SUMMARY OF RESULTS.

The literature of the vast region covered by the western coast ranges and British Columbia is too meager to make possible any systematic comparisons between the rocks of different districts. No attempt has been made accurately to map any considerable areas in the region. The crystalline series have been referred to the pre-Cambrian, Cambrian, Huronian, or Laurentian, as the particular author thought advisable.

In California, Whitney evidently regarded all of the granites and metamorphic rocks as of very late age, but Becker, on the contrary, regards the main mass of them as the equivalent of the most ancient complex of Arizona and other western Territories. The earlier observers, such as Antisell, speak of the granites and metamorphic rocks which occur in the different ranges as Primary, but this reference was clearly made upon lithological grounds. While nothing definite can be said, the descriptions of some of the areas in southern and southeastern California and in the district along the Cañada de las Uvas certainly suggest that in these districts are thoroughly crystalline complexes which are lithologically like the fundamental complex of the Rocky mountain region, but it can not be positively asserted that anywhere in this region, except in British Columbia, such an ancient rock system has been found. Here the recent work of Dawson has shown the existence of a fundamental complex in all respects like that found in the Rocky mountains of the United States.

Nothing definite can be said as to the existence in California of pre-Cambrian clastic series later than such a possible fundamental complex. It is not at all impossible that such great series of crystalline schists as that described by Gilbert at Whites peak, in the Amargosa range, is the equivalent of the clastics of the Grand canyon group. This series was by this author referred to the Silurian; but the Grand canyon series at that time, when the lowest fossiliferous rocks were so called, was also called Silurian.

In British Columbia the lower 7,000 feet of the Bow river series of rocks may be pre-Olenellus, and not improbably belong to the Algonkian under our usage of the term, although placed by Dawson under his usage as a part of the Cambrian. If a part of this Bow river series is Algonkian, it would carry with it also, in all probability, the Nisconlith series, with possibly a portion of the Selkirk series, and doubtless also a portion at least of the section at Kootanie and Adams lakes; hence it is not improbable that in British Columbia is a great area in which Algonkian rocks occur.

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[101] Note on the Geological Structure of the Selkirk Range, George M. Dawson. Bull. Geol. Soc. America, vol. II, pp. 165–176. See also Report on a portion of the West Kootanie District, British Columbia, 1889, George M. Dawson. Geol. and Nat. Hist. Survey of Canada, Ann. Rept. (new series), vol. IV, pp. 28–40 B. With a map.

CHAPTER VII.

EASTERN UNITED STATES.

SECTION I. THE NEW ENGLAND STATES.

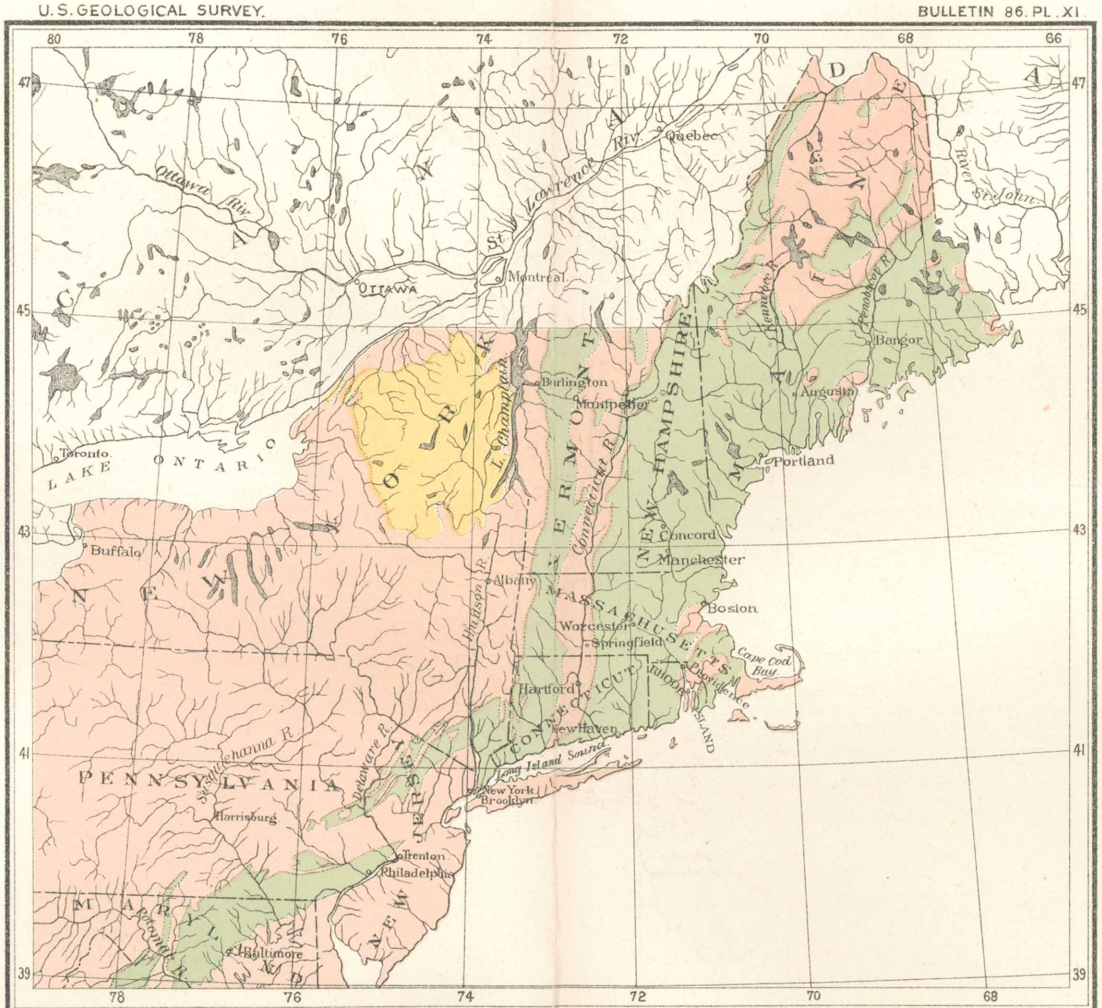
LITERATURE OF MAINE.

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[2] (EDWARD) 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 are in a vertical position and the whole are 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[4] (CHAS. H.), 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 which 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 correspond with the planes of stratification, but may cross the strata like cleavage planes. The trap dikes are believed to be eruptive.



UNCLASSIFIED PARTLY OR WHOLLY CRYSTALLINE ROCKS — UNCLASSIFIED PRE-CAMBRIAN — POST-ALGONKIAN

GEOLOGICAL MAP OF THE NORTHEASTERN STATES

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

After McGee and Hitchcock

Scale 1/7,500,000

HITCHCOCK (CHAS. 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, the 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 only possible to get at the true direction of lamination by following the limestone belts. At one place is an abrupt change from mica-schist to granite. A red conglomerate rests uncomformably upon a slate at Woodstock.

HITCHCOCK (CHAS. H.),[6] in 1874, describes at Portland three groups of rocks, 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 continuity of mineral character indicates similarity of age till otherwise proved.

HUNTINGTON,[7] in 1878, describes the region about the headwaters of the 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. Going across the stratification are places where 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.

SHALER,[8] in 1889, describes the rocks of mount Desert. The island consists of a central mass of hornblende-granite and a succession of sedimentaries on the north and south sides. About the massive core are the following series: The Sutton island series of highly metamorphosed clay-slates, quartzites, bedded felsites, and associated traps; the Cranberry island series, essentially the same as the Sutton island series, with many beds of volcanic ash; the Schooner head series of contorted argillaceous schists, shales, and the associated injected rocks; the Bar harbor series of thick-bedded flaggy slates and associated bedded felsites and quartzites, with numerous injections of igneous rocks; and the Bartletts island series of contorted schists, with frequent beds of quartzites, which often assume a gneissic aspect with the associated injections of igneous rocks. The great central mass of granite is said to be essentially a dike. In approaching the central granite the amount of granitic dike injections in the sedimentary series greatly increases, and in the sedimentary rocks are found numerous dikes of granite. No two of the various sedimentary series are found superimposed upon each other, although there are at least a half dozen series which are regarded as representing different parts of the geological section. The aggregate thickness of the various sections is not less than 6,000 feet and may be one half more than this. The great part of mount Desert rocks are referred to the lower part of the Cambrian section, although the volcanic rocks of Cranberry island resemble deposits of similar nature at Eastport, Maine, which seem to be of Silurian age.

LITERATURE OF NEW HAMPSHIRE.

JACKSON,[9] in 1841, in a general consideration of the geology of the state, states 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 eruptions of trap dikes, as is shown by the manner in which they cut each other.

JACKSON,[10] 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 metamorphosis of the sedimentary deposits by igneous action.

ROGERS, (HENRY D. and WM. B.),[11] in 1846, states 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,[12] in 1848, maintains that in the White mountains are numerous localities where fragments of slate are included in the granite 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,[13] in 1877, give a full account of the geology of New Hampshire. Hitchcock divides the pre-Paleozoic rocks of the 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. Contained 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 in ascending order, as follows: (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 Moto 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 imbedded 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 quite a 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 upon 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 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 which are of Cambrian age, which dip away from them both to the east and west, because the Labrador series is present, and because fossiliferous Helderberg strata are found on both the east and 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 west 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 east 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-schist; (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 upon 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 Pawtuckaway, 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, as, 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, from the base upward, is, 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 and 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 Merrimack, 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 doubtful Paleozoic is placed at 11,600 feet thick; 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,[14] 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; there are granites filling well defined dikes; there are granites which so far as can be seen are entirely devoid of structural relations; there are 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 the stratification of the gneiss is then 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,[15] 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, (CHAS. H.)[16] 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,[16] in 1890, with the same facts before him gives an exactly opposite interpretation to Hitchcock, that is, that the central granites are younger intrusive masses.

LITERATURE OF VERMONT.

ADAMS,[17] 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, 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 north part of Madison county. The Taconic system includes roofing slate, Taconic slate, Sparry limestone, magnesian slates, Stockbridge limestone, and granular quartz-rock.

ADAMS,[18] 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,[19] in 1847, gives additional details as to the rock occurrences in particular localities.

THOMPSON,[20] 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),[21] 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, Rhode Island, East Wallingford and Plymouth, Vermont, 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; they are indented deeply into each other; they are sometimes a good deal bent; they are cut across by parallel joints and fissures. At times the process has gone so far as to merge the pebbles together, and as to 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 their edges are what have been regarded as folia. If the process of flattening was carried a little farther no evidence would remain that they were ever pebbles. How extensively the process has been carried through, thus producing schists and gneisses from conglomerates in the Green mountains, is unknown. No examples have been found of decided pebbles in a gneiss.

At Whately, Massachusetts, on Ascutney, and at Barnet and Granby, Vermont, 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, Massachusetts, 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 if we are not mistaken 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 grounds 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 be possibly 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 the cases of subsequent thorough alteration exceptional. The theory of the Laurentian age of the Azoic rocks of New England and that 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, (CHAS. H.),[22] 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 quite a 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),[23] in 1861, considers in detail the relations of the granitic to the other rocks and considers 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, Massachusetts, and Ascutney, Granby and Barnet, Vermont, which contain fragments, are described in detail. These may be described as conglomerates whose cement is syenite, or a syenite through which is scattered pebbles mechanically rounded. Generally the pebbles are 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, 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 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 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 both in the stratified and unstratified rocks.

THOMPSON,[24] 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, (CHARLES H.),[25] in 1861, gives detailed descriptions of sections in Vermont. The relations of the Ascutney syenite to the stratified rocks is again described. Upon examining the ledges immediately contiguous to the granite, most powerful marks of alteration by heat are found. Everywhere in approaching the syenite it is surrounded from a quarter to half a 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.),[26] 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 the fragments which are there contained have been caught from the strata cut. As evidence that the granite has been thrown up since the mica-schists were formed are cited the facts 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 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 imbedded in masses of granite, and retain the characteristics of the slates, without any essential change. Nodular granite, containing masses imbedded like plums in a pudding, run from Memphremagog lake through Derby, Browningtoh, Irasburg, Craftsbury, and Calais.

HITCHCOCK (CHARLES H.),[27] in 1868, gives the following succession for the rocks of Vermont: Unstratified rocks, including granites, syenite, protogine, 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,[28] 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,[29] 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 not capable of being formed from aqueous solution or by metamorphic action.

LITERATURE OF MASSACHUSETTS.

HITCHCOCK (EDWARD),[30] in 1818, divides the Primitive rocks of a section of Massachusetts on the Connecticut river into syenite, granite, argillite, alternating with mica-slate, siliceous slate, and chlorite-slate.

DEWEY,[31] 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 the 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,[32] 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),[33] in 1823, describes granite as occurring at many localities in the region contiguous to the Connecticut river. It sometimes shows a tendency to stratification, which at Southampton is in beds in the mica-slates, at Bellows falls 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, primitive 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° to 90° to the east. At Hatfield, by following up the syenitic ridge, a rock is found which contains numerous imbedded masses of other primitive rocks, and these imbedded fragments are almost uniformly rounded and are often 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,[34] 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 more 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,[35] 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 oftentimes 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),[36] 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 are greenstone, porphyry, syenite, and trap, each of which is discussed. Among the agents which have consolidated the rocks heat is the predominant one, 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 forms 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),[37] 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 is 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 which have been changed to their 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, is cut by veins of other rocks, but is regarded as generally regularly stratified.

At Whately occurs a peculiar conglomeratic syenite. The syenite 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 each other in age. These are as follows: The Oldest Meridional system, the Northeast and Southwest system, the East and West system, 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,[38] 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 the graphite metamorphosed organic material.

ROGERS,[39] in 1857, describes Trilobites belonging to the Paradoxides as occuring 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.),[40] in 1859, describes the rocks from Greenfield to Claremont, Massachusetts, 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 dips as far as the West Shelburne falls gneiss are to the east; at this latter point it is to the west. The whole is regarded as an anticline.

GREGORY,[41] 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,[42] in 1866, gives the following section at the base of South mountain, at Chester, Massachusetts, 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 the 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,[43] 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 they all may eventually be found to be a part of the same series of beds as the Braintree. The slates have a perfect cleavage in the plane of stratification in some places. Over both the slates and conglomerates are outflows of amygdaloid.

JACKSON,[44] 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,[45] 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 to be 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, as crystalline rocks are found later than the Stockbridge limestone; as quartzite changes into mica-slate, schist or gneiss, these into hydromica-slates, and these into chloritic mica-slate.

HUNT,[46] 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 the 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,[47] 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 the Merrimac river, supposed to contain Eozoon, are not true stratified rocks, but are subsequent deposits of a vein-like character. As evidence of this are cited the facts that 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 not more than 220 feet in length, the widest part being 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,[48] 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. While 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, 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.

Among 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,[49] 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 sometimes 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 only been found at Braintree. The argillite of Kents island and the metamorphic slate of Newport are also regarded as Paleozoic.

BURBANK,[50] in 1876, lithologically divides the formations of the Nashua valley into (1) argillite; (2) mica-slate and quartzite; (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 overlie the gneiss, and the argillite beds appear to be for the most part conformable with the mica-slate.

DANA,[51] 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,[52] 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,[53] 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 (although it contains no labradorite), as older than the Huronian, 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 uncrystallines, 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, in the granite at many points at the contact with the mica-slates are found angular fragments of the latter. 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 is 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 different troughs which rest unconformably upon the older series.

DILLER,[54] in 1881, describes the felsites and their associated rocks north of Boston. The granite is found to contain fragments of distinctly stratified rocks, and is regarded as an eruptive rock. The felsites are found to have all the microscopical characteristics of eruptive rocks; to cut both the stratified rocks and the granites; to show no transitions into the clastic rocks, and are regarded as eruptives. The diorites contain distinct fragments of the granites and felsites, cut across the bedding of the stratified quartzites and schists, and are eruptives of later age than the granite and felsite. The framgental rocks are in part older and in part younger than the felsites, as a portion of them is cut by the felsites while certain conglomerates contain fragments derived from the felsites.

WADSWORTH,[55] in 1882, states that the Quincy granite is eruptive, as is shown by the fact that its junction with the slate is irregular. Along the contact the latter rock is greatly indurated and changed in color, and the granite has lost its distinctive characters, being transformed into a spherulitic quartz-porphyry.

WADSWORTH,[56] in 1882, describes as a trachyte at Marblehead neck and having all the characteristics of this eruptive rock, a rock which Crosby has described as a sandstone or arenaceous slate.

WADSWORTH,[57] in 1884, describes the relations of the argillite and conglomerate of the Boston basin. At the junction of the two the argillite is found to be irregularly eroded and the conglomerate laid down unconformably over it; in places the argillite is cut off and the conglomerate abuts unconformably against it, and pebbles of the argillite are found in the conglomerate at the junction. There are at least two distinct argillites. One, underlying the conglomerate at Beacon street, resembles that of the Paradoxides argillite at Braintree; the other, of a coarser grain, oftentimes a true sandstone as far as its relations have been ascertained, is a component part of the Roxbury conglomerate. So far as any evidence is at hand, the oldest surface rocks in the basin are the argillites and schists. Of these the age of only a small area at Braintree carrying Paradoxides is known. Through the schists and argillites have been protruded immense quantities of eruptive rocks in the forms of lava flows, ashes, dikes, and bosses.

PERRY,[58] in 1885, states that the mica-schist at Worcester contains a coal seam, and bears fossils of Carboniferous age. The mica-schist is cut by granite.

JULIEN,[59] in 1887, describes the succession of rocks in the Great Barrington, from the base upward, as consisting of Stockbridge limestone, schist or gneiss, quartzite, and dolomite. The proof that the dolomite occupies a distinct bed at a higher horizon from the main sheet is clear.

EMERSON,[60] in 1887, describes the succession of crystalline rocks in Hampshire county, in order of their age from the base up, as gneiss, feldspathic mica-schist, hornblende-schist, hydromica-schist, and calciferous mica-schist. Granite and syenite are placed as eruptive rocks of the older series.

CROSBY,[61] in 1888, maintains that there are no Carboniferous beds in the Boston basin; that it contains essentially one formation of conglomerate and one formation of slate; that these sediments include the Paradoxides bed at Braintree, are conformable, and therefore are Primordial or at least of Cambrian age; that the conglomerate underlies the slate. The pebbles of the conglomerates are made up of crystalline rocks of the regions adjacent. The contacts of the conglomerate and felsite are always well defined, and fragments of the latter are always contained abundantly in the former. The same relations hold between the granites and conglomerates. The conglomerates and slates have often a well developed cleavage, which frequently cuts across the bedding, although in places where the folding has been intense the two correspond. The discordance is shown by bands of the conglomerate cutting across the cleavage.

SHALER,[62] 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.

EMERSON,[63] in 1890, describes the Bernardston series of rocks. The succession is here found to consist of fourteen members. From above downward 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 of 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 batholites. 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 batholites 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 batholitic 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 contain 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.

PUMPELLY,[66] 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 synclinal 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 white gneiss are traced into each other laterally, and are therefore but different forms of a sediment of the same age, and unequally metamorphosed. Across the valley the Hoosac phyllite was traced by gradual transitions 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 synclinal, while Hoosac mountain is an anticlinal overturned toward the west. At the ends of the Hoosac ridge the anticlinal bends nearly to an east and 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,[67] in 1889, gives a systematic account of the geology of Hoosac mountain. The rocks of the region are thoroughly crystalline, but little trace remains of their original elements, whether of detrital or of eruptive origin; but the bedding corresponding to their original planes of deposit is well marked, and under proper conditions the order of succession can be determined. The basement rock is a coarse granitoid banded gneiss, which forms the base of the Hoosac mountain proper. Crushing and development of new minerals makes 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 between coarse gneisses similar to the basement gneiss; finer grained banded gneisses; gneisses with but a small amount of mica; metamorphic gneiss-conglomerate; ordinary quartzite-conglomerate and quartzites. These phases pass into each other 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 and distribution of the pebbles 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.

The next member of the series is the Hoosac schist, which conformably overlies the Vermont formation. In this schist no recognizable clastic element is found. The minerals appear to have formed contemporaneously. This schist is often coarsely crystalline, yet it is very similar to the albite phyllites of Germany.

The next rock found is the stratified limestone, which occurs in the Hoosac valley, where it is in contact with the Vermont formation and the Hoosac and Berkshire schists. The rock is generally an impure, coarsely crystalline white marble. Layers of quartzite are frequent in the limestone and the change from one to the other is gradual. Also, there is in some sense a transition between the Stockbridge limestone and Vermont gneiss, and also a transition between the limestone and Hoosac schist. There also occur certain dark colored rocks interstratified with and in one case cutting the others, amphibolites. Detailed descriptions are given of the occurrences at the various districts.

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 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 anticlinal of Hoosac, consisting of the Stamford gneiss, Vermont formation and Hoosac schist, has a pitch to the northward of from 10° to 15°, while the western side has been overturned, which makes the beds in inverted order on the west side. The whole northern third of the region and a broad strip along the east is occupied with albite-phyllite. In the district south of Cheshire and that of Hoosac valley the Stockbridge limestone and Vermont quartzite are found to be conformable, and the latter lower in horizon, as shown by contacts, lithological passages and the corrugations of the two together; the quartzite-conglomerate of the Vermont formation is identical with the fine grained white gneisses of the Dalton-Windsor area and to those of Hoosac mountain; and the schist area of Hoosac mountain is conformable with the quartzite and white gneiss series of Hoosac valley. The Hoosac valley schist and limestone appear to be conformable, although contacts are wanting.

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. The two in a general way appear to be conformable, but in one place an undoubted dike runs in a straight line through the granitoid gneiss, but abuts against the quartzite without passing into it; and the quartzite has a curious thickening of its layers where the dike joins it, as though there had been a hollow owing to erosion of the dike before the deposition of the quartzite. It seems, therefore, to show the most perfect unconformity between the granitoid gneiss and the overlying quartzite, although the structure of both rocks is parallel. Excepting the granitoid gneiss and the amphibolite, if the rocks are simply the Cambrian and Silurian limestones, sandstones and shales, altered by metamorphism, as they appear to be, the transition ought to be traced to the unaltered forms toward the Hudson. An examination of the rocks of Greylock suggests that the metamorphism is in general in accordance with this idea eastward, and also perhaps downward.

As a result of the work it is concluded that the gneisses of the Green mountains are just as capable of stratigraphical investigation as the unaltered sediments of the Appalachians, only the problem is much more difficult, owing to the secondary structures produced by metamorphism.

DALE,[68] in 1889, gives a systematic treatment of the structural and areal geology of Greylock. The rocks are all metamorphic and of few kinds, crystalline limestone and various schists. The key to the structure is in the distinction between cleavage foliation and stratification foliation. The phenomena of cleavage and stratification as studied on Greylock lead to the adoption of the following structural principles: I. Lamination in schist or limestone may be either stratification foliation or cleavage foliation, or both, or sometimes, in limestone at least, "false bedding." To establish conformability the conformability of the stratification foliations must be shown. II. Stratification foliation is indicated by: (*a*) The course of minute but visible plications; (*b*) the course of the microscopic plications; (*c*) the general course of the quartz laminæ whenever they can be clearly distinguished from those which lie in the cleavage planes. III. Cleavage foliation may consist of: (*a*) Planes produced by or coincident with the faulted limbs of the minute plications; (*b*) planes of fracture, resembling joints on a very minute scale, with or without faulting of the plications; (*c*) a cleavage approaching slaty cleavage, in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible. IV. A secondary cleavage, resembling a minute jointing, occurs in scattered localities. V. As ascertained by Pumpelly, the degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications. VI. The strike of the stratification foliation and cleavage foliation often differ in the same rock, and, as suggested by Pumpelly, are then regarded as indicating a pitching fold. When the fold is horizontal the two are parallel. VII. Such a correspondence exists between the stratification foliations and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

There are large areas, sometimes half a mile square, where the only foliation presented by the outcrops is of secondary character and where no trace of stratification can be detected. As the cleavage foliation in some places coincides with the stratification foliation both in strike and dip, in others agrees in strike while differing in angle of dip, and in still others differs both in strike and dip, and, furthermore, as the marks of stratification are not infrequently subject to purely local changes, the whole matter is attended with much difficulty. As a rule the most reliable structural data on Greylock have been obtained from outcrops where two different beds were in visible contact, or from a series of related outcrops in all of which both cleavage foliation and stratification foliation were equally manifest and discordant, or else from large surfaces of rock at right angles to the strike where the general trend of the minor folds could be distinctly seen. As a result of a large number of observations the difference in angle of dip between the cleavage foliation and stratification foliation was found to be from 10° to 120°. When the difference is over 90° the direction of the two dips is opposite. The absolute dip of cleavage in a large number of cases is almost universally to the east. Also, there is lack of conformity in the strikes of the cleavage foliation and stratification foliation.

Early in the work attention was directed by Pumpelly to methods of detecting the pitch in the axes of folds. It is usually determined by observing the pitch of the axis of any part of the fold. The correctness of the method seems to be verified by the general parallelism which exists between the minute and general structure of the rock masses, and also by the opposite direction of the pitch as determined at the extreme ends of the mountains. An application of these principles to Greylock shows that the range consists of a series of more or less open or compressed synclines and anticlines which, beginning near North Adams, increase southerly in number and altitude with the increasing width and altitude of the schist area, and then, from a point about a mile and a half south of the summit, begin to widen out, and to diminish in number and height until they finally pass into a few broad and low undulations west of Cheshire. Between that point and the villages of Berkshire and Lanesboro the folds become sharper and more compressed and the schist area rapidly narrows, terminating within a short distance of Pittsfield.

Mount Greylock, with its subordinate ridges, is then a synclinorium, consisting at the surface of eleven synclines alternating with as many anticlines, but in carrying the sections downward they are resolved into two great synclines with several lateral and minor ones. There are five more or less distinct lithological horizons in the Greylock mass.

Beginning above, the succession and correlations, with the classifications of E. Emmons, James Hall, Dana and Walcott, are as follows:

Horizons, natural order.	Lithological character.	Thickness.	Age.			
			Emmons, 1855.	Hall, 1839–1844.	Dana, 1882–1887.	Walcott, 1888.
		Feet.				
V................ (Upper schists.)	Muscovite (sericite), chlorite and quartz-schist, with or without biotite, albite, magnetite, tabular crystals or lenticular plates of interleaved magnetite and chlorite; ottrelite, microscopic rutile and tourmaline. These schists are rarely calcareous or graphitic.	1,500–2,200	Pre-Potsdam. Lower Taconic No. 3, "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
IV................ (Upper limestone.)	Limestone, more or less crystalline, generally micaceous or pyritiferous, passing into a calcareous mica-schist or a feldspathic quartzite or a fine-grained gneiss with zircon and microcline or a schist like V and III. The more common minerals are: graphite, pyrite, albite and microscopic rutile and tourmaline. More rare: galena and zinc-blende.	600–700	Pre-Potsdam. Lower Taconic No. 3, included in "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
III................ (Lower schists.)	Muscovite (sericite) chlorite and quartz-schist, with or without biotite, albite, graphite, magnetite; frequently with tabular crystals or lenticular plates of interleaved magnetite and chlorite; garnet; (ottrelite?); microscopic rutile and tourmaline. These schists are in places calcareous, especially toward the underlying limestone.	1,000–2,000	Pre-Potsdam. Lower Taconic No. 3, "talcose or magnesian slate."	Trenton (Hudson river).	Lower Silurian.	Trenton (Hudson river).
II................ (Lower limestone.)	Limestone, crystalline, coarse or fine; in places a dolomite, sometimes quartzose or micaceous, more rarely feldspathic, very rarely fossiliferous. Galena and zincblende rare. Irregular masses of iron ore (limonite), associated sometimes with manganese ore (pyrolusite). Some quartzite.	1,200–1,400	Pre-Potsdam. Lower Taconic No. 2, "Stockbridge limestone."	Lower Silurian. (Trenton and lower.)	Lower Silurian.	Trenton (Trenton, Canadian, Chazy, calciferous).
I................ (Quartzite.)	Quartzite, fine grained, alternating with a thin-bedded, micaceous and feldspathic quartzite. (The latter with calcite, pyrite, tourmaline.) Associated with these quartzites, and probably at the base of this horizon, is a coarse grained micaceous quartzite (tourmaline) passing, in places, into a conglomerate, and containing blue quartz, feldspar (plagioclase, microcline) and zircon, all of clastic origin.	800–900	Pre-Potsdam. Lower Taconic No. 1, "granular quartz."	....	Cambrian (Potsdam).	In part Lower Cambrian (Olenellus).
	Total thickness: Minimum........ Maximum........	5,000 7,200				

LITERATURE OF RHODE ISLAND.

JACKSON,[69] 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, gniess 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 are perfectly sharp.

COZZENS,[70] in 1843, finds that the section on the island of Rhode Island, from the base up, includes granite, serpentine, black slate, graywacke, black slate, Rhode Island coal and diluvium.

JACKSON,[71] in 1859, maintains that the pebbles of the Newport conglomerates in their present condition were mechanically formed by being rolled upon beaches, often the distortions and indentations being accounted for in this way.

HITCHCOCK (CHAS. H.),[72] in 1861, describes the lower rocks of the island of Aquidneck, in ascending order, as (1) talcoid schists, and conglomerates with red jasper pebbles; (2) the 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,[73] 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 is possibly due to wave motion or to the contraction of the conglomerate in cooling from a heated state. The chronological order and thickness of the series is in ascending order as follows:

	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
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
Total	5050–5300

LITERATURE OF CONNECTICUT.

SILLIMAN,[74] 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,[75] in 1832, describes the succession from Killingly to Haddam as consisting of gneiss, granite, syenite, mica-slate, hornblende-slate, 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 beds.

MATHER,[76] in 1834, divides the rocks of Connecticut into gneiss, hornblende-slate, mica-slate, granular feldspar, granular quartz, syenite, granite, 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 so. The limestone occurs in beds from 1 to 20 feet thick, embraced in the contorted gneiss in the northwest part of Stonington.

PERCIVAL,[77] 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 the 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 fact as to 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, limestone. The formations as a whole present a series of parallel ridges which have a general curvature with a 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, micaceous and chloritic rocks. In one of the granitic formations the arrangement consists of a central nucleus of granite-gneiss surrounded by narrow concentric ranges 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 were observed of series of granitic, micaceous, hornblendic and various other formations. The trap rocks occurring in the primary and secondary formations are so near 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,[78] 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.

GENERAL LITERATURE.

DANA,[79] in 1877, maintains that the conformable succession in Berkshire county, Massachusetts, 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 gneiss which are believed to represent transitions from sand deposits to mud deposits in the old seas.

HITCHCOCK, (C. H.),[80] 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 is 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,[81] 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 belong 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,[82] 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 one another through the low regions, cross the Taconic line, and prove the two 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 synclinal. The limestones which constitute the lower part of the Taconic system contain fossils, which designate it as 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 synclinal. Mount Washington is a synclinal of the same kind, which dies out to the south with a multiplication of small subordinate flexures.

HITCHCOCK (C. H.),[83] 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 from above downward are as follows:

	Feet.
Calciferous mica-schist and Coös 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
Total thickness	77,000

The various groups are classified according to stratigraphical and not lithological reasons. Unlike rocks are never assumed to be identical. If a hornblende-schist and clay-slate dip toward each other they are assumed to be of different age and 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 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.),[84] 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, Bristol and Clarksburg, Massachusetts, 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, 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 stratigraphical column. The gneisses are regarded as older than either the Cambrian or Huronian. The pre Silurian rocks of New Hampshire are classified as follows:

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.
		Coös group.
		Clay slates.
		Mount Mote conglomerate.

The 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,[85] in 1886, places the Georgia formation, which is found to contain the Olenellus, in the middle Cambrian, and the Braintree series of Massachusett bearing the Paradoxides fauna is placed in the Lower Cambrian.

WALCOTT,[86] 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 a 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.

WALCOTT,[87] in 1889, after a consideration of the Cambrian fauna reverses the position of the Georgia and Braintree horizons, placing the latter as Middle and the former as Lower Cambrian.

SUMMARY OF RESULTS.

In this discussion no attempt will be made to consider in detail the structures worked out by the various authors in individual districts, but rather to indicate the general character of the results which have been reached.

It is plain that the knowledge of the pre-Cambrian structure of the New England states is in a very unsatisfactory condition. Even in such a district as that of eastern Massachusetts, including the Boston basin, there is the greatest diversity of opinion, a district which one would naturally expect would have been systematically studied and certain results reached. In western Massachusetts, where the most elaborate of the older surveys has been made, the rock successions given from time to time and the correlations with other series have varied greatly. These areas are particularly mentioned because most studied. What is here true is still more emphatically the case with the remainder of the region.

While, then, systematic work in the New England states is but fairly begun, one great structural fact is clearly apparent, that large areas of rocks which have commonly been regarded as pre-Cambrian are proving to be Cambrian or post-Cambrian. This is most marked in western Massachusetts, where the recent work of Dana, Pumpelly, Dale, Wolff, Emerson and Walcott has established the conclusion that the pre-Cambrian rocks are confined to small areas. The results reached in this district show that it will not do to call the crystalline rocks pre-Cambrian and the uncrystalline ones post-Cambrian, a principle clearly recognized by Adams and the elder Hitchcock many years ago. Over large areas mica-slates, mica-schists and evenly granular gneisses have been demonstrated beyond all question to belong to the Cambrian or post-Cambrian. If in the remainder of New England the pre-Cambrian rocks shrink in proportion as they have done in the districts closely studied, they will not occupy more than a fraction of the area usually assigned to them.

If it be true that a very large proportion of the New England rocks which have been supposed to be pre-Cambrian are really Cambrian or post-Cambrian, it is evident that the reference of them to the Montalban, Norian, Huronian, Laurentian, etc., is wholly unwarranted. In the districts already referred to where definite knowledge is available many of the rocks before referred to these various series are being divided into two classes, sedimentary and igneous, and are being distributed from the Cambrian to the Carboniferous.

As yet it can not be positively said of any district that the pre-Cambrian rocks can be subdivided upon a structural basis, although recent unpublished results by Pumpelly and his assistants in the Green mountains indicate that it may be possible to do this in the future.

This New England region is one of great interest as being the first in which it was clearly shown by structural work that fragmental rocks pass over into crystalline schists. The descriptions by the elder Hitchcock of the way in which the schist-conglomerates at various points pass over into mica-schist in which no trace of the pebbles remain are remarkably like those given many years later by Reusch, the chief difference being that in the latter case partly destroyed fossils were found in the semicrystalline rocks. Hitchcock's summary of the evidence for the production of completely crystalline schists from fragmental rocks over extensive areas, published in 1860 in the Vermont reports, is demonstrative in its nature. The case could hardly be put more forcibly at the present time, except by the additional evidence derived from microscopical structures.

One of the most interesting differences of opinion has been as to the origin of the granite and its relation to other rocks. The elder Hitchcock believed that the granites and syenites are produced by the aqueo-igneous fusion of the sedimentary beds, that they have usually not moved far, and thus represent older stratified rocks. Locally it was recognized that they have become fluid and have intruded the adjacent rocks, showing all the characteristics of an ordinary eruptive. The term metamorphic was made to cover this once fluid material. Along the contacts of the granite with the slates and schists, at various localities were found many rounded fragments which were taken as evidence of the metamorphic origin of the whole, the matrix being regarded as completely fused and the fragments as residuary bowlders which had resisted the process of metamorphism. Stevenson and Marvine interpreted like facts in the Rocky mountains in the same manner. These relations are precisely the same as those described by Lawson between his Laurentian granite-gneiss and the clastic series northwest of lake Superior. The latter writer, however, declines to carry the term metamorphism over to the final product and regards the granite-gneisses along the contact zone containing fragments of the adjacent rocks as irruptive ones, the fragments being caught in the fluid material rather than being a residual unfused substance. The emphasis is then thrown upon the intrusive character of the granite-gneiss, a position less consonant with the theory of subcrustal fusion than that of Hitchcock, Stevenson, Marvine, and Winchell. An objection to the acceptance of this theory of the origin of granite and granite-gneiss is that it is one that is not easily verifiable. As soon as a rock becomes liquid it does not longer reveal the source of the material, and the conclusions that it has not moved far and has been produced by the fusion of the adjacent rocks is an unproved and perhaps unprovable assumption.

By Crosby the granites which cut other rocks are placed as the older; this conclusion follows from the hypothesis that the granites are metamorphic. If they intrude overlying rocks they must have been produced from a more deeply buried series and are hence older. Most geologists interpret these relations to mean that the granite is a later intrusive rock. By Shaler the lamination of the minerals in the syenites and granites, and particularly the more distinct lamination of the exterior parts of the exposures, is regarded as unquestionable evidence of sedimentary origin. Jackson, among the older geologists, has steadily maintained the essentially igneous origin of the granites and syenites. Hawes was the first, however, to clearly study from the modern point of view the granites and granite-gneisses and to show that the lamination of the latter is not necessarily an evidence of original bedding, and that such a structure may appear in an igneous rock as well as in a sedimentary one. It is only since the recent work of Pumpelly and Emerson that it has been generally appreciated that there are two classes of granites in New England. These geologists have shown that in western Massachusetts is a granitoid gneiss, which beyond all question antedates the Cambrian rocks and has yielded débris to them. While this is the case, the greater mass of the granites are far later in age, some of them ranking in time as late as the Carboniferous. Frequently the masses are so large as to metamorphose the sedimentary beds about them by contact or dynamic action, or more probably by both, producing the concentric schistose structure so early mentioned by Percival and so fully described by Emerson.

By the early advocates of metamorphic granite a massive form was regarded as evidence of the completed process and of the great age of the granite. In any given granite the age of which is not known, from the modern point of view, its perfectly fresh granular form, or an even lamination of mineral constituents which results from crystallization under ordinary circumstances in great beds or masses, bears rather toward its late formation; while the contorted and foliated granitoid gneisses, because of their structures, show that they have undergone repeated powerful dynamic actions, and consequently are more likely to be ancient rocks.

The "diorite-schists," "amphibolites," "metamorphic diorites," and similar schistose rocks described even by Hawes as metamorphic, probably belong for the most part with the other greenstones, which have almost universally in late years been placed with the eruptives. These schistose phases are more ancient than the massive forms or have been subjected to more intense metamorphism.

While it was early recognized by most geologists that slaty cleavage and foliation may cut across the bedding, it was generally assumed that cleavage and stratification foliation correspond. As early as 1842 Percival so clearly saw the danger of this course that he states that he prefers to use the term parallel instead of stratified in describing the structures of the crystalline rocks as expressing the fact of the arrangement of the minerals without implying any opinion as to the mode of formation. Hawes, in 1878, states that the granite-gneisses in their affinities are like the eruptive granites, the lamination being an induced structure which may or may not correspond with bedding in case they are completely metamorphosed material. He, however, includes among the metamorphic rocks diorite, quartz-diorite, and amphibolite, since they have marked distinctions from the fresh basic rocks recognized as eruptives. From the assumption that cleavage foliation and stratification generally correspond have probably resulted more mistakes than from any other cause.

The cautious work of Adams, the elder Hitchcock and Percival in correlation is noticeable. Adams preferred to call the rocks of Vermont Azoic, referring to their present state, and specifically saying that many of them might prove quite late in the fossiliferous series. The same course is followed by the elder Hitchcock, who says that probably most of the Vermont rocks will prove to be later than the Laurentian of Logan. Percival, in Connecticut, carefully described the rocks as they occurred without attempting to give any succession or to correlate them with other rocks. The building up of successions upon insufficient data and crude correlations is mainly the work of later men.

The work of Dana, Pumpelly, Emerson, Dale, Wolff, and Walcott in the past decade marks a new epoch in the study of the crystalline rocks of New England. The complexity of the problem has been for the first time appreciated. It has been seen that the old method of making a few sections wide apart across a district, and bringing the discrepancies into harmony by assumptions, wherever necessary, of inversions and faults, and making correlations of formations with those of distant regions because of lithological likenesses, can lead only to conclusions worse than valueless.

In applying the new method of work, as exemplified in western Massachusetts, it has not been assumed that a rock stratum is the equivalent of another stratum in a different locality. In order to establish equivalence it is necessary that the two be actually traced together, or else that unquestionable fossil evidence be found. Instead of assuming that stratification and cleavage foliation correspond, the assumption has been rather that they usually do not correspond and that nothing can be taken as bedding which can not be demonstrated to be this, as, for instance, the contact planes of two formations, such as quartzite and limestone or one of these with schist. Instead of building up a structure from a few sections wide apart, all sources of information have been sought; every outcrop was visited; the information furnished by artificial excavations was utilized; full suites of specimens were collected, and all the light which can be furnished by the modern petrographical methods has been brought to bear upon the problems. Finally, a more careful search for fossils has revealed their presence in rocks so crystalline that former search has resulted in failure. In this study Pumpelly, besides using these and other well known principles, has formulated new ones. These are:

(1) The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides. (2) When the strike of the stratification foliation and cleavage foliation differ in the same rock, this is regarded as indi-

cating a pitching fold. (3) Such a correspondence exists between the stratification foliations and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

This author has further ascertained that apparent conformity, which sometimes exists between strata really unconformable, may be due to the disintegration of the earlier series.

Notwithstanding that advantage has thus been taken of all sources of information, the problems of the structure of western Massachusettts have been found so difficult that it has taken years of labor of a number of men to build up correctly the stratigraphical succession. The labor involved in this work and the relatively small size of the area covered show that before any accurate map of the whole of New England can be presented many years must elapse, although it may be reasonably hoped that, as experience accumulates, the application of the new method will proceed more rapidly than in the decade of its inauguration.

That the structural mapping of the crystalline rocks in New England is less extensive than in some other parts of America has not been due to a lack of ability or industry upon the part of the workers in this region as compared with those of others, but rather to the greater difficulty of the problem. This region is one in which repeated dynamic movements, accompanied by great outbursts of igneous material, have occurred until late in Paleozoic time.

SECTION II. THE MIDDLE ATLANTIC STATES.

LITERATURE OF NEW YORK.

PIERCE,[88] in 1818, describes the nucleus of Staten island as consisting of steatite, which stamps the formation as Primitive.

AKERLY,[89] in 1820, describes a section running from Long Branch, in New Jersey, northward to New Marlboro, Ulster county, New York. 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, 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.

JESSUP,[90] in 1821, describes in Essex county, in the vicinity of lakes George and Champlain, rocks of the primitive class, including trap, syenite and carbonate of lime.

EATON,[91] 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.

EATON,[92] 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 limerock, sparry lime rock and primitive argillite, which are described as occurring at numerous localities. There are two primitive districts, that in southeastern New York and that west of lake Champlain, called Macomb mountains.

EMMONS (E.),[93] 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, 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,[94] in 1837, describes at the base of the Mohawk valley ridges of gneiss which are regarded as a prolongation of the northern primary chain. Upon the gneiss is found calcareous sandstone.

MATHER,[95] in 1838, mentions gneiss on Long island; granite and serpentine on Staten island; and granite, gneiss and granular quartz in the southeast part of Dutchess county. In the serpentine was observed a trap rock.

EMMONS (E.),[96] 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 vein-like 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,[97] in 1838, finds Primitive rocks in Montgomery, Herkimer and Oneida counties.

MATHER,[98] 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, 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,[99] 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 and 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,[100] 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 the 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 retains the structure of that rock with the mineral matter of limestone, but the pure limestone is in beds without stratification.

EMMONS (E.),[101] 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 greenstone dikes so prevalent in the hypersthene rocks.

EMMONS (E.),[102] in 1840, states that the 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,[103] 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,[104] 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),[105] in 1841, mentions primary limestone at lake Janet, gneiss at Long lake, and on Racket river hypersthene rock.

EMMONS (E.),[106] 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 rensselaerite. The stratified rocks include gneiss, hornblende, syenite, talc or steatite; the subordinate rocks include porphyry, trap, 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 dike-like forms and its association with eruptive rocks, the imbedded minerals being of such a character as would be produced by metamorphism. Also limestone produces a metamorphosing effect upon the minerals imbedded 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 the latter is concluded to have a probably 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,[107] in 1842, describes the primary system as occurring in the northern parts of Montgomery and Herkimer counties, the northeast corner of Oneida, 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; the first at the Noses on the Mohawk; the second at the little falls of the Mohawk; the third 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.

MATHER,[108] 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 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 Caldwells landing, and range south-southwest until they disappear beneath the red sandstone formation. The strike and dip of the rocks of this system are the same 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 position are the facts that the succession is the same; that both of these systems are superimposed upon the primary without any intervening strata; the unmodified beds are traced into those that are metamorphic; and the places where the rocks are most metamorphic are those where there are intrusives and have been upheavals.

Under the head metamorphic rocks are described such rocks as are not included in the foregoing, and which, while there is no demonstrative evidence of it, are regarded as originally sedimentary rocks, which have since been altered in their character so as to change them into such rocks as have usually been called primary. The metamorphic rocks are divided into two divisions, 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 proportion 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 Highlands are in a continuous range from Bennington in Vermont to the west 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 and 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 district, 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 imbedded 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 it would not be suspected as a limestone. Quartz is frequently found in it, transparent or translucent, with irregular, rounded forms, as if it had been partially melted. Many localities that I have 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 talcy 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 from 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 pre-existing 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.,[109] 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 the 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.),[110] 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. As 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 the 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 each other 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, greatly disturbed, and their relations with the underlying and overlying rocks are obscure, so that the true structure can only be ascertained by most careful examination.

CREDNER,[111] in 1865, states that the island of New York and the east 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, of serpentine, with layers of soapstone.

MACFARLANE,[112] 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.

STEVENS,[113] 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. At times it is distinctly separated and in others 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,[78] 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 era 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 conformability 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.

LEEDS,[114] in 1878, describes the rocks of the Adirondacks. They are found to be stratified rocks which belong in the Norian system, are composed of hypersthene and diallage, and labradorite with menaccanite.

DANA,[115] 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,[116] 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 do belong here. A part are Primordial.

NEWBERRY,[117] 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 and Staten Island rocks.

HUNT,[118] in 1883, describes near port Henry coarsely crystalline limestones in the highly inclined Laurentian gneisses, 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.

DANA,[119] 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.

HALL (CHAS. E.),[120] 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 eastward under the Silurian limestones.

BRITTON,[121] 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 northern end of the Lower Saranac lake. Norite occurs at Miller's hotel, about a mile distant.

JULIEN,[122] in 1886, states that the borders of the Adirondack region consist very largely of thinly bedded gneisses, especially to the eastward.

SMOCK,[123] 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 gneiss, granite, granulite, quartz-syenite, syenite-gneiss, and mica-schist chiefly. Between the quartzite and the gneiss, when they are seen close to one another, is a want of conformability. 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 railroad 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),[124] 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,[125] 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 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,[126] in 1887, describes the serpentine of Staten island as a stratified rock probably derived by the extensive alterations of limestones. This serpentine appears to overlie the crystalline limestones. These metamorphic rocks with the gneisses are regarded as Archean.

KEMP,[127] 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,[128] 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 divided into several divisions from the base upward, as follows: (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 unconformability between the Lower Silurian strata of Peekskill hollow, Tompkins cove, and Verplanks point with the partially metamorphic beds of the Manhattan group.

PUMPELLY, WALCOTT, and VAN HISE,[129] 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 rather a 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 also 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 pigmatite by powerful dynamic movements. In passing from Westport within a short distance appeared coarse gabbro, which continued as far as the region was penetrated, near 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,[130] 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 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 this is first found in small quantity, then appears more and more abundant, until finally it becomes predominant. At Bonaparte lake a contact of the gabbro with the limestone was found 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 upthrust and intruded itself 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 is doubtless due to the intrusion of the gabbro. 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.

LITERATURE OF NEW JERSEY.

VANUXEM and KEATING,[131] 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 Franklins to Dr. 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,[132] 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.),[133] 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, upon the whole, decidedly less 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° to the southeast, and 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 its crystalline character.

JACKSON,[134] in 1854, maintains that the New Jersey crystalline limestones are of igneous origin.

KITCHELL,[135] 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; exhibit violent dislocations; their general strike is northeast and southwest, the same as the intrusive dikes, and their dips 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 an angle varying from the horizontal to 45°. At one place limestone rests unconformably upon the gneiss.

COOK,[136] 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 inclined a good deal, but the dip varies from zero to 90°. The axes of the folds are generally in a northeast and 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,[137] 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,[138] in 1883, states that the rocks of the Highland 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 from 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 not probably true in every case, and the valleys are synclinal. The massive syenites, granites, and traps are very limited in quantity, and they 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,[139] in 1883, states that at Sparta granite cuts across the limestone beds and may be in true veins.

COOK,[140] 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,[141] 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 unconformability found, although at some places abrupt changes in the lamination have been observed within short distances. This leads to the conclusion that the massive beds are only so 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 and causing the quartzite to dip under the older rocks, and it is difficult to say where the line of separation is.

BRITTON,[142] 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 occur 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,[143] 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,[144] 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; 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, 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. Graphite is found to be 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 the 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 range of Ramapo mountains. Also, graphite occurs at other places.

NASON,[145] in 1891, describes the relations of the white and blue limestones of Sussex county, New Jersey. 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 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 that in this region there are no Archean limestones, as has been supposed.

LITERATURE OF PENNSYLVANIA.

FINCH,[146] in 1824, finds, near Easton, syenite, serpentine, and transition limestone, transition granite, transition clay-slate, and transition sandstone.

FINCH,[147] 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.),[148] 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 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 Fair-mount 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 of massive or thick-bedded gneisses, with which is no talcose slate, or else 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, dip to the southeast, and, as the breadth of the chain is so great, the structure is believed to be due to overturn flexures.

On 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 are Primal crystalline schists, or the Azoic group; Primal conglomerate; Primal older slate; Primal white sandstone, 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 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, and 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 passing southward on the Susquehanna the rocks become 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 over. 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,[149] in 1870, states that on the Germantown railroad, 3 miles from Philadelphia, in the micaceous schists are imbedded 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,[150] 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,[151] 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 over

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 unconformability between the older (Huronian?) orthofelsites and schists and the more recent (Cambrian?) sandstone, but it 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 hydro-mica schists and chlorite-schists. The felsite itself ranges from a sandy slate to a coarsely porphyritic rock.

HUNT,[152] 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,[153] 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,[154] in 1880, includes in the post-Eozoic series of Lancaster county calcareous argillites, nacreous slates, hydro-mica-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 nonconformability, the transition from one rock to the other being gradual and the line between them difficult to define.

FRAZER,[155] 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 Hudson river age as supposed, a difficulty is here presented.

HALL (CHAS. E.),[156] 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, 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 the 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,[157] in 1883, describes in the southern part of Northampton county the continuation 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 only be judged 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 they are comparable with the Laurentian system. Why they are not covered by Huronian or Cambrian rocks is not known. If the views of Hall are accepted that the Philadelphia belt underlies the Potsdam and overlies the Philadelphia syenites, it is hard to see why they do not appear between the Potsdam and 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 nonconformity. The syenite rocks underlie the limestones, which may represent residual material which 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. In contact with a dike of coarse granite near the south side of the gap the slates are changed into chlorite, mica-slate, and hornblende-slates, but in the coarser grits the original pebbles are seen.

HALL, (CHARLES E.) [158] in 1883, describes many localities of slates, gneisses, and granites in the South mountain area.

D'INVILLIERS,[159] 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 where 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.),[160] 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 the 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,[161] 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,[162] 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,[163] in 1889, describes a section of the crystalline rocks from the Triassic of Chester county, Pennsylvania, 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.

LITERATURE OF MARYLAND.

DUCATEL and ALEXANDER,[164] in 1834, describe the Primary rocks as one of the chief divisions. These include the following formations: Granite, gneiss, limestone, and serpentine.

AIKIN,[165] 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 greywackes interstratified with transition limestones.

DUCATEL,[166] in 1839, states that the limestones of Harford and Baltimore counties occur in the valleys. In the northwest 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,[167] 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 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 cases 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—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. In proceeding northwest mica-slate increases in quantity, and in passing still farther this mica-slate passes into talc-slate. The metamorphic limestones are found in two ranges; the first, the gneisses and mica-slates; and second, the talcose slates.

WILLIAMS,[168] 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,[169] 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,[169] 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 acid 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.

LITERATURE OF DELAWARE.

BOOTH,[170] 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 north 47° east, and the dip 70° northwest, but occasional bearings are found which differ widely from this, and the dip is vertical. The trap rocks have a dip and strike conformable with the gneiss and grade into them. 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,[171] 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 Centreville. 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,[172] 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 each other by imperceptible stages, and the two latter are regarded as a metamorphosed product of the former and all 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 mica-schists in Delaware county, Pennsylvania, 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 horizontally the eruptive character of the gabbros, gabro-diorites, and hornblende rocks is but the more evident.

GENERAL LITERATURE.

MARTIN,[173] in 1886, states that the Tide-water gneiss has mineralogical characters which distinguishes 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.

SUMMARY OF RESULTS.

The literature summarized clearly shows that in the central Appalachian area, as in the northern, only general certain results have been reached. While there are numerous areas of crystalline rocks, it is not clear that many are of pre-Cambrian age. The exceptions are the Adirondacks; the Highlands of New Jersey, with its northern extension the Highlands of New York, and its southern extension South mountain of Pennsylvania; and the eastern area of Maryland. A part of the northern extension of the Blue ridge is probably also to be here included.

The most widespread rock in the Adirondacks is a gabbro, which has all of the characteristics of this eruptive rock. The outer border of the mass has a well laminated structure, due either to original crystallization or to subsequent metamorphism. This rock is in all respects like the Labradorian or Norian of the Canadian survey, to which indeed it has been referred by the advocates of the Norian system. The bedded succession of gneisses, limestones, and quartzites is in nearly all respects like the original Laurentian described by Logan. While now it nowhere has indubitable clastic characters, its beds are such as to show that it was originally a sedimentary series. Since the series is not closely folded, probably the principal cause of its metamorphism is the great batholitic mass of gabbro occupying the core of the mountains, which seems to have thrust itself up among the clastics. Whether the coarse gneisses which underlie the limestones belong with the latter series or represent an earlier one, we have no knowledge. There is, then, in this district a possible pre-clastic series, which in its character, so far as seen and described, is like the fundamental complex, the true Archean; and a clastic series of great but unknown thickness which belongs with the Algonkian. That the Adirondack rocks as a whole are unconformably below the Potsdam has been unquestioned from the first.

The relations of the Highland area of New Jersey with the Potsdam sandstone are such as to make it certain that between them there is a great structural break. The rocks comprising this area consist largely of granite-gneiss, in general very nearly massive, but having a somewhat laminated arrangement of the mineral constituents. The strike of the lamination conforms closely with the trend of the area as a whole, being east of north and south of west. The gneisses over large areas are graphitic. Interlaminated with them are beds of iron ore, and apparently of crystalline limestone. They are cut by various basic and acidic eruptives.

The weight of opinion in former years has been in favor of the sedimentary origin of this gneissic series. Mather, who gave by far the best early descriptions of the district, and Nason, who has recently been closely studying the limestones of New Jersey, find that the white crystalline limestones which have been regarded as Archean grade into the blue limestones which are fossiliferous. These writers regard all of the white limestone as parts of a newer series which have been metamorphosed either as a result of extreme folding or by intrusive masses of granite of later date, with which they are frequently associated. If all of these limestones are excluded from the pre-Cambrian and this is a very doubtful assumption, the evidence in favor of the detrital origin of the Highland area is restricted to the widely disseminated graphite and to the magnetite beds of iron ore. Magnetite is widely associated with certain belts of the granite-gneisses of New Jersey, but this and its concentration in lenticular masses within the gneisses in the form of magnetite can hardly be considered as decisive evidence of their sedimentary character. The magnetites associated with the basal gabbros of the lake Superior Keweenawan are in purely igneous rocks. The graphite of the graphitic gneiss is a point of more weight. The absence of graphite as an important constituent over large areas in any definitely determined igneous granite-gneiss, bears in favor of the sedimentary origin of the gneissic series. If this theory proves true, the Highland gneissic series more nearly approaches the characters of a massive eruptive than any other metamorphic sedimentary rock known to the writer. Upon the whole, in the regularity of its lamination, in its lack of extreme contortion and foliation, and in the presence of graphite, the Highland gneiss is not like the fundamental complex, the genuine Archean of Canada and the West. However, there are no certain criteria upon which it can be referred either to the Algonkian or Archean. It must be simply classified, so far as present knowledge goes, as pre-Cambrian.

If it can not yet be decided whether the Highland gneisses are sedimentary the supposed structural divisions of Britton and Nason can be regarded as only lithological. Britton's arrangement of a massive group in the cores and schistose groups on the outer parts of the ranges can be as well explained, as has been repeatedly seen, by the eruptive theory of the origin of the series as by the sedimentary. From Nason's work it appears that certain varieties of rock have a continuous widespread distribution; but the descriptions show that his various types grade into each other instead of being sharply differentiated as supposed. Magnetite is the distinguishing characteristic of one type, and yet, in order to make out the continuity of this belt, rocks have to be classed with this type, in which hornblende and biotite are the chief basic constituents. The same thing is true of the second type, in which the hornblende, the distinguishing characteristic, is locally almost wholly replaced by magnetite or biotite.

Of the eastern Crystalline area of Maryland nothing can be said as to age, except that it is pre-Cambrian.

The work of Mather and Dana in eastern New York and on Manhattan island, the work of Emerson, Dale, Wolff, and Pumpelly in the adjacent district in Massachusetts, combined with the paleontological work of Walcott, show beyond all reasonable doubt that a considerable part of the crystalline area of southeastern New York, including in all probability Manhattan island itself and the so-called Taconics, belong with the Cambrian and post-Cambrian formations. The detailed evidence for this is rather for another to consider.

Various other crystalline areas in southeastern Pennsylvania, in Maryland and in Delaware, are in large measure metamorphosed Cambrian and post-Cambrian rocks, as shown by the work of Rogers, Hall, Williams, and Chester. There are also probably in these areas pre-Cambrian rocks, although often the gradations described between the gneissic series, supposed to be pre-Cambrian and the crystalline schists supposed to be Cambrian or post-Cambrian, are so complete as to leave the reader quite in doubt as to the reality of the break supposed to exist between them.

Among all the earlier writers on the crystalline rocks of the Middle Atlantic states, Mather is distinguished for the fidelity of his descriptions and for the keenness of his insight. While in his great New York report of 1843 there are some crude notions, the comprehensive general results announced accord to a remarkable degree with the views held by the best informed of the geologists who are working in this field to-day.

SECTION III. THE SOUTHERN ATLANTIC STATES.

LITERATURE OF THE VIRGINIAS.

CORNELIUS,[174] 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 westward.

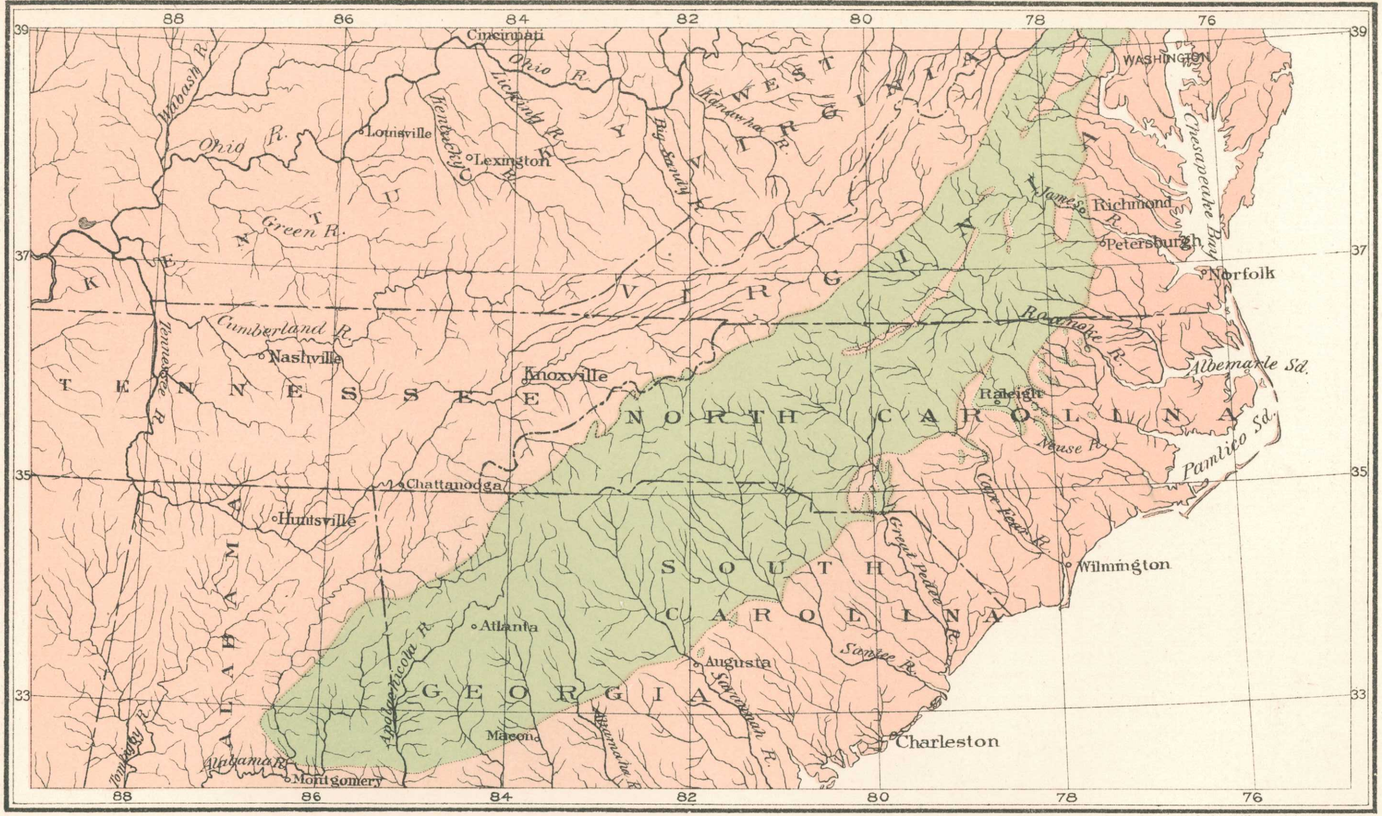
ROGERS (W. B.),[175] in 1840, describes the southern district east of the Blue ridge as occupied mostly by rocks of very ancient date, most of them believed to be primary. A part of them are in irregular masses, and others have regular stratification, but all are alike considered of metamorphic origin. 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 which compose them. The igneous rocks cut the shales and sandstones of the Middle Secondary.

ROGERS (W. B.),[176] 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,[177] 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,[178] 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, Massachusetts. 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 argillite apparently shows the latter to be Huronian, although its age is not positively determined.

CAMPBELL (J. L.),[179] 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.



UNCLASSIFIED PARTLY OR WHOLLY CRYSTALLINE ROCKS

POST-ALGONKIAN

GEOLOGICAL MAP OF THE SOUTHEASTERN STATES

SHOWING PRE-CAMBRIAN AND CRYSTALLINE ROCKS

After McGee and Hitchcock

Scale

CAMPBELL (J. L.),[180] in 1880, describes the metamorphic Archean rocks along the James river and Kanawha canal as including limestones, schists, and quartzites.

CAMPBELL (J. L.),[181] 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, 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 from the influence of heat 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,[182] 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.),[183] 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, and 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 northwest 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 northwest sides 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. As 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.),[184] 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,[185] 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.

LITERATURE OF NORTH CAROLINA.

OLMSTED,[186] in 1824, describes as parallel with the freestone and coal formations a great slate formation which extends across the state from northeast to southwest, being about 20 miles wide, 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 courthouse hardly any kind of rock but granite is met.

OLMSTED,[187] 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 is 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 non eare 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,[188] 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 their 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 occurs most of the gold mines.

MITCHELL,[189] 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 and 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.),[190] 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 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. 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 and 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 instrusive 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, and which often appears 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, in these cases, are the farthest removed from rocks of this description, and with which water has had nothing to do. The lamina 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 demarkation 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 and mica-slate and hornblende-rocks with laminæ parallel with them, but still 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. It might be doubted whether they were sediments at all were it not that they are associated with conformable pebbly beds, which is the only proof that these rocks are really sedimentary.

The Taconic rocks are divided into lower and upper parts. The lower series contains talcose slates with white and brown sandstones and quartz, with 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,[191] 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 southeastern corner of Clay county. This central area is the axis of the state and is composed for the most part of granitic and gneisses 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, [192] 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 two or three 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. These are that east of the Raleigh Laurentian, that between the Raleigh and Salisbury granite, that west of the Salisbury granite or King's mountain belt, that of the Blue ridge mountains, and that of 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 them 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 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. The western Huronian area by Safford and Bradley has been concluded to be Potsdam and sub-Potsdam. If this turns out to be Silurian it is probable that the Cherokee, Blue ridge, and King mountain belts are of the same age and therefore post-Huronian.

FURMAN,[193] in 1889, describes a section through King's 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.

LITERATURE OF TENNESSEE.

TROOST,[194] 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 greywackes, which are fossiliferous. The state line is approximately the dividing line between the crystallines and the fossiliferous rocks.

OWEN,[195] 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,[196] 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,[197] 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; 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, the 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, are mostly of the variety called gneiss or stratified granite, and all are metamorphic. 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 Laurentian.

BRADLEY,[198] 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, Georgia. The Silurian rocks thus include the Taconic and pyroclastic rocks of Emmons.

ELLIOTT,[199] 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.

LITERATURE OF SOUTH CAROLINA.

RUFFIN,[200] 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,[201] in 1848, gives a report on 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 each other 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,[202] in 1858, describes the rocks of 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 are 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,[203] in 1858, divides the rocks of Union and Spartanburg into a 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 southeast. 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,[204] 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. Toumey'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 are 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. 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,[205] 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.

LITERATURE OF GEORGIA.

PECK,[206] 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,[207] 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-slates. Gneiss also passes into the stratified mica-slate, and the mica-slate into talcose slate. The graywacke is the beginning of the transition.

LITTLE,[208] in 1875, mentions crystalline rock, presumably primary, at various points.

CAMPBELL (J. L.) and RUFFNER,[209] 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 sometimes left in a vertical position, and not infrequently 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 Archean is attributed to a fault, with a downthrow of the former.

LITERATURE OF ALABAMA.

TUOMEY,[210] 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,[211] 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,[212] 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 semicrystallines 15,000 to 20,000 feet in thickness.

SCHMITZ,[213] 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, is found the following zones, which, however, cannot be sharply separated. (1) *Silurian.*—Crystalline limestones, conglomerates, heavy quartzites, and slates (often gold-bearing), semi-metamorphosed. (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.

GENERAL LITERATURE.

BRITTON,[214] in 1886, describes at Natural bridge the contact between sandstones which appear to be under the Potsdam and over the Archean. The two are widely unconformable; the sandstone dips 45° to the northwest 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 the 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 the French Broad river are found quartzites like those of the Doe river, which are succeeded by basal crystalline rocks, and near Mare shall 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, New York, and Philadelphia gneisses to the basal rocks to the westward. These rocks extend to the top of mount Mitchell.

SUMMARY OF RESULTS.

The state of knowledge of the crystalline rocks of the southern Appalachians is in a still less advanced condition than that of the middle and northern Appalachians.

It is reasonably certain that from northern Virginia to Alabama there are large areas which are pre-Cambrian, including much of the granite and granitoid gneiss region. Not only this, but, if lithological characters are sufficient evidence, parts are Archean; that is, belong with the fundamental rocks of Canada and the West; for areas are found which consist of an intricate complex of foliated and contorted granite and gneiss cut by or containing masses of basic eruptives of various kinds. In their intensely implicated structure and lack of thoroughly massive characters they give evidence of vast antiquity.

How far the rocks which have been denominated Huronian belong with the pre-Cambrian there is no means even of guessing. It is very certain that large parts of the rocks called Taconic and Huronian are Cambrian, Silurian, or later. When the Cambrian and Silurian have been definitely outlined, whether any of the unmistakable clastics will remain to be correlated with the Huronian, or, more accurately, to be placed in the Algonkian, is uncertain.

The disturbances in the southern Appalachians are of a different type and, upon the whole, have been less intense than in the central and northern regions, as a consequence of which it will be easier to reach definite results here than it has been farther north.

The only really systematic work which has been done is that 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 wo granites, one of which is more ancient than the clastics and the ther intrusives within these. According to Emmons the ancient form s predominant, but occasionally granite has been projected through issures like other intrusive rocks.

The great discovery that regularly laminated rocks are produced by he metamorphism of eruptive rocks as well as from sedimentary rocks aturally carried the discoverer too far in the application of the princi- ple. Emmons included in the metamorphic igneous rocks many mica- chists, talcose slates, and limestones for which he gave no evidence vhatever. Lieber's discrimination between the metamorphic-igneous nd metamorphic-sedimentary rocks was much more satisfactory. But Emmons's general statements as to the small value of lamination alone n rocks as an evidence of origin and the method of stratigraphical vork in the crystalline rocks can hardly be improved upon at the pres- nt day. Says this writer: Rocks of igneous origin are often massive, but also are frequently laminated, and laminated rocks are frequently alled stratified, but this latter term should be restricted to the sedi- nentary rocks. The metamorphic rocks are excluded from the sedi- nentary classification because all rocks may become metamorphic, and stratum metamorphic in one locality may not be metamorphic in nother. The highest proof of the age of rocks is the order of super- osition. When this method can be applied it is paramount, but pale- ntology may be used subject to proper principles.

The Primitive rocks from Emmons's point of view are all igneous; vith aqueous rocks begins the Azoic, the oldest sedimentaries, and bove 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 sys- em. We have here a definite theory as to the order of development of he earth, the primitive rocks being wholly pyrocrystalline, the Azoic tratified rocks being earlier than the dawn of life, and the Taconic ocks being the fossiliferous rocks earlier than the Potsdam.

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CHAPTER VIII.

GENERAL SUCCESSIONS AND DISCUSSIONS OF PRINCIPLES.

SECTION I. LITERATURE.

MACLURE,[1] 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, white stone; and in the Transition, transition limestone, transition trap, graywacke, transition flinty-slate, transition gypsum. The rocks of the Primitive prevail to the east of the Hudson river. Throughout the greater part of the eastern and northern states the sea washes the primitive rock, but to the southwestward 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 and 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, granular lime rock. These primitive rocks are all contemporaneous, excepting the granular quartz and lime rocks, since they alternate continually. These rocks 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 comprises massive rocks, including granite, syenite, hypersthene, pyrocrystalline limestone, serpentine, rensselaerite, octahedral iron ore, and laminated rocks, including gneiss, mica-slate, hornblende, talcose-slate, etc., laminated limestone, laminated serpentine. The Pyroplastic rocks comprise Subaerial, including lavas, tufa, or volcanic products, and Submarine, including greenstone, porphyry, basalt, 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 recognized as classes, as they may occur in all series from the earliest to the latest sediments. That gneiss, mica-slate, hornblende, and 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 the contractions of these rocks fissures are formed, through which flow fluid material which are hydroplastic and later. The age of rocks may be deduced from the perfection of their crystalline state. The pre-eminently 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; one more ancient than the Taconic rocks, and others, which are later eruptions, certainly as new as the Carboniferous. In New England the ancient granites are widespread, but there are also found granitic areas which have been erupted from fissures and which have overflowed wide areas 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 must make up the matter which composes them; but a comparison of the lower members of the Taconic and the Silurian show 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; (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 East 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 left which 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 and 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 Laurentain 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.

In the Cambrian and Huronian system are found the rocks on the north shores of lakes Huron and Superior where are present a series of schists, sandstones, limestones, and conglomerates, interspersed with heavy layers of diorite, and resting unconformably 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 whose cracks are 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 which we have 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 two latter. 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, and 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, 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 the State of 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 30,000 feet, and probably much exceeds it. 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 as now. 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 there 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 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 the presence of recognizable organic forms resembling Stromatopora.

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

Under the name of Laurentian terrain, the Geologic 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 Geologic 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 afterwards 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 terrain 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 gneiss, 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, to the 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 terrain 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 terrain 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 terrain 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 of *Eozoon canadense.*

The Lower Laurentian terrain 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 terrain. The beds of the Upper Laurentian also are upraised at high angles, but the structure of this terrain, which has evidently undergone part of the movements that affected the lower, has not yet been studied. The lower terrain 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 of Huronian terrain is designated a series of rocks, more or less altered, resting unconformably on the Lower Laurentian terrain, and probably also on the Labradorian terrain. This series is composed of quartzites, of more or less chloritic or epidotic schists, sometimes with impure serpentines, and with 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 terrain comprises, moreover, a band of about 300 feet of granular limestone, which is impure and often very siliceous. The Huronian terrain on lake Huron has a thickness of about 18,000 feet. It is also found on the Ottawa, and from there it extends to the west of the Mississippi, though covered in large part by Paleozoic terrains. 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 there the existence of rocks that have been referrèd to this old terrain, which for the rest seems to correspond to the primitive schists (Urschiefer) of Scandinavia. No fossils have yet been found in this terrain. Considerable masses of schistose hematitic iron ore are inclosed in this Huronian terrain 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 terrain 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 means something, or probably so, with respect to Laurentian rocks, but it did not until the age of the rocks, in their relations to others, was first stratigraphically ascertained. It may turn out to be worth something as regards later rocks when the facts have been carefully tested by stratigraphy. A *fossil* is proved, by careful observation, to be restricted to the rocks of a certain period before it is used—and then cautiously—for identifying equivalent beds. Has any one *proved* by careful observation that crystals of staurolite, kyanite, 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 the first life began to exist. 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 mountains series, embracing 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, 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 laws which come out of the comparison of these exposures are, that, 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, secondly, 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 upon petrological grounds. The first type consists of quartz, orthoclase, an unimportant amount of plagioclase, and muscovite, with a small quantity of microscopical apatite. These are all west of Reese river, longitude 117°. These 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 any of 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 clew as 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 alliances 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 neither parallelism 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 the other strata which were deposited horizontally and afterwards 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 under-dip 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. Into 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 Gaspé; (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 formations respectively 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, both in the crystalline and fossiliferous rock, there is no doubt 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 on to 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 only possible to distinguish them or to define their respective limits 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, or at any rate 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,[14] in 1884, states 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, then 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 writer has no hesitation in asserting that it has, as such, no existence in Canada, its theoretical birthplace. Wherever these Norian rocks have been observed they are either 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 in such constant alternations, 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 such a condition as were 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 of the "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 examinaion, 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, are 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 only be separated into subsystems on purely lithological grounds; if they are fossiliferous, as held by the Canada survey, then 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 debris 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 the 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 has been 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 debris 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 debris 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 both in 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 neecssarily 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 debris 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 which 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, 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 the state of 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 the 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, 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, i. e., 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 they include a considerable content of volcanic crystallines, they are nevertheless 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 are not only 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 have unconformably placed beneath the Cambrian, here developed with 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 has 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; 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 matter of genuine 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 the existence 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 equal to or greater in volume than the Paleozoic. For this place is suggested the term Agnotozoic, but some of the writer's colleagues prefer the more noncommittal term of Eparchean, signifying simply the position of these formations upon the Archean.

The following table shows alternative arrangement suggested by the above:

Systems.	Groups.	Systems.
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 of Upper Laurentian was for some time given by Logan to the terrane designated afterward as 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 with an anorthic feldspar base, to which the name norite has been given. This terrane, however, includes intercalated beds of gneiss, quartzite, and crystalline 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 mineralogic 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, also 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 red 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 lithologic 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 of 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 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 as gneissic mica-schist or as 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 under the titles of argillaceous schists, or, rather, lustrous, talcose, micaceous, and sericitic (silk-like) schists. Associated with these schists are also found quartzites, statuary and Cipolino marbles, with dolomite, karstenite, and sometimes amphibolic rocks and serpentines, 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 of "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 found 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 for the rest appears diamond-bearing, was described in 1859 by Lieber under the name of 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 of Upper Taconic. Long studies have convinced the author that this upper division is entirely in-

dependent 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 for that matter 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 of 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 Prof. Kerr, in North Carolina, to refer the latter terrane to the Huronian terrane. In the vicinity of lakes Superior and Huron, too, where the Laurentian, Norian, Arvonian, Montalban, and Taconian terranes are found all at once, the outcrops of the latter 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 of Animikie series. Only later did he recognize the fact that this series, which in certain localities rests unconformably on the Huronian terrane, is only 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 of Keweenaw group, a term which he in 1876 converted into that of 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.

BELL,[20] 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 those 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 such a vast 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,[21] 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 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 a 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 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 such ancient date and which have undergone such 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 Cambrian is a great unconformity. Between the Animikie and Nipigon and the Nipigon and Potsdam are probable unconformities.

WALCOTT,[22] 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 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, Texas; 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, a fragment of what appears to be the pleural lobe of a segment of a trilobite, and an obscure, small Hyolithes, in a layer of bituminous limestone. In layers of limestone, still 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 known of it prove little of its character, but they prove that life existed in a period far preceding Lower Cambrian time, and they foster the hope that it is only a question of search and favorable conditions to discover it.

DANA,[23] 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 æon, as it has been called, or that of liquidity.

II. The Azoic æon, 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 Archæozic æon, 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 Archæozoic time, and this is all in the way of correlation that can be said. 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 Archæan terranes.

SECTION II. GENERAL DISCUSSION.

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, including under it in a general way 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. It was nearly universal in 1820 and 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, and has not yet disappeared. 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 definitely defined by Foster and Whitney in their application of it to the lake Superior rocks and the Azoic was held by them to be strucurally indivisible. While the rocks of the Primitive and Azoic were early subdivided into lithological divisions there was little or no attempt to apply stratigraphical 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. They found in different places in Canada pre-Cambrain 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 upon 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 afterwards 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 as 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 series now known as Keweenawan and Animikie. 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 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 systems, 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 of any names for designating the ancient rocks.

If Logan and Murray departed in their later work from strict scientific methods in their use, 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 as 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 series Huronian; others regarded metalliferous rocks as the important feature of the Huronian.

Lying at the root 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.

As to the relations between the Laurentian and Huronian, it was plainly believed by Logan, Murray, and the other early geologists that where the two come in contact they are unconformable, although oftentimes the structural relations which obtain are admittedly obscure. That was the position of the present director of the Canadian survey as late as 1879, who used the term Huronian not only to include rocks that had been theretofore placed, but to cover all of the Upper Laurentian and the Upper Copper-Bearing series, thus greatly expanding the system. In recent years he has held that the Huronian and Laurentian are always conformable, and that often the former grades downward into the latter, and this is the position which has been taken by many geologists of the United States, both in the East and in the West.

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 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, it was recognized by a number of geologists 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 advantage of a theory of origin was avoided, but in common with Primitive and Azoic it was not 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 it was thought by many 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, and retains a place in literature to the present time. 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 acid 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 perfectly massive rocks, such as diabases, gabbros, granites, etc., among the metamorphics. Recently the term has also been applied to rocks recognized as laminated eruptives, but this is not the use referred to. This 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 have been applied to formations or series in order to avoid any theory of age or correlation. The most conspicuous example of this kind is that of the Keweenaw series of lake Superior. More recently Lawson has proposed the terms Keewatin and Coutchiching for certain series northwest of lake Superior, and to include these two he proposes the Ontarian system. In the Grand canyon the local names Chuar, Grand canyon, and Vishnu have been applied to pre-Cambrian series which there occur. Comstock has proposed the terms Burnetian, Fernandian, and Texian for series which are found in Texas.

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

Recently Irving has proposed that there be placed below the Paleozoic group another group of coordinate value, for which the term Agnotozoic or Eparchean is suggested. This term cuts out of the Archean a large class of rocks which have before been here included. Finally, the name Algonkian has been brought forward by the United States Geological Survey for a systematic place opposite Agnotozoic or Eparchean.

In the following discussion, as stated in the introduction, Cambrian is defined as extending downward to the base of the Olenellus fauna. The pre-Olenellus clastics and their equivalent crystallines are called Algonkian, and the completely crystalline rocks below the Algonkian are denominated Archean. The reasons for these usages will appear in the following pages. The stratigraphical terms, group, system, and series correspond with the usage proposed by the International Geological Congress. The same is true of the chronological divisions, era and period. Formation is a lithological subdivision of a series.

THE CHARACTER OF THE ARCHEAN.

From the review of the literature it is plain that there is an essential unity in the character of the complex of rocks which is the oldest known in America. This statement covers all the areas in which the rocks are demonstrated to be exceedingly ancient. It includes the basal complex of Arizona, between which and the Tonto sandstone is a clastic system 15,000 feet thick, separated into three series by unconformities, and these again separated from the Tonto above and the basal complex below by great unconformities; it includes the basal complex of the Wasatch and certain of the ranges of Nevada, between which and the Olenellus Cambrian is a great unconformity and a thick series of quartzites; it includes the basal complex of southwestern Montana, between which and the Olenellus Cambrian is 12,000 feet of unaltered slates and a thick series of crystalline rocks of clastic origin, the two being probably separated by a great unconformity; it includes the basal complex of Texas, between which and the Cambrian is an unconformity, at least one and perhaps two thick series of clastic rocks; it includes the basal complex of the lake Superior region, between which and the Cambrian is an enormous system of clastics many thousands of feet thick, separated by unconformities into three series, and the whole bounded above and below by unconformities; it includes the basal complex of the north shore of lake Huron, between which and the Cambrian is a clastic series 18,000 feet thick, bounded above and below by unconformities; it includes the basal complex of the original Laurentian area, between which and the Cambrian is a clastic series estimated to be many thousands of feet thick; it includes the basal complex of Hudson bay, between which and the Cambrian are almost certainly two, and perhaps three series of clastics separated by unconformities; it probably includes the basal complex of Newfoundland, between which and the Olenellus Cambrian is a series of clastics 12,000 feet thick, and above this a great unconformity; it includes much of the great area of northern Canada known as Laurentian, between which and the Cambrian in various districts are clastic series.

In all of these regions in which the basal complex is vastly older than the Cambrian, it consists of a most intricate mixture of nearly massive rocks, among which granite and granite-gneiss are predominant; of gneissic and schistose rocks, all of which are completely crystalline, and so folded and contorted that nowhere has any certain structure ever been made out over considerable areas. The granites and basic eruptives may occupy considerable areas; the gneisses may be regularly laminated and grade into the granites; the crystalline schists may occupy the outer zones of an area; they may all be confusedly intermingled, schists, gneisses, and granites alternately predominating; sometimes the schistose rocks appear in dike-like forms in the granites; at other times the massives are in dike-like forms in the schists; at still other times the alternations of granite, gneiss, and schists are quite uniform and persistent for considerable areas. The granites usually show a rough lamination, which may not appear in hand specimens, but which is evident in large masses.

The minerals in the rocks generally show evidence of dynamic action; they do not have the clear cut, definite relations characteristic of the later plutonic rocks. In the chief mineral constituents of the rocks there is essential uniformity in all of the areas, although certain less common minerals may be found in one area which have not been discovered in another. Orthoclase and acid plagioclase feldspar, quartz, hornblende, muscovite, and biotite are the standard minerals. To describe accurately the appearance of the rocks of the basal complex is exceedingly difficult, but any one who examines a series of specimens from the various areas will perceive the truth of the statement made as to the essential likeness of the rocks from different regions. A suite from any one of the regions which has been personally examined by me, if unlabeled, could by no possibility be asserted not to come from any other.

The unparalleled intricacy of the structure of this complex, the general laminated arrangement of its parts, and the broken and distorted forms of the constituent minerals are evidence of repeated dynamic movements of the most powerful character. Further, the basal complex is not only recognized by its positive but by its negative characters. Nowhere in it is a persistent thick formation of quartz-schist (although vein-quartz is abundant), of limestone or marble, of a graphitic schist, or of a conglomerate. If sandstones and limestones or other sedimentary materials have been a part of this system the profound and varied mutations through vast lapses of time have wholly obliterated all evidence of their presence.

Besides the areas mentioned in which these most ancient rocks occur, there are many other areas in which there are between the Cambrian and the basal complex great series of clastic rocks, although the evidence at hand in favor of vast age for the basement complex is less than in cases before cited. Here are included the Front range of Colorado, which has between the basal complex and the fossiliferous rocks on its eastern slope the clastic series of Boulder, Coal, and Thompson creeks; and the Quartzite mountains of Colorado, where between the basal complex and the Carboniferous is a great series of quartzites. There is definite structural evidence for placing these and other areas with the group first considered. In a third class of areas no definite evidence in the nature of intervening series shows that between the Cambrian and the basal complex has intervened an era or even a period.

Because of the unique lithological character of this fundamental complex in all these regions, and because of the essential likeness in structure prevailing, we have ground for grouping these rocks together, whether exactly of the same age or not. Lithological arguments for correlation may be well distrusted; but the exceedingly strange, varied, and complex lithological and structural characters of this system, the like of which we have no evidence has been duplicated anywhere in later times, is an argument of great weight. In the complexity of its parts and the implications of its structure it gives evidence of vast antiquity.

In Algonkian, Cambrian, Silurian, Devonian, and even later times, completely crystalline schists have been produced over large areas; but, while often in these systems no evidence now remains of clastic characters, they rarely if ever closely resemble this fundamental complex. A clastic series was in the beginning of its history of necessity a shale, a sandstone, a limestone, a chert, or some other form of sediment and often containing carbonaceous material. Cementation, metasomatism, dynamic action may have profoundly changed any of these deposits. A limestone may have been transformed into a crystalline marble, or if impure into a hornblende schist containing scarcely a remnant of original carbonate. A cherty carbonate of iron may have become an actinolite-magnetite-schist. Carbonaceous shaly material may have become a graphite-schist, but if such a rock is represented in the fundamental complex what has become of the carbon? A sandstone may have become a granular quartzite or a foliated micaceous quartz-schist. But that a great quartzite formation like those of the Huronian of lake Superior or the pre-Olenellus of the Wasatch can have become wholly obliterated by any process short of fusion is almost inconceivable. As has been said, none of these rocks are found in this fundamental complex throughout its whole vast area. In its positive as well as its negative qualities it is a unit. While it can not be considered demonstrated that all of its area are of the same age, it may then be accepted that in North America is a system of granites, gneisses, and crystalline schists which are the oldest rocks of North America, and which have representatives in many areas throughout the United States, although most widespread and abundant in Canada. That such a basal system exists is no new idea; but it has not generally been recognized that between it and the Cambrian there elapsed an era in which were alternating cycles of the deposition of systems of rocks and of vast erosion intervals.

As here used the term Archean is restricted to this fundamental complex. It is no longer possible to regard as a unit or treat together all the pre-Cambrian rocks. The rocks included in the fundamental complex are everywhere called Azoic or Archean. The crystallines and semicrystallines above this complex, often called Archean, must be distributed from the Devonian or later to the pre-Cambrian. It is clear that if Archean is to remain a serviceable term it must be restricted to some unit. Such a unit is the fundamental complex, and to it this term is most appropriate.

ORIGIN OF THE ARCHEAN.

As has been shown, whatever the origin of the Archean, it is of vast age. It will be remembered that south of the lake Superior region, where is known the greatest volume of pre-Cambrian clastics, there is abundant evidence showing that the lowest of the clastic series has derived its débris from and rests upon the foliated edges of the Archean. In the Arizona region, in which the time of the pre-Cambrian clastics is only inferior to that of the lake Superior region, the evidence of a great hiatus below these clastics is of the most decisive character. The same may be said of several of the other areas of Archean. Consequently in many regions the Archean complex, in essentially its present condition, may be asserted upon definite structural evidence, to be vastly older than the Cambrian.

As to the origin of the Archean rocks, three different views are prominent: (1) The Archean has been considered as metamorphosed detrital rocks; (2) it has been considered as igneous, but later in origin than certain of the pre-Cambrian clastics with which it is in contact; (3) it has been considered as igneous and representing a part of the original crust of the earth, and therefore earlier than any sedimentaries. A modification of this theory is suggested under the topic Delimitation of the Archean.

(1) Those who believe in the detrital origin of the Archean, as above defined, will not question the conclusion reached as to the age of the fundamental complex; for to produce results so different from any known metamorphic clastic series must not only imply great age, but probably sediments which were originally deposited under different conditions from those of later times. This school, while believing in the detrital origin of the Archean as a whole, is conscious that it has been cut again and again by eruptives of all kinds; that the supposed clastics have thereby been profoundly metamorphosed by contact and dynamic action, and often have been so changed that the place can not be pointed out where the intrusives end and the clastics begin.

If this sedimentary view of the origin of the Archean be correct, as no universal break in geological continuity can be accepted, it should be found that between the Archean and the clastics there are somewhere gradations. It has been seen in the summary of the literature that Hitchcock, Marvine, Stevenson, King, Winchell, and others, accepting such a sedimentary origin, believe gradations have been found in the Rocky mountain system, in the lake Superior region, and in the Appalachians, between the basal complex and the recognizable clastics. These authors have regarded the fact that as a whole these rocks show lamination as evidence that they were originally sedimentary. A few years ago it was a matter of course that distinct lamination in a rock, however faint, is evidence of sedimentation. Lamination being found in the granite-gneisses, combined with the fact that these rocks graded into the clastics, was taken as conclusive evidence of the original sedimentary origin of the whole.

It is now everywhere recognized, as early shown by E. Emmons and Lieber, that schistose structure is often produced in eruptive rocks; also like structures are produced in sedimentary rocks which have no relation to the original lamination, as early noted by Tyson, E. Emmons, Blake, Adams, E. Hitchcock, Jackson, Jukes, Rogers, and Lieber. E. Hitchcock, E. Emmons, and Lieber traced the actual gradations between schist-conglomerates and crystalline schists, while Mather traced the blue fossiliferous limestones into completely crystalline granular marbles. Laminated or schistose structure in crystalline schists then bears neither for not against a clastic origin.

The manner in which the finely laminated schists and gneisses vary into the coarsely granitoid phases has been admirably described by Jukes in the rocks of Newfoundland, by Lieber and E. Emmons in the rocks of the southern Appalachians, by Hitchcock in the rocks of Massachusetts and Vermont, by Marvine and Stevenson in the rocks of Colorado, by King, Hague, and S. F. Emmons in the rocks of the fortieth parallel, and by Lawson in the rocks about lake Superior. Most of these writers and many others, including Selwyn, approaching the problem from the side of the clastic rocks, have regarded the coarsely crystallized rocks as produced by metamorphism, although in the more granular rocks the process has gone so far as to produce aqueo-igneous fusion. Those who have maintained this origin for these rocks have recognized the fact that they have locally acted as eruptives, although in general the material is thought not to have moved far. Marvine so clearly saw that the facts could be explained in two ways that he says that, while he regards the whole as metamorphosed sedimentary rocks, another observer approaching the field from a different direction, where the evidences of intrusive nature are most manifest, would reach the conclusion that the whole is eruptive. Hitchcock and Stevenson and most of the others are in practically the same position.

The school of geologists that regards massive rocks as metamorphic without any intervening time of fluidity, the granitic and gneissic layers interlaminated with the schistose being selectively metamorphosed, and the fragments of schist and gneiss within the massive rocks as residual unmetamorphosed material, while nearly gone, still has representatives. That the matrix of a fragmental rock could become slowly heated to such a temperature or be subject to such other conditions as are necessary in order that it should crystallize as a coarsely granular granitoid gneiss or granite, and not at the same time destroy the bowlders and pebbles which it contains, seems incredible. The explanation of these rocks and of the interlaminations of granite with slate and schist by metamorphism implies not only that the fragments and the bands of slate and schist have been able to resist the forces of change during the slow processes which have been sufficient to produce coarsely crystalline material adjacent, but that in situ they have continued to resist these forces during all the time required by the matrices to pass once more into ordinary conditions. The processes embodied in such "selective metamorphism" certainly need explanation.

The need of an exact definition of metamorphism is evident. It appears to the writer that it should not be applied to a rock which has actually suffered igneous fusion. Shall it apply to sedimentary material which has been free to recrystallize under aqueo-igneous fusion? May not rocks under pressure beyond the crushing strength of rocks and saturated with hot water recrystallize at a much lower temperature than is required for ordinary fusion? If so, where is the boundary between aqueo-igneous and ordinary fusion? Is there not a transition between the two and does not aqueo-igneous fusion pass by imperceptible steps into ordinary metamorphism? Is there not here a transition between the extremes just as there is between different rock species, between basic and acidic rocks, between organic and inorganic sediments, between fragmental and crystalline rocks, between aqueous and surface igneous rocks.

(2) All or a part of the Archean is considered as of igneous origin, but later in age than the pre-Cambrian clastics. The facts of those who have described downward gradations from unmistakable clastics into a crystalline complex by this school have not been interpreted as above. It has declined to apply the term metamorphism to a product which has become fluent, and has insisted upon its essentially igneous character. Lawson is conspicuous as having recently strongly put this side of the case; but it is noteworthy that Winchell, belonging to the first school, and Lawson, to the second, have had essentially the same facts before them, both having done their work in the same region. The difference is one of definition and emphasis rather than ideas. Both schools regard the granite-gneiss as material which has resulted from a change in the condition of original sediments and has not moved far.

This theory that the Archean or a part of it is the liquefied floor of the clastic rocks has the objection that it is an unverified hypothesis. When once a sedimentary rock has become fluent and is wholly free to crystallize anew how shall the material be identified? To state that such material has not moved far is pure assumption. If the fusion theory is true the average composition of the unfused part of the clastic series and the subjacent material should agree. To obtain average analyses of rocks which vary widely in mineral character within short distances is not easy, but is a thing which must apparently be attempted if this theory is to be maintained, for the writer sees no other way in which an attempt can be made to verify the hypothesis.

Another class of geologists, noting these contact relations between the granitic rocks and the clastics, hold that the former, called by others Lower Laurentian or Archean, are eruptives of later age than the clastics with which they are in contact, without attempting to give any theory as to the source of the material. Here are included Hawes, Hall, Mather, Foster, Whitney, Wadsworth, Rominger, Herrick, and others. Rominger distinctly recognized the granites and granite-gneisses of this kind on the south shore of lake Superior as the subjacent rocks upon which the schists rest. Herrick saw the same relations with reference to his granitic and schistose groups on the north shore. In the last two cases the facts before the writers are precisely the same as those of the geologists of the second school; but, by giving no explanation of the source of the material for the granite-gneisses, they have escaped the difficulty of the unverified assumption that these eruptives represent fused sediments. They fail to explain what has become of the floor upon which the clastics are deposited. Some floor they must have had. Where these eruptive contacts are found the floor has disappeared, and if so the eruptives, if extraneous, must be considered to have eaten up or absorbed it.

The three positions, that the granite-gneiss is selectively metamorphosed material, is due to subcrustal fusion, or is an extraneous intrusive, may be considered to grade into each other. Those who insist on the first have selective metamorphism and contact phenomena to explain. Those who insist on subcrustal fusion may be called upon to identify their material. They can only show the former fused condition by contact phenomena, and contact phenomena are not evidence of progressive fusion, but intrusion. Those who regard the granite-gneiss as intrusives may be asked what has become of the floor upon which the clastics were deposited.

(3) That the Archean is an igneous system earlier than any of the sedimentaries is apparently the conclusion of Emmons, Lieber, and others. These careful observers not only maintained the igneous origin of the granite-gneiss of the southern Appalachians, but traced the gradations between basic schistose rocks and massive eruptives, including hornblende-schist and unmistakable dikes, and drew the correct conclusion, lately regarded as a new discovery, that such rocks are sometimes

metamorphosed eruptives. While the major portion of granite-gneiss and associated rocks were considered older than the oldest clastics, later intrusives of a similar character were recognized. This theory that the fundamental complex is igneous is that of Geikie as to the major part of the Archean of Great Britain and that of many German geologists as to the basal complex of Germany, among whom Lehmann and Roth are conspicuous. Indeed, these last two maintain the igneous origin of all the pre-Cambrian rocks, and Geikie says of the true Archean of Great Britain that with certain possible exceptions it not only contains no material which gives any evidence of ever having been sedimentary material of any kind, but it further contains no material which can be considered a surface volcanic, while in it there are many rocks which are certainly plutonic eruptives.

The geologists of this third school, with the second school, recognize the igneous character of the granite-gneisses having irruptive contacts with the clastic series, but they decline to recognize these rocks as Archean. Such rocks are eruptives. Their age is to be designated precisely as are eruptive rocks which cut Cambrian, Silurian, or Devonian strata.

As bearing in favor of the really igneous character of the Archean is the fact that no case has been demonstrated, except possibly that of the marbles, of the production of a perfectly massive crystalline rock from a clastic without intervening fluidity. Metamorphism, whether the original rock is a massive eruptive or a stratified sedimentary, produces a laminated or schistose rock. If a granitic structure can be taken as evidence of eruptive origin, and we know many eruptive rocks do have such a texture, a very strong case can be made for the eruptive origin of the larger part of the fundamental complex. The line of argument is precisely analogous to that by which the whole has been held to be sedimentary. There are complete gradations from the most completely schistose and laminated phases to the most massive phase. Also bearing in favor of a truly igneous character for the basal complex is the fact that the rocks referred in the first part of this section to the Archean are more nearly simulated by igneous rocks which have irruptive contacts with ancient clastics than by any recognizable metamorphosed sedimentaries. In this connection may be mentioned the occurrences in the Appalachians and in British Columbia of relations between granitic rocks and strata as late as the Carboniferous or Triassic, analogous to those which often prevail between the granite and granite-gneiss and the pre-Cambrian crystalline schists. Here the one class of rock is known to be sedimentary, the other intrusive. It may be said that the actual gradations between the Algonkian and Archean in certain places are evidence that the latter are not igneous rocks earlier than the former; that gradations can be explained between subsequent intrusives and clastics, but not between igneous rocks and sedimentaries of later age. It has, however, been shown that as a consequence of powerful dynamic action two unconformable series, the one of which is composed of material from the other and therefore resembles it in composition, may have developed conformable secondary structures and gradations, the latter consequent upon the induced crystalline character of the clastic series, the original structures being simultaneously obliterated. Also recently Pumpelly has ascertained that subaerial disintegration of the earlier series is an important assistance in the production of such gradations. In certain areas it has been demonstrated that perfect conformity and complete gradation exist between series separated originally by wide unconformities, the earlier of which was probably of igneous origin while the later was certainly sedimentary.

Whatever the origin of the fundamental complex, it is plain that the parts of any given area of it are not all of the same age. The dikes which everywhere cut it are the pipes through which have passed the later eruptives. At the time of the intrusion of these eruptives, large lakes of liquid material may have formed which crystallized as bosses, causing the Archean to contain considerable masses of rocks of really later age. Where these rocks are predominant the material must be classified as a later eruptive; where they are subordinate to the Archean material they are often difficult to separate from it although really later in age. Between the areas which rank as eruptives of later age and the genuine Archean, there are doubtless gradations. Along the zone of contact, if the mass of later eruptive be great, there might be an area which could equally well be placed with the fundamental complex or with the later eruptive. Between the Archean and later eruptives, as between the Archean and undoubted sedimentaries, there are gradations.

The problem of the relations of the Archean as a whole to the overlying clastics is the same as that within the Archean itself. The finely laminated crystalline schists and gneisses, and the granite-gneisses and granites with which they are associated, have contacts in every respect analogous to those occasionally found between the Archean complex and the clastic series. For example, it has been seen that the rocks heretofore called Archean on the north shore of lake Huron comprise two parts. One part is older than and lies unconformably below, yielding fragments to the original Huronian. The other part has relations with the clastics of the character just considered with transition phenomena. If this material is an extraneous intrusive it is a post-Archean eruptive. If in situ it represents a portion of the pre-Huronian floor completely metamorphosed by selective metamorphism, or by aqueo-igneous fusion, it can fairly, according to the first and second school, be called a part of the Archean.

It is plain from the great diversity of opinion as to the origin of the Archean rocks, and from the fact that many of the opinions are beliefs rather than verified conclusions, that we have no definite knowledge upon parts of the subject. That there are comparatively few or no wholly massive rocks in this complex is precisely what would be expected under any theory. Its history is too long. Whether originally igneous or aqueous, it could not be hoped that there would be found the characteristic lithological forms of igneous or aqueous agencies. Many or all of these rocks, not only subject to the movements which have taken place since Paleozoic time, but to the movements which have occurred in the far greater length of previous time—if not too deeply buried to be beyond the influence of the outer foldings, in which case they were buried beyond the crushing strength of rocks—were latently plastic, and were probably at a high temperature. If originally massive and igneous in the ordinary sense, dynamic action has obliterated the regularity of the arrangement of the constituent particles and has given them a more or less laminated or schistose structure. If sedimentary, all trace of that original sedimentary structure has been obliterated by the repeated foldings, contortions, and perhaps high degree of heat to which they have at various times been subjected. Of a necessity, through this complex have passed all subsequent eruptives. Doubtless at various places and times in its history, parts of it have become practically fluid and from this condition it has again crystallized in the forms characteristic of eruptives.

DELIMITATIONS OF ARCHEAN.

It is generally accepted that the Archean has no limit downward. It is the oldest system, and surely includes, if such rocks exist, all of the original crust of the earth. But as denudation progresses, material far within the earth approaches its surface, not by intrusion but by gradually rising as a whole. Before reaching the surface the material has become crystallized. This original crystallization may have taken place in or even later than Algonkian time; hence, if these rocks are to be considered as belonging to the age in which they crystallized, the Archean grades below into the Algonkian, even as it is believed in places to grade above into the Algonkian. The truth of this position is not lessened by the fact, if fact it be, that the earth as a whole, subject to sudden strain, acts as a rigid body. Even if true, it is equally certain that the crust of the earth, under continued strain, adapts itself to it, thus showing real plasticity. But in any case it can not be assumed that the rock material deep within the earth, under pressure far beyond the crushing strength of any known material, and at a high temperature, exists as crystallized minerals. We only know that it has these forms when the material rising by erosion nears the surface.

The upper limit of the Archean is not easy to define, and the task is rendered more difficult because geologists are not agreed upon the origin of the Archean. If either the sedimentary or the subcrustal fusion theory of its origin be accepted, there will be found gradations from rocks constituting the ancient complex described to rocks having like relations with clastics of Algonkian and post-Algonkian time. Upon either of these theories, if sedimentary rocks are only buried deep enough, they will pass into crystallines by progressive metamorphism or by subcrustal fusion, just as do rocks of Cambrian and post-Cambrian age. This the elder Hitchcock so clearly saw that he distinctly said that the so-called Laurentian granites and gneisses of Vermont are probably, in part at least, not older than the fossiliferous series. If the Archean be made to include all the thoroughly crystalline rocks below pre-Cambrian clastics, it includes rocks the age of which varies from Algonkian to pre-Algonkian. This anomaly is perhaps best met by making a more or less arbitrary division between Archean and post-Archean crystallines. The natural theoretical plane to choose is the beginning of life; that is, to include in the Archean all truly azoic rocks. While this suggestion has a plausible sound, we must believe that the dawn of life was very gradual and that its traces in its early stages are exceedingly sparse, so that there would be great, if not insuperable difficulties in its practical application.

If the third theory, that the Archean includes only pre-sedimentary rocks, be correct, its upward limit is easy to define; the Algonkian begins for each region at the time of the deposition of the first sedimentaries. But there are those who deny the existence at the present time of any such ancient rocks, although they concede their existence at one time, and they believe that the Archean as thus defined represents a vast lapse of time in the history of the earth. This denial of the present existence of any rocks of greater age than the oldest sedimentaries is of course a pure unverified assumption defended on the ground of probability. If the original crust of the earth be defined as including more than the first outer skin, it is a question whether the converse proposition is not equally probable. Even if the position be true, the school that believes in the igneous origin of the Archean would still have a large mass of rocks for the Archean by shifting their ground so as to include in it all the material which in the slow process of inward crystallization has now reached the surface of the earth, not by intrusion in the rocks above, but by erosion. This position would, however, be controverted by those who regard such rocks as plutonic and belonging to the age of their equivalent sedimentaries. But in the nature of the case it is not possible to designate the particular age to which these rocks belong. That there exists upon the surface of the earth a part of the original crust of the earth, or its downward continuation by later cooling, can hardly be doubted; and since these can never be assigned to any definite period of sedimentaton they might well be considered as Archean. At any rate they are a class by themselves which, if not here placed, can not be referred to any of the geological periods. Further, this class of rocks when in contact with detritals of whatever age, by the very hypothesis of their origin must rest unconformably below them. The coincidence that so frequently. if not always, there is really a great hiatus between the ancient sedimentaries and the basal complex might be urged as evidence of the truthfulness of this hypothesis. It is interesting here to remember that Emmons defined pyrocrystalline rocks as those due to the consolidation of the earth's crust, which rocks were said to increase in thickness by additions below.

Sedimentation must have begun in the earliest seas, while upon parts of possible continental areas volcanic materials alone were still accumulating. These latter, in accordance with the definition, would belong to the Archean. There would be in this case no positive equating one with the other. When later, upon these Archean rocks contemporaneous with the earlier Algonkian rocks, sedimentaries began to form, this would be for this region the opening of the Algonkian. However, it is not impossible that all such supposed contemporaneous Archean materials may have been carried away by erosion. Certainly this would have been the case with a large portion of them, and it follows that this difficulty may be rather theoretical than practical.

The banded and contorted granite-gneiss which serves as a background for the Archean may not improbably be the part which has the origin above suggested, while the other parts of the complex may be due to subsequent intrusives; the whole being kneaded into their present extraordinary complex relations by repeated dynamic movements and other metamorphic influences. This igneous theory of the origin of the Archean, modified so as to include the pre-sedimentary original crust, if any remains, and the deeper crust which has reached the surface by denudation, perhaps more nearly covers the facts than any other as to the relations of the Archean to subsequent rocks, its complex lithological character, the relations of the rock phases to each other, and the long history written in the strained, altered, and broken mineral constituents. It accords with the idea held by Irving, Bonney, and others, that this earliest crystalline complex was produced under conditions differing from those of the rocks of any subsequent period.

But the difficulties in the theoretical delimitation of the top of the Archean are so great that I prefer to confine myself to a statement of some possible solutions rather than to commit myself to any theory, although now inclining toward the third theory modified as suggested. Although the obstacles are not nearly so great in delimiting later periods, the difficulties of making an exact definition for the Silurian, Devonian, or Carboniferous are so considerable that almost any of those given have been found to controvert the facts of some locality. If this is the case with reference to these later periods in which so much more is known, it should not be surprising that the obstacles to an accurate delimitation of the Archean are at present apparently insuperable.

But while it is impossible to make a wholly satisfactory theoretical definition of the Archean, it is frequently easy in the field to say with a great degree of probability what rocks are Archean and what post-

Archean. For instance, in the Arizona region, as has been seen, above the typical Archean complex there is the most profound unconformity, upon the upper side of which the rocks are readily recognized clastics. From the writer's point of view the same thing is true for a large part of the lake Superior region. In the Uinta and Wasatch mountains, again, below the quartzites of probable Algonkian age, is a great unconformity, and then appears the implicated Archean. In certain other regions the separation of the Algonkian and the Archean is a matter of exceeding difficulty. As representative of this class of cases may be taken the Front range of Colorado, along the east side of which are unmistakable clastics, with an apparent gradation between them and the crystalline complex. In the Appalachians, again, where for the most part the oldest clastic rocks recognizable are Cambrian, it can not be said whether the crystalline complex below is Algonkian or Archean. Here the separation of the Cambrian from the pre-Cambrian has been accomplished only by a minute and laborious study. The two appeared to be in conformity and to grade into each other. It is only recently that this gradation has been shown by Pumpelly to be consistent with a great unconformity between the two. The causes producing this gradation between the Cambrian and pre-Cambrian in Massachusetts (post-Cambrian dynamic action and pre-Cambrian disintegration) may also be found to explain the conformities and gradations between the Algonkian and Archean.

While it is then not easy to define the Archean, it is plain that the discrimination in the field between Archean and Algonkian is a real one and should continue to be applied even if its exact theoretical meaning can not be said to be certainly known. It has been the custom in the past to refer to the Archean practically all crystalline rocks, with many semicrystalline rocks which seem to be old, or the age of which was not determined. Under this practice vast areas in the Appalachians have been referred to the Archean, which are now being placed in the Cambrian, Devonian, and Carboniferous. Doubtless in the same way many other areas which have been placed in the Archean upon closer study will be removed from it and the rocks distributed from the Algonkian upward. At this point a reform in geology is needed. If, for instance, the oldest rocks of clearly recognizable age are Triassic, and these Triassic rocks rest upon a complex, the structural relations of which are not studied in detail, this complex should be denominated pre-Triassic rather than Archean. A large part of the difficulty in getting to understand from the literature the actual facts as to the occurrences and relations of the crystalline rocks has arisen from this practice of using the Archean as the dumping ground for everything of unknown age.

STRATIGRAPHY OF ARCHEAN.

In characterizing the Archean the methods applicable to its subdivision are clearly pointed out. If no part of it is demonstrably sedimentary, structural methods can not apply. Its subdivisions must be made upon purely lithological grounds. If a part of it is demonstrably eruptive the relative ages of these parts may often be ascertained and all are necessarily newer than the part not recognized as eruptive, else these could not be shown to have this origin. Many attempts to apply stratigraphical methods to parts of the Archean have been made, but they have not thus far been successful. Such attempts have been based upon the belief that foliation represents sedimentation, but even working upon this erroneous basis it has been stated that the structures are so complicated that little progress has been made. So far as attempts to apply stratigraphical methods to this fundamental complex are concerned the conclusions of Whitney and Wadsworth are very largely true. If their review of the "Azoic rocks" had been confined to this basement system, which is perhaps truly Azoic, the conclusion as to its indivisibility on a structural basis would have plausibility.

The only division generally applicable to the Archean warranted by present knowledge is its separation into (1) fine grained mica-schists, feldspathic mica-schists (technically gneisses), hornblende-schists, hornblende-gneisses, etc; and (2) the granites and granitoid gneisses with their associates. The first class is generally dark colored, the second light colored. The lithological affinities of the second are with the igneous rocks. As already indicated, the change from a granite-gneiss area to a schistose area is not infrequently a transition. In passing from the schists to the granites often veins or dikes of granite are first found, or interlaminations of granite-gneiss with the schist. After a time the schistose rocks and granite-gneiss are about equally important. Proceeding onward the granite-gneisses become predominant. These relations are precisely those already described and interpreted by one school to mean that the granite-gneisses are extraneous intrusives, by another that they are the aqueo-igneous fused sedimentary beds in situ, and by a third that they are selectively metamorphosed beds. To designate the gneissoid granite part of the Archean the term Laurentian has always been employed and is now generally restricted, the finely laminated crystalline schists being commonly referred to the Huronian. Laurentian under this usage is made to include the implicated granite-gneiss of the basal complex, somewhat regularly laminated granite-gneiss, and also many areas of nearly massive granite, a part of which latter may be and probably is of later age than the former. The first is clearly Laurentian. It is equally clear that the granite-gneisses known to be of later age than Algonkian clastics, like those described by Lawson northwest of lake Superior, should be excluded from the Laurentian. To place these rocks here is to introduce a new principle in geology; i. e., it is giving rocks of recognized eruptive origin a separate term when they should be given the name of their contemporaneous clastics. The eruptives which are contemporaneous with the Tertiary rocks are so named. Rocks which cut Tertiary rocks and can not be more accurately located are called post-Tertiary. In like manner the granite-gneisses which are recognized as eruptives of later age than sedimentaries should be assigned if possible to the age to which they belong, and if not, their limitations expressed. This restriction of the term Laurentian will undoubtedly eliminate from it large areas of rocks which have heretofore been recognized as Laurentian, but to include both the original granite-gneiss and later granite-gneisses under a single time term is but to deliberately continue a confused classification after facts have been discovered which render it unnecessary. All were first referred to the Laurentian only because a discrimination as to age had not been made between them.

It appears to me that the best use which can now be made of the old term Laurentian is to restrict it to the Archean granite-gneisses, including in it no rocks which traverse Algonkian sedimentaries. This use of the term Laurentian is different from the original proposal of Logan. The original Laurentian is largely and, with the exception of the great lower "orthoclase" gneiss, perhaps wholly a series of detrital origin, being composed of limestones, quartzites, and regularly laminated gneisses which almost certainly are altered clastic rocks. Dawson (Sir William) in a late paper insists that the bedded sedimentary character of this and adjacent series can not be doubted. It was natural in the days in which lamination of any kind was by most geologists regarded as proof of sedimentation, that the term Laurentian should be carried over to the underlying thoroughly crystalline granitoid gneisses. The known area of this latter class has now become so great that the clastics of the type series and other clastics here placed are insignificant in comparison. The Hastings series, afterwards connected by Vennor with the original Laurentian, was first referred by him to the Huronian, and there is little doubt that this series would, if newly found in the great expanse of northern Canada, be thus placed. This is still more emphatically true of the so-called Laurentian clastics of lake Nipissing, which were referred to the Huronian by Selwyn. That two groups of rocks were included in the Laurentian of Logan, that author early recognized by his subdivisions: Lower Laurentian, including the basal granitoid formation; and Upper Laurentian, including all the limestones, etc. The later work of the Canadian survey has emphasized the reality of this division. In recent years the practice of the Canadian Survey has been to include all or nearly all of the more regularly laminated rocks which may be positively asserted to be of clastic origin, as well as many of which this assertion can not be made to the Huronian. The difference between the Laurentian of lake Superior and that of Logan's original area was early noted by Macfarlane, Brooks, and Rominger. The last two went so far as to suggest that about the lake Superior region it is probable that the Laurentian of eastern Canada is not represented. That possibly the fragmental rocks of the Laurentian of the East may be equivalent to the more crystalline of the fragmental rocks about lake Superior, here called Lower Huronian, was early suggested by Chamberlin. Excluding from the Laurentian the small areas of clastics here referred, and applying the term to the vast areas of rock referred to this system during the last forty years would seem now to be the preferable course. This usage accords with the principles of good nomenclature in that it makes the Laurentian a definite unit and avoids the anomaly of including under one term two radically different groups of rocks.

The fine grained, dark colored schists belonging to the basal complex and antedating the Algonkian should have a name assigned to them coordinate with Laurentian as the other main lithological division of the Archean. If Lawson's Coutchiching series belongs here this term has priority for this place. Lawson, however, regards this series as probably sedimentary, although upon this point additional evidence is needed. If it turns out that the Coutchiching is sedimentary under the classification proposed in this paper the series belongs with the Algonkian. As a provisional name for this second division of the Archean is proposed the term Mareniscan. This term, like Laurentian, is a geographical one derived from Marenisco township, Michigan, south of the Gogebic range, where these rocks have a typical development.

The Archean as a whole naturally occupies a group place in the classification, and its Laurentian and Mareniscan would be systematic in their value if they were structural terms. But until the Archean can be separated on a structural basis, if it ever can be, it will be necessary for the purposes of atlas sheet mapping to treat the group as a unit, except that lithological divisions may be made. With reference to Archean, we are in the same difficulty as with Agnotozoic or Proterozoic, considered below. This group can at present have but a single system division, the Algonkian, because we are not yet able to subdivide the group into systems which can be shown to be general for the whole of America.

The anticlinal structure described as generally characteristic of the Archean ranges of the west has been based upon the belief that foliation represents bedding, and also on the obsevations that the overlying sedimentary rocks often dip away from the axes. The anticlinal structures of the sedimentary rocks and that of the Archean are independent questions. If the Archean as a whole be regarded as of igneous origin, it would be expected that a gradation from massive rocks in the cores to schistose rocks upon the flanks would be found, for these outer zones are the places where the most powerful effects of dynamic action are felt, and also the parts where greater interior accommodations of the constituent particles are necessary. In dynamo-metamorphic eruptives of post-Archean age precisely these relations prevail. The determination of the structure of the Archean cores must wait until the origin of the Archean has been determined; in short, until it is known whether structural methods are applicable at all.

NECESSITY FOR A GROUP BETWEEN CAMBRIAN AND ARCHEAN.

The Olenellus fauna is taken as the base of the Cambrian. The reasons for thus delimiting the Cambrian below are fully considered by Walcott in one of this series of correlation papers and will be summarized on a subsequent page. His results are accepted. The Cambrian fauna in development is far, some biologists say nine-tenths of the way, up the life column. This statement, if accepted, implies a prior life of vast duration.

Just as another period of life has succeeded the Cambrian, another has preceded it. The progress of paleontologic knowledge has of late been downward. Before there was a recognized Cambrian there was a well known Silurian, and it is probable 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. If this be done, definite information will be available to correlate rock series of different parts of the world in the time place between the Cambrian and Archean.

If the condition of the globe was such that life existed in pre-Cambrian time, it also was such that stratified rocks could be deposited not unlike those of later times, so that the only question which arises is whether any of these stratified rocks now remain in such a condition as to be recognizable. The foregoing pages and the literature summarized give a mass of evidence upon this point which is overwhelming. Such intervening clastic series do exist below the Olenellus fauna in many regions in North America, and in some cases the volumes of rock and great intervening erosions represent a lapse of time which may be not inaptly compared with all subsequent time. If geological history were to be divided into three approximately equal divisions, these divisions would not improbably be the time of the Archean, the time of the clastic series between the Archean and the Cambrian, and the time of the Cambrian and post-Cambrian. In this connection it is well to recall that many years ago Logan suggested that the thickness of the Laurentian and Huronian may surpass that of all succeeding formations, and the appearance of the so-called Primordial fauna may be considered a comparatively modern event.

It is imperative that some term shall be available to cover the great mass of rocks between the Cambrian and Archean. Irving was the first to realize and urge the necessity for such a term and proposed for it Agnotozoic. This term implies the existence of life in this system, and the evidence upon this point is conclusive. Life is indicated by the presence of thick beds of graphitic limestones, beds of iron carbonate, and by great thicknesses of carbonaceous shales, which are represented by graphitic schists in the more metamorphosed phases of the rocks. It has been urged by Whitney, Wadsworth, and others that the limestone and graphitic schists may have an origin other than organic. Whitney and Wadsworth have gone so far as to say that there is no valid evidence of life in any pre-Potsdam rocks. This was, however, before it was generally recognized that the Potsdam is Upper Cambrian and that an abundant Cambrian life extends far below. If it were true that these limestones and ore beds are no evidence of life (and it may be admitted that another origin is possible without implying that it is probable), it will hardly be maintained that the hydrocarbons which occur so abundantly in the little metamorphosed shales of the Huronian about lake Superior are other than of organic origin, and, if so, the graphitic schists which stand in the same great system in the geological column are in all probability only these hydrocarbonaceous shales in a more altered condition. However, we are not obliged to depend upon the presence of these varieties of rocks as the only evidence of life. Whether the *Eozoon canadense* found in the original Laurentian of Canada is of organic origin will not be discussed here. Its literature is voluminous and it is a question which concerns the paleontologists. It is doubtless true that many of the specimens which have been called Eozoon are results of the forces of crystallization; but, admitting this, it does not follow that all of the material called Eozoon is of this character. Passing by this question, the pre-Cambrian fossils described by Walcott in the Grand canyon of the Colorado include: "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, or Paradoxides. There is also an obscure Stromatopora-like form that may or may not be organic."

A Lingula-like shell has been found by Winchell in the pipestones of Minnesota. Selwyn has described tracks of organic origin in the Animikie (Upper Huronian) series of lake Superior. Murray, Howley, and Walcott found several low types of fossils in the pre-Olenellus clastics of Newfoundland.

That these fossils are of organic origin can not be doubted. But while many will admit the clastic character of the great groups of rocks considered, and the organic origin of the forms mentioned as well as the carbon of the carbonaceous shales and schists, they will say that these are merely evidences that the rocks in which they lie are Cambrian. The reply to this is that it is a question of nomenclature. If it be premised that all clastic and fossiliferous rocks more ancient than the Olenellus horizon are Cambrian it is useless to try to prove that there are pre-Cambrian clastic rocks which bear life. It is, however, necessary to recognize that the carrying downward of the term Cambrian to cover not only the great thicknesses of rocks which are now included within it, but all pre-Olenellus clastics, will probably make the Cambrian as great as or greater than all the subsequent periods put together. That this is inadvisable is plain, and the clastic rock masses below the Olenellus fauna are so enormous that the proposal to introduce a general term like Agnotozoic as the equivalent of Paleozoic, Mesozoic, Cenozoic, to cover this great group is a conservative one. Irving foresaw that the term would be objected to because sooner or later the life will become to a greater or less degree known, and he suggested as an alternative for Agnotozoic, Eparchean in contradistinction to Archean, which was reserved by him to cover the fundamental complex. As the character of the life of this group is already beginning to be known, it seems to me that the term Proterozoic, considered for the place by Irving, but rejected, is preferable to either Agnotozoic or Eparchean.

In a conference of the members of the U. S. Geological Survey, called by the Director at Washington, these terms were discussed with reference to atlas-sheet-mapping, although there was no question on the part of any one as to the necessity for some such term. Recognizing the impracticability of the certain correlation with one another of the one or more pre-Cambrian clastic series which occur in the various regions, and recognizing the fact that for use in mapping a uniform plan must be adopted, it was suggested that a term of the same class as Cambrian, Silurian, and Devonian should be selected for rocks here included, and to occupy this place the term Algonkian was proposed and accepted. The proposed general scheme of classification for the lower part of the geological column is then as follows:

Paleozoic	Carboniferous. Devonian. Silurian. Cambrian.
Agnotozoic, or Proterozoic	Algonkian.
Archean	Archean.

The introduction of the term Algonkian has been objected to on the ground that it will supersede the older term Huronian. In answer to this it may be said that Huronian has not been generally used as Algonkian is defined, and it therefore does not supersede this term. Huronian will be retained for certain of the clastic series of Lake Superior and Canada, as well as for rocks in an equivalent position in other parts of North America and Europe, if such equivalence can be determined, just as before Algonkian was introduced. The Huronian will stand as one of the great series of rocks which together make up the Algonkian.

DELIMITATIONS OF THE ALGONKIAN.

The further back we go in the history of the world for any given region the more frequent have been the changes through which a rock stratum has passed, and therefore there is increasing difficulty in determining bounding planes with sharpness, although in different regions rocks of the same degree of metamorphism may differ vastly in age.

The truth of this is well illustrated by comparing the eastern and western regions of the United States. In the former powerful dynamic movements have occurred until late in Paleozoic time, as a result of which the Cambrian, Silurian, and Devonian rocks over large areas have not been separated from the pre-Cambrian. In certain areas this separation has been accomplished, but only by the most accurate and painstaking application of modern methods. In parts of Massachusetts and Vermont the areas covered and the results reached have involved an enormous amount of labor, although of late paleontology has been an important help in unraveling the problem. Under these circumstances how much more difficult would one expect it to be to separate the pre-Cambrian clastic series from the Archean!

In parts of the West, where no close folding has occurred since Cambrian time, it is easy to separate the Cambrian from the pre-Cambrian, and in regions in which metamorphosing influences have not been at work for a still longer time it is easy to separate the pre-Cambrian clastics from the Archean. But in other regions this separation is made with the greatest difficulty, and doubtless over large areas this will never be satisfactorily done. Just as in the Appalachians, in parts of which it may be impracticable to separate the Cambrian rocks from the pre-Cambrian clastic series, if such exists, so it will be for a long time impossible to decide in some regions upon sharp boundary lines between the pre-Cambrian clastics and the Archean. Giving full force to this position, it is no reason why the discrimination should not be made where it can be.

Recent work in petrography has demonstrated that dynamic movements and environment, not time, are the important elements in the obliteration of clastic characteristics. Dynamic movements also destroy the evidences of discordances between series where there have been real unconformities. This destruction of the evidence of structural breaks comes about largely as the result of an approaching parallelism of bedding, caused by the close folding, but far more important than this is the production of a common cleavage and foliation with the simultaneous development of crystalline schists from the newer series. As a consequence basal conglomerates are often almost the only means of discriminating between the newer and the older series, and if the metamorphosing influences are powerful enough to destroy the pebbled character of such beds, changing them into schists or gneisses, as has occurred in many places in the Cambrian of the Appalachians, this means of detecting a break between series is also lost. The problem is rendered still more difficult because of the fact that often when there is a real unconformity there has been originally no basal conglomerate. At many localities in the far West the basement fossiliferous series are built up of the constituent minerals of the underlying rocks rather than of large fragments of them, and even when not folded have sometimes so closely simulated the original rocks that geologists have been at a loss to determine at what plane the clastics end and the crystallines begin. If it has proved difficult to separate the unfolded clastics from underlying crystallines how much more difficult must it of necessity be to separate series that have together been subjected to intense and perhaps repeated dynamic actions.

The Algonkian has been defined as including all recognizable pre-Cambrian clastics and their equivalent crystallines. In the consideration of the character, origin, and delimitation of the Archean the lower limit of the Algonkian has been given. Its basal plane is the lowest of the recognizable clastic rocks. It has been seen that there are great differences in the ease of recognition of the basal Algonkian plane in different regions. In the Uinta mountains, in the Grand canyon region of Arizona, in portions of the lake Superior region, in the original Huronian region, and elsewhere, between the Algonkian and the Archean, there are great unconformities, above which are the readily recognizable clastic rocks, and below which are the thoroughly crystalline basal complexes. Even in many regions in which there have been repeated foldings since Archean time, and in regions obscured by eruptive activity, it is perfectly clear that a large part of the rocks are clastic and belong with the Algonkian, while other parts have all the characteristics of the fundamental complex. Occupying an intermediate position are occasionally found areas of rocks which can not certainly be placed with the Algonkian or Archean, but this difficulty is not peculiar to this separation any more than to other general recognized planes, such as that separating the Cambrian and Silurian in folded districts. Many of the members of the Canadian Geological Survey have described the Huronian and the Laurentian as conformable, with gradations between the two. This apparent accordance and gradation is in many cases due to the fact that placed with the Huronian are many rocks which would under the use of the terms here proposed be regarded as Archean. In other cases there are apparent conformities and gradations between undoubted clastics and the underlying rocks having all the characteristics of the fundamental complex. The significance of these gradations is discussed in another place, where it was seen that they are not inconsistent with genuine structural breaks.

It has been stated that the reasons for placing the base of the Cambrian at the Olenellus fauna are considered by Walcott in this series of correlation papers, and that his results are here accepted. It is, however, to the point to consider whether this horizon answers equally well for the upper limit of the Algonkian. Evidently all the arguments brought forward by Walcott for placing this fauna as the base of the Cambrian apply as well for considering the horizon below this as uppermost Algonkian; for the widespread character, both European and American, of the Olenellus fauna makes it a particularly easy one to identify and therefore valuable for the purposes of discrimination. In the lake Superior region and in many other localities above the upper Algonkian are unconformities, the first of the Cambrian being middle or upper. In other regions, as in Newfoundland, the upper Algonkian is marked by an unconformity, and the formation immediately above bears the Olenellus fauna. This is the most favorable and clear case. In the Wasatch and several other ranges of Utah and Nevada, in British Columbia, and probably in the southern Appalachians, below the Olenellus fossiliferous Cambrian are conformable series of quartzites and slates of great thicknesses. Are these lowest Cambrian or uppermost Algonkian? May not the Olenellus fauna in the future be found to extend downward through a greater or less thickness of these apparently barren rocks? If in any region the fauna be found to extend downward for a long way, it is probable that species and genera characteristic of the Olenellus horizon as now known will drop out and others appear which are different. The Olenellus would thus grade into a pre-Olenellus fauna. Such a gradation will doubtless somewhere be found, while in other regions the change from an Olenellus fauna to one of a pre-Olenellus type may occur abruptly. In either case there will finally appear a fauna which is not the present known Olenellus fauna, but which is as different from it as is the Cambrian from the Silurian (Ordovician). As the term is here used, such a fauna is pre-Cambrian, and the rocks containing it are Algonkian. In the following paragraphs great barren inferior series conformably below the known Cambrian are placed with the Algonkian on the ground of probability. The presence of an abundant lower Cambrian life at a certain horizon within the conformable succession, with apparent complete absence of life in immense thicknesses of rocks conformably below, which, so far as lithological character is concerned, are equally likely to bear fossils, throws the weight of evidence in favor of the Algonkian age of these rocks. It is, however, more than probable that some part of the conformable downward extensions of the Cambrian which are here provisionally referred to the Algonkian will in the future be found to belong with the post-Algonkian.

The newest Proterozoic or Algonkian rocks of different regions may stand in different positions, just as the superior rocks of the Paleozoic may in any given region be Cambrian, Silurian, Devonian, or Carboniferous.

DIFFICULTIES IN ALGONKIAN STRATIGRAPHY.

Since among the pre-Cambrian clastics, paleontology is not yet available in correlation, it is exceedingly difficult to make widespread subdivisions of the Algonkian, such as are made in later time. The difficulty is further increased by the unequal metamorphism in different regions of series of the same age. The Algonkian is in just such a position as regards wide correlation of its constituent series as would be the Paleozoic and Mesozoic if their known fossil contents were so small as to be useless for the purposes of correlation. The structure of individual districts and regions could be worked out and the formations correlated, but the attempt to equate the Cambrian, Silurian, Devonian, or Carboniferous of one region with rocks of the same age in a far distant one would be an almost hopeless undertaking. In the Carboniferous the beds of coal would serve as an important guide, but if implicitly followed and no fossils were available the Triassic of Virginia, the Carboniferous of the central United States, and the Cretaceous of the west would be placed together. If the iron carbonate formations of the Algonkian in the lake Superior region, which appear to be the most characteristic of any one kind of rock, were followed as a guide, the results would probably be as far from the truth.

We may, perhaps, go so far in some cases as to correlate series which occur in different districts of the same region when a set of characteristic formations forming the series occur in like order and the series as a whole is in the same relative position to overlying and subjacent series, one or both of which are known to be identical in both districts. It is probable, when several pre-Cambrian series occur of the same general character, with like relations to each other and to the Archean and Cambrian, and not so far apart as to be outside of the same geological basin, that a provisional correlation is warranted. While, then, it is not practicable to subdivide the Algonkian into general systems which shall cover the whole of North America, it is often possible so to do in a single geological basin, or in adjacent basins in which the relations of the separate formations and series can be worked out.

Before considering the principles applicable to the subdivision and correlation of the Algonkian series, it will perhaps be well to review briefly the regions in which pre-Cambrian rocks occur, and indicate their character and relations, as well as their relations to the Archean. The order followed is that of the review of literature. No attempt is made to give detailed evidence for the conclusions stated. For this it will be necessary to refer to the fuller accounts of the several regions in the previous chapters.

THE ORIGINAL LAURENTIAN AND ASSOCIATED AREAS.

In this region are Algonkian rocks at the following localities: Hastings district, lake Nipissing, Ottawa river, and Upper St. Lawrence river. The Grenville area of the Ottawa is the original Laurentian type district and the one mapped in most detail. While the maps do not connect these areas, the similarity of their clastic rocks is such as to indicate a present or former continuity, with the exception, perhaps, of those of lake Nipissing. The clastics consist of interstratified limestones, quartzites, conglomerates, green slates and schists, mica-schists, hornblende-schists, and regularly bedded gneisses, together estimated to be thousands of feet thick. Associated with these are diabasic and chloritic rocks, both massive and schistose.

In the Hastings series there are found considerable areas of peculiar volcanic clastics. Below these rocks is a great complex in every respect like the Laurentian Archean as above defined. This latter system, called usually Lower Laurentian, occupies the main area of the region, and the clastics are in a series of troughs within it. What the relations are between the clastics and the fundamental complex has not been definitely made out, although Vennor believes that between the two is an unconformity, and that the clastics are infolded patches. The evidence given for this is, however, rather meager, and doubtless almost as good a case could be made out with present facts for the theory of an irruptive contact between the crystallines and the clastics. The Labradoritic rocks (gabbros) found in this region need not be considered in the stratigraphical succession, as they are eruptives of later age than the clastic series. Besides this eruptive, other acid and basic eruptives cut the bedded succession.

To the clastics, Logan, Murray, Vennor, and all who have worked in this region recognized that ordinary stratigraphical methods could be applied. The persistence of the bands of limestones is such as to enable them to be traced for long distances. Although the problem was a difficult one, a detailed mapping, with sections, has been submitted for a small part of the area. The structural relations and correlations which Vennor first gave differ greatly from his final ones, and it may be that even in the areas in which detailed mapping was attempted that serious mistakes had been made; but if this be true, the region is in no respect different from any other in which the structure is difficult.

All of the pre-Cambrian rocks here found were supposed by the Canadian geologists to be lower in the geological column than the Huronian of lake Huron. Upon the last point no positive evidence is at hand. The two rock series do not come together. In the most western Hastings district of the Laurentian, the clastics, in lithological character, degree of crystallization, and amount of folding are intermediate between the Laurentian and Huronian of the type areas. At first the Hastings clastics were correlated by Vennor with the Huronian, and with this correlation certain of the official Canadian geologists now agree, but afterwards they were traced with breaks of not very great distances to the original Laurentian area and have always been thus mapped.

THE ORIGINAL HURONIAN.

The Original Huronian of the north channel of lake Huron consists of comparatively little-altered quartzites, slates, slate-conglomerates, graywackes, cherts, and limestones having a total thickness of 18,000 feet, counting considerable masses of interstratified greenstone which are recognized as eruptives. Recent observations render it probable that these rocks are to be divided into two unconformable series, the lower of which is 5,000 feet and the upper 13,000 feet thick. The first would thus be properly designated as Lower Huronian and the second as Upper Huronian. Although cut locally by later granites, the lowest member of the inferior series is separated from the basement complex by a great unconformity. The upper members rest unconformably below the Potsdam sandstone. The upper series is so gently folded that the careful work of Logan and Murray enabled them to map these rocks in detail and to work out their structure. This has been done for a considerable district with as much certainty and accuracy as in many areas among the fossiliferous rocks. The rocks were divided into a number of formations, which were found to be persistent throughout the district. They were traced as a broad belt for several hundred miles in a general direction northeast. Along the Canadian Pacific railway as far as Sudbury and in the vicinity of Sudbury more than a general study of this great area has been made. The clastic rocks of this part of the region have the same general character as the type district, but in the Sudbury district there are peculiar contemporaneous volcanic clastics. In the little studied remainder of the region, as mapped, numerous granitic and gneissic areas are included, some of which may be subsequent intrusives, but many of which probably represent the underlying Archean.

LAKE SUPERIOR REGION.

In the lake Superior region, between the Archean and the Potsdam sandstone, the great Algonkian system is subdivided into three series, which are separated by very considerable unconformities. The lowest series is closely folded, semicrystalline, and consists of limestones, quartzites, mica-slates, mica-schists, schist-conglomerates, and ferruginous and jaspery beds, intersected by basic dikes, and in certain areas also by acid eruptives. It includes volcanic clastics, often agglomeratic, and a green chloritic, finely laminated schist. The thickness of this series has not been worked out with accuracy, but at its maximum it is probably more than 5,000 feet. As the term Huronian has been for many years applied not only to the Upper Huronian series, but to this inferior series about lake Superior, it is called Lower Huronian.

Above this series is a more gently folded one of conglomerates, quartzites, shales, slates, mica-schists, ferruginous beds, interbedded and cut by greenstones, the whole having a maximum thickness of at least 12,000 feet. In the Animikie district a fossil track has been found, and in the Minnesota quartzites lingula-like forms as well as an obscure trilobitic-looking impression. Carbonaceous shales are abundant. In its volume, degree of folding, and little altered character the Upper Huronian is in all respects like the upper series of the original Huronian, and can be correlated with it with a considerable degree of certainty. Above the Upper Huronian is the great Keweenawan series, estimated at its maximum to be 50,000 feet thick, although its average thickness is much less. Its lower division consists largely of basic and acid volcanic flows, but contains thick beds of interstratified sandstones and conglomerates, especially in its upper part. The upper division, 15,000 feet thick, is wholly of detrital material which is largely derived from the volcanics of the same series.

The unconformity which separates the Lower Huronian from the Upper Huronian and that which separates the latter from the Keweenawan each represents an interval of time sufficiently long to raise the land above the sea, to fold the rocks, to carry away thousands of feet of sediments, and to depress the land again below the sea. That is, each represents an amount of time which perhaps is as long as any of the periods of deposition themselves. In parts of the region the lowest clastic series rest unconformably upon the fundamental complex, but in certain areas the relations have not been ascertained. The upper of the three clastic series, the Keweenawan, rests unconformably below the Cambrian.

In the lake Superior region it has been possible with a considerable degree of certainty to refer the detached areas of pre-Cambrian clastic rocks to one or another of the three series mentioned, although there have been sharp differences of opinion with reference to certain of the areas. It has been possible further to subdivide the series into formations, some of which have a widespread extent within the region. The best results in correlating the subdivisions within the series have been reached in the Penokee and Animikie districts.

Correlations of series in this region have been based upon unconformity, upon lithological similarity, upon the belief that the greater dynamic movements which have affected the region have been widespread, and upon degree of crystallization of the rocks. The correlation of the formations within a given series has been based upon lithological characters and upon a similar succession of like beds.

THE REGION ABOUT HUDSON BAY.

Within the main Canadian area of pre-Cambrian in the region about Hudson bay exist several troughs in which there certainly occur fragmental rocks such as slate-conglomerate, limestone, and dolomite. These are associated with "imperfect" gneisses, a great variety of schists, and schistose and jaspery iron ores. The Marble island series, with that of the adjacent shore, is closely analogous in lithological character to the Upper Huronian, while the more crystalline phases resemble the Lower Huronian. The chief indication available as to the relations of these rocks to the basal complex is the presence in the slate-conglomerates of syenite pebbles, like the rocks of the underlying crystallines. Resting unconformably upon the foregoing clastics and upon the basal complex is the Manitounuck series, which consists of siliceous and argillaceous limestones, sandstones, quartzites, shales, ironstones, with interbedded amygdaloids and basalts, all the members of the series being in a practically unmetamorphosed condition. This series, in its structural and lithological characteristics is remarkably like the Keweenawan of lake Superior, and its distance from the nearest area of this series, the Nipigon, is not very great, so that its correlation with the Keweenawan can be made with a fair degree of probability. There are then about Hudson bay, between the Cambrian and the Archean, at least two, and perhaps three, series of rocks, the uppermost of which rests upon the lower series unconformably.

OTHER REGIONS OF NORTHERN CANADA.

Too little is known of the vast expanse of pre-Cambrian rocks which constitute the northern parts of Canada to make any definite statements. It is, however, evident that rocks lithologically like the Archean of the previous regions discussed constitute the great area. It is equally plain that within this area, at various districts, are rocks which show undoubted evidences of clastic characters as shown by the presence of limestones, schistose conglomerates, volcanic clastics, etc., which have a lithological likeness to the Keweenawan, Upper or Lower Huronian of lake Superior, but which can not yet be closely located. The Huronian area of the north channel of lake Huron extends to an unknown distance in a north and northeast direction. Also, it is by no means certain that many of the rocks referred by Dawson to the Cambrian are not really pre-Cambrian, as used in this essay. The Coppermine series, for instance, in its lithological character and position, is such as to lead to a comparison of it with the Keweenawan or Animikie of the lake Superior, or both. But the structural work in this vast area can be considered but as barely begun.

THE EASTERN TOWNSHIPS.

In the Eastern Townships there is unconformably below the fossiliferous Cambro-Silurian a series of little altered slates which rests unconformably upon crystalline or semicrystalline schists. These have been regarded by the Canadian geologists as Lower Cambrian, although in them no fossils have been found. In position and lithological character they are compared with the gold-bearing slates of Nova Scotia. As the Canadian Geological Survey uses the term Cambrian, including the Animikie and Keweenawan, this series is probably Cambrian, but, making the basal Cambrian as is done in this essay the series bearing the Olenellus fauna, it is probable, although not certain, that this series of slates is pre-Cambrian and Upper Algonkian. Of the series of schists unconformably below this series there are no very full descriptions. It, however, includes mica-slates, staurolitic schists, crystalline limestones, argillites, and graphitic schists, and with these volcanic clastics. This is certainly a clastic series in part at least. The whole is associated with granites which are regarded by Ells as intrusives in the schists, and one of the causes of their metamorphism, but by Selwyn are supposed to be the clastic series in a more metamorphosed condition. In this region it is probable that the fundamental complex does not appear, the lowest series found being a clastic one which is to be placed in the Algonkian. The lithological character of the Lower Algonkian crystalline series more nearly resembles the Upper Laurentian of the original Laurentian area than any other. The unmetamorphosed slate and quartzite series unconformably above it can not now safely be correlated with any of the clastic series to the west. It may be that it is Upper Huronian or later.

SOUTHERN NEW BRUNSWICK.

In southern New Brunswick, while the geology is exceedingly complicated, and the later conclusions of the official geologists differ fundamentally from those earlier held, it is plain that there exists here a pre-Cambrian clastic series of great thickness. The wholly crystalline granites, gneisses, etc., at the base, in their general lithological description, resemble the Archean of the West, but from present evidence it is impossible to decide whether these are subsequent intrusives, the product of complete metamorphism of the clastic series, or are a basement complex. The geologists who have described the region clearly maintain that this series is more ancient than the oldest associated clastics, although the relations strongly suggest the possibility of an eruptive contact between the latter and the granites and gneisses. The older series of clastics, called the Upper Laurentian, does not have a great thickness, consists of quartzites, slates, and crystalline limestone interstratified with argillites, slate-conglomerates, and gneisses. This series in its lithological character is like the original Upper Laurentian. Above it, conforming with this series and the granites and gneisses, is the Coldbrook series, which is very largely composed of surface volcanic flows and clastics. Above this are the Coastal and Kingston series, which are wholly unmetamorphosed clastic rocks, associated with contemporaneous eruptives. Between the two is something of an unconformity, but it is not thought by the New Brunswick geologists to have marked a considerable epoch of time. The two upper series can not certainly be correlated with series in other parts of Canada and about lake Superior, but not improbably they belong above the horizon of the Lower Huronian, being perhaps equivalent to the Upper Huronian or Keweenawan, or with the erosion intervals which separate these series.

NOVA SCOTIA AND CAPE BRETON.

In Cape Breton the relations between the basal complex and the George river limestone series are identical with those between the basal complex and the so-called Upper Laurentian of southern New Brunswick; i. e., there is here a clastic series and a granitoid gneiss series in which it is impossible to say definitely whether the relations are those caused by an eruptive contact or whether the crystalline complex is older than the clastic series, the latter being deposited upon it.

In Nova Scotia the great gold-bearing series of the Atlantic coast, of unknown thickness, mapped by the Canadian Survey as Cambrian, may be pre-Cambrian as terms are here used. It contains the evidence of life in Eophyton, but this does not forbid regarding it as Algonkian in our sense of the term. The series may be as high as the Cambrian, or it may be the equivalent of one or more of the pre-Cambrian series. In this region the relations of the granites and gneisses to the gold-bearing slates are such as to demonstrate with a reasonable degree of probability that the granites are intrusive, although they have been regarded by certain writers as metamorphic. This fact suggests that a part of the granite of the fundamental complex of southern New Brunswick and Cape Breton may also be a later eruptive, but even if this were the case it would not demonstrate the absence of an earlier granite-gneiss series.

NEWFOUNDLAND.

In Newfoundland is a clear case of a great series of rocks of perhaps 10,000 feet thick, referred to the Huronian by Murray, which is a part of the Algonkian. Here is found the Olenellus fauna in the basal Cambrian rocks, and these are separated by an unconformity from the underlying clastic series, in which, however, has been discovered two or three fossils of a low type. What the relations of this lower slate series are to the crystalline granite-gneiss which has been referred to the Laurentian is uncertain. No evidence is available showing that lower than this slate series are any clastics. Certain of the granites of the island of Newfoundland are intrusives of later age than the slates, some of them being as recent as Carboniferous; so that it is not impossible that many of the granites, syenites, and porphyries referred to the Laurentian may be of far later age.

THE BLACK HILLS.

In the Black hills is a great series of slates, quartzites, quartzose conglomerates, mica-schists, and mica-gneisses of unknown, although probably of great, thickness. These are cut both by intrusive granites and basic rocks of Algonkian age and by eruptives of later time. All of the clastic rocks are more or less metamorphosed by the contact and dynamic action to which they have been subjected, and adjacent to the great batholites of granite they have become thoroughly crystalline. In degree of folding, crystalline character, and mineral composition they resemble the Lower Huronian of the lake Superior region nearer than any other series. They are separated from the Potsdam sandstone by a very great unconformity, that formation resting upon them in a wholly unfolded condition, while the prominent secondary structures of the underlying series are nearly vertical and the bedding is in a series of sharp folds. No pre-Algonkian rocks are here known.

MISSOURI.

The Algonkian clastics of Missouri are a group of isles surrounded by Paleozoics. They consist of limestones, slates, iron ores, and conglomerates, the most of the débris of which is from porphyries and are interbedded with surface quartz-porphyry flows, which make up the greater part of the volume of the series. There are here also granites, which are probably of the same age. If this is the case no rocks older than the Algonkian are here known. The series shows conclusive evidence of vast denudation before the horizontal Cambrian was deposited upon it. The lithological character of the series is intermediate between the Upper Huronian and Keweenawan of the lake Superior region, and it may stand as the equivalent of one or the other of these, or in an intermediate position.

TEXAS.

In Texas the Algonkian is represented by the Llano series of Walcott or the Texian series of Comstock and by the Fernandian of Comstock. The first series consists of gently folded shales, sandstones, limestones, and schists with ferruginous beds, and is cut by both basic and acid eruptives. It is for the most part very little metamorphosed, and is said to repose unconformably upon the Fernandian. The Fernandian series consists of quartzites, ferruginous rocks, carbonaceous schists, chloritic slates and shales, calcareous rocks, and other acidic and basic schists. It is now a rather crystalline series, but it is clearly, in part at least, of clastic origin. The series is cut by numerous eruptives, both basic and acidic, of which granite is the most prominent. As to the relations of the clastic series to the Burnetian (Archean), they are believed by Comstock to be unconformably above it. They are separated by a great unconformity from the Cambrian sandstone. Comstock correlates the Texian with the entire Grand canyon clastic section, which, if true, and the above supposed relations correct, make the Fernandian rather low Algonkian.

MEDICINE BOW RANGE.

In the Medicine Bow mountains, the clastic series of Medicine and Mill peaks, consisting of slates, cherts, siliceous limestones, quartzites, and conglomerates, all of considerable thickness, appear to be conformable with the more crystalline granite-gneiss complex. The only evidence that there is a break between the two is the presence of granite and gneiss fragments in the lower parts of the clastic series. In degree of crystallization and lithological character this Algonkian series is like the Lower Huronian of the lake Superior country.

SOUTHWESTERN MONTANA.

In southwestern Montana the Algonkian is probably represented by two series. The upper series consists of 12,000 or 15,000 feet of unaltered strata, mostly shales. The lower consists of completely crystalline regularly bedded gneisses, quartz-schists, quartzites, chlorite schists and mica-schists. The upper series, the topmost of the Algonkian, is separated from the Archean by a great unconformity. The relations of the lower series of the Algonkian to the basal complex are unknown, but it is known to lie unconformably below the Cambrian. Also the two Algonkian series are not found in contact, but that there are two series is indicated by the facts that one of them is conformably below the Cambrian while the other is not, and the first is nearly unaltered while the second is crystalline. There is no sufficient information upon which to correlate either of the Algonkian series with the region about lake Superior. The affinities of the Upper Algonkian are rather with probable Algonkian series to the west yet to be considered.

THE UINTA MOUNTAINS.

An ancient clastic series in the Uinta mountains covers an area of several thousand square miles. This series, 12,500 feet in thickness, is one of red quartzites and sandstones, interstratified with layers of slate and ferruginous shale. It rests upon the upturned, truncated edges of a thoroughly crystalline complex which is probably the equivalent of the Archean of other regions. It is unconformably below the Carboniferous. There is, then, no definite evidence upon which this series can be referred to the Algonkian. It, however, in lithological character, absence of fossils, and position, is more nearly analogous with the quartzite series of the Upper Huronian than any other to the east, but the distance which separates it from the Upper Huronian is so great as to render correlation on this ground very unsafe. The series may, with more probability, be regarded as the equivalent of the slates of southwestern Montana and the probable Upper Algonkian of the Wasatch to be considered. Also it is possible that it may not be Algonkian at all, but Cambrian or Silurian.

THE WASATCH MOUNTAINS.

In the Wasatch mountains the Algonkian is probably represented by one series, and perhaps by two. The supposed Upper Algonkian is a series of quartzites, sandstones, and micaceous shales and mica-schists 12,000 feet in thickness. It is possible that below this series, separated by an unconformity, is another more ancient and crystalline series which belongs with the Algonkian, represented by the small area of quartzites and quartz-schists at the foot of the Cottonwood canyons. The Upper Algonkian is separated by a great unconformity from the Archean. Its relations to the supposed older series of clastics in the lower Cottonwood are not made out, but it rests conformably under the Olenellus Cambrian, and therefore if not Cambrian is uppermost Algonkian. This series occupies the same position as the series of slates in southwestern Montana, and the two, as has been said, are perhaps the equivalent of the Uinta series.

PROMONTORY RIDGE, ANTELOPE AND FREMONT ISLANDS.

In this range are a series of mica-schists, quartzites, argillites, which are occasionally calcareous, rocks which are probably clastic and therefore represent the Algonkian. The relations of this series to the Archean complex are not known. At Promontory point it rests unconformably under the Weber. The rocks on Antelope and Fremont islands are regarded as of the same age because of their likeness to the Promontory point rocks and they are believed to be pre-Cambrian because no Cambrian or post-Cambrian rocks in this region are more than indurated.

THE AQUI MOUNTAINS.

In the Aqui mountains the probable Algonkian consists of a series of quartzites 6,000 feet thick containing beds of conglomerate with argillaceous schists and imperfect mica-schists. This series rests upon the granite, which is presumably a part of the basal complex. It is conformably below the basal Cambrian, stands as Upper Algonkian, and may be correlated with the Wasatch Algonkian.

SCHELL CREEK, EGAN, POGONIP OR WHITE PINE, AND PIÑON RANGES.

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 all of these ranges these series rest unconformably upon the Archean and are conformably under basal Cambrian. They therefore are probably Upper Algonkian and stand as the equivalent of the Wasatch Algonkian.

FRONT RANGE OF COLORADO.

In the district of Ralston, Coal, Boulder, and Thompson creeks of the Front range of Colorado the Algonkian is represented by quartzites, quartz-schists, mica-schists, and schist-conglomerates, the thickness of the series being unknown, but certainly more than 1,000 feet. The series has become very nearly crystalline. Its structural relations to the basal complex are not surely known. It appears to grade downward into these rocks, but this may be merely a superinduced conformity. The series of schistose rocks in the Front range, referred by King to the Huronian and estimated at 25,000 feet thick, probably belong in large part to the fundamental complex.

THE QUARTZITE MOUNTAINS.

In the Quartzite mountains the Algonkian is represented by a series of quartzites, interstratified with slates several thousand feet thick. The series had suffered powerful dynamic action, being turned on end and deeply truncated before Carboniferous time. The relations of this series to the Archean are not certainly known, but all the evidence points toward the conclusion that the Algonkian is of later age and that between it and the Archean is a great unconformity.

GRAND CANYON OF THE COLORADO.

The Algonkian in the Grand canyon region is represented by three series, the Chuar, the Grand canyon, and the Vishnu. The Chuar series consists of shales and limestones, over 5,000 feet thick. It contains a fauna of a pre-Cambrian type, including at least five distinct forms. The Grand canyon series is of sandstones, with basic lava flows in its upper part, and is nearly 7,000 feet thick. The Vishnu series consists of bedded quartzites and schists, cut by intrusive granite, and is known to be at least 1,000 feet thick, but how much thicker has not been determined, as it has not been measured to its base. The Chuar rests upon the Grand canyon and between the two is a minor unconformity. The Grand canyon rests upon the Vishnu and between the two is another unconformity. The Chuar and Grand canyon sediments are wholly unmetamorphosed, while the Vishnu sediments are indurated quartzites and semicrystalline schists. Between these series as a whole and the underlying Archean complex is a very great unconformity. Between the Chuar and the Tonto sandstone (Upper Cambrian) there is another unconformity sufficient to have caused the cutting across of at least 10,000 feet of the flexed beds of the Grand canyon and Chuar series. In this region is the fullest known succession of Algonkian rocks in the United States, with the exception of the lake Superior region. The statement would not be warranted that the series here found stand as the equivalent of like series in the latter region, but there is a remarkable lithological likeness both in the detrital and eruptive material of the Chuar and Grand canyon to the Keweenawan. Also these series occupy a position of unconformity below the Upper Cambrian, as does the Keweenawan, and is separated by an unconformity from a series of quartzites and quartz-schists which are analogous to the Huronian. This latter, Vishnu series, is not well known, so that it is unsafe to assert whether it is nearer like the Lower or the Upper Huronian of the lake Superior region.

BRITISH COLUMBIA.

The recent work of Dawson appears to show that in British Columbia there is a widespread series of Algonkian of great thickness. It consists of argillites, argillite-schists, quartzites, conglomerates, and limestones. Between this series and the Archean there is evidence of a great physical break, although the two are in apparent conformity. The series in one section rests conformably below the Olenellus Cambrian and the whole is regarded by Dawson as Cambrian, but as terms are used in this paper it is probably in part or in whole Upper Algonkian. By Dawson the series is compared with the Wasatch Algonkian and the Chuar and Grand canyon series.

THE ADIRONDACKS.

In the Adirondacks is a core of gabbro about which in a peripheral manner is a great series of regularly bedded gneisses, quartz-schists, and crystalline limestones which are often ferruginous or graphitic. At times in the gneissic series are beds of graphitic schist of sufficient richness to serve as graphite mines. While the interior structure of the rocks of this series now shows no positive clastic characteristics, the limestones, graphitic schists, and regularity of what appears to be bedding in the gneisses leave but little doubt that the series was originally clastic and belongs with the Algonkian. The studies of Walcott render it probable that there is here also a basal complex, and along the contact lines of the series Walcott has discovered evidence of an unconformity. This Algonkian is so remarkably like the not far distant original Upper Laurentian in the neighborhood of Ottawa that one can not doubt that the two are or once were continuous.

OTHER ALGONKIAN AREAS.

Besides the foregoing list of areas in which it is certain, or nearly certain, that there are Algonkian rocks, the indefinite knowledge available of many other districts indicates the presence of series which probably fall within this period. In much of the work in the West the pre-Cambrian rocks are treated as a unit, being spoken of as the metamorphic group, absolutely no attempt being made to treat them upon a structural basis. This was natural in pioneer work, but the fact that so many extensive areas of pre-Cambrian clastics have been discovered in districts where closer work has been done, suggests that in the future there will be discovered many new series of pre-Cambrian clastics. The most extensive areas which will be found to swell this system will doubtless be found in the vast stretches of pre-Cambrian rocks of Canada, but similar series may be found in central New Brunswick, in Gaspé peninsula, in the Wind river and Teton ranges of Wyoming, in a number of the desert ranges of Utah and Nevada, in Southern California, and in the Appalachians. In this last and most difficult region, the recent work of Prof. Pumpelly's corps appears to indicate that a subdivision of the pre-Cambrian will be accomplished in Vermont, and it is rather probable that in the southern Appalachians are areas of pre-Cambrian clastics.

SUBDIVISIONS OF ALGONKIAN.

The foregoing review of the occurrences of pre-Cambrian clastic rocks makes apparent the propriety of introducing the term Agnotozoic or Proterozoic to cover the series between the Paleozoic and Archean. The desirability of dividing the group into several systems is also apparent, but it is equally apparent that our limitations of knowledge at the present time make it impossible to do this for the whole of North America, hence, as with Archean, it is unavoidable that a single system term shall be used for the Proterozoic group, and as already explained, Algonkian is given this place. However, the major subdivisions of this Algonkian system, in volume of rocks and time duration, are equivalent to the systems of the Paleozoic. For instance, the Keweenawan, Upper Huronian, and Lower Huronian series of lake Superior are each of them parallel in volume to the Carboniferous, Devonian, Silurian, or Cambrian. The same may be said of the Grand Canyon and Chuar series. If in the future it shall be possible to subdivide the Agnotozoic or Proterozoic group on a systematic universal basis, as the Paleozoic is subdivided, the term Algonkian must be replaced by Wasatchian, Keweenawan, Upper Huronian, Lower Huronian, etc.

COMPARISON WITH OTHER CLASSIFICATIONS.

The major classification proposed in this paper differs in some respects from any previously given, although it accords closely with that advocated by Irving, and does not differ radically from that proposed by Selwyn in 1879, but afterwards abandoned. Irving did not recognize that within the formations called Huronian there is a structural break, which properly divides them into two series, Upper and Lower Huronian, although he realized that unconformably below rocks which he denominated Huronian are clastics, which were supposed to be inseparable from the Laurentian. As a consequence of this and of the failure to appreciate that in this lower series, as well as in the Upper Huronian, there are abundant evidences of life, he excluded from the Agnotozoic a part of this Lower Huronian, placing it with the clastics of the original Laurentian. In the lake Superior Lower Huronian there are carbonaceous and graphitic schists and beds of iron carbonate. In the original (Middle) Laurentian of the East there are great beds of limestone, regularly bedded gneisses, quartzites, quartz-conglomerates, graphitic schists, and also very graphitic limestones. While the evidence of life is not quite so conclusive as with the Upper Huronian, it is so strong that one who believes in its existence in the latter series can hardly doubt its existence in the Lower Huronian of lake Superior and the Laurentian of the East, although no fossils universally recognized as such, nor any hydrocarbons have been discovered. The reasons for the introduction of the term Agnotozoic to cover the Keweenaw, an Upper Huronian and equivalent series as clearly demand that it shall also cover other pre-Cambrian clastic series. Once started on the downward way toward the fundamental complex there is no plane at which to stop until this is reached.

This places the boundary between the Proterozoic and Archean at the plane placed by Selwyn between the Laurentian and Huronian. In the regions in which Selwyn and most other Canadian geologists have studied, they in general find no unconformity between the Huronian and Laurentian. It has been seen that similar apparently conformable relations and gradations obtain in various areas in the United States. However, in many cases, as has been seen, there are easily discoverable structural breaks between the Proterozoic and Archean.

As to the positions of Whitney and Wadsworth and Hunt, my conclusions are so radically different that little need be said. The reasons for the conclusions reached have appeared in the summary of the literature and in this discussion. To attempt to disprove the positions of these authors would be merely to repeat the arguments already presented. It may, however, be remarked that both of these positions can not be correct, and recently Wadsworth has found evidence which has led him to change entirely his views from those expressed in the "Azoic System." One maintained the absolute indivisibility and complete lack of life in all pre-Potsdam rocks, while the other maintained an invariable aqueous succession of pre-Cambrian rocks, consisting of seven different series, separated by unconformities. The position here taken is in some degree intermediate, that is to say, there is abundant evidence of various pre-Potsdam clastic series which bear the evidence of life, but no reason in the facts of occurrence nor in the principles of geology which indicates for all regions an invariable succession. It is not worth while to discuss whether in 1884, the time when Whitney and Wadsworth's account of the Azoic rocks appeared, evidence was available which would prove the divisibility of the pre-Potsdam rocks. If any one desires to answer this question for himself he will consider only that part of the literature which was extant prior to this time. This comparison will show that within the last decade has appeared a volume of evidence upon the existence of pre-Potsdam life and upon the divisibility of the pre-Cambrian rocks which far surpasses that obtained before. At the present time the evidence in favor of these positions is simply overwhelming. With the discouraging view taken by Whitney and Wadsworth as to the state of pre-Cambrian geology, I have had no sympathy. They said that the 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 has been written about it were at once struck out of existence." Crude methods have frequently led to crude results, but often even in unsatisfactory reports are contained facts which serve as clews to later workers. Further, much that was written before the present decade is as good work in proportion to the light at hand—the only proper method of comparison—as any since. The only way to get well on a road or to a goal is to start. Also it must be insisted, in opposition to Whitney and Wadsworth, that stratigraphy and classification are possible without paleontology. Both of these preceded this branch of geological science, and paleontology is useful only as it is guided by stratigraphy. Forgetting this, fossil evidence has frequently been misused. In dealing with the pre-Cambrian rocks we are exactly in the position that geologists are among the post-Cambrian rocks where fossil evidence is lacking. Each district must be studied stratigraphically by its formations and discordances. The lack of fossils is most keenly felt in correlation. However, the protests of Whitney and Wadsworth against many of the subdivisions of the pre-Cambrian and the principles upon which they were made are well founded.

As to the supposed invariable aqueous succession of Hunt, the writer can only say that so far as he is familiar with North America he knows of no region in which this succession does occur in its fullness; while every complex region with which he is familiar contradicts it at one or more fundamental points. As one illustration among many which might be mentioned, the Labradorian, supposed to be a part of the invariable succession, is demonstrated beyond all question to be an eruptive rock. Large areas of this rock are associated with or underlie the earliest pre-Cambrian and it also occurs in the form of great flows in series as late as the Keweenawan. The whole scheme is one which is highly theoretical and seems to have been evoked by laboratory study rather than from a consideration of the actual rock successions within the pre-Cambrian in the field. The chance that a scheme evolved in this manner should accord with the facts of the world is indefinitely small.

PRINCIPLES APPLICABLE TO ALGONKIAN STRATIGRAPHY.

The clearest discussion of the principles which, from the writer's point of view, are most applicable to the classification, correlation, and mapping of the pre-Cambrian rocks are the structural and lithological principles enunciated by Irving, Pumpelly, and Dale. Accepting these in the main, a few supplementary remarks may be made.

In the stratigraphical work of the past, methods have oftentimes been defective. Instead of giving close lithological descriptions of a series of rocks, noting carefully the relations of the different strata, in case they are found to have strata, to each other, and giving a detailed account of the relations which actually obtain between the series considered and surrounding series, writers have too often called the rocks of regions far distant from the original localities to which the terms have been applied Laurentian, Huronian, etc. Sometimes this is done on the ground that a series as a whole has a certain color, which has been thought to be characteristic of the period. At other times the abundance of volcanic material has been the reason for the reference. Again, quartzites from the Appalachians to the Black hills have been correlated on no other ground than lithological likeness, as though thick sandstone formations which subsequently have been cemented to quartzites have been produced but once in the history of the world. To some geologists the degree of crystallization has been the controlling fact. In other cases the occurrence of some mineral or association of minerals has been the ground upon which the reference of the containing formation is made to some specific period. This has gone so far at times as to lead to the conclusion that a single rare mineral, such as chondrodite, is proof of the pre-Cambrian age of the containing formation.

As a natural result of work of this kind, rocks of a certain lithological character or degree of crystallization, or containing certain constituents, have been called Arvonian, Huronian, Norian, Laurentian, as the case may be, which have afterwards proved to be high in the Paleozoic. Other series, which are now known to be pre-Cambrian, have been called Triassic, because of a prevailing red hue.

Any of the above characteristics may be a valuable guide in a given district, or with qualifying and guiding facts of a different character in a region; but it is their use in an indiscriminate manner on the assumption that rocks of a given time are everywhere alike that is protested against. When it is everywhere recognized that, considering the continent as a whole, age is no guide to the chemical or mineral composition, texture, color, degree of crystallization, or any other property of a formation, or vice versa, we shall be on the way to use the properties of rocks in districts and regions as guides to age. For the most part this principle has been recognized, if not practically, at least theoretically; but at one point this is less true than with the others. Degree of crystallization, because often so useful in a district, has been used by many as a general guide in correlation, although the elder Hitchcock, Rogers, Adams, and others gave early warning against such practices. It can not be too strongly insisted upon that contact action of great masses of eruptive rocks and dynamic action accompanying this, or dynamic action without accompanying volcanic activity, are prime and perhaps the chief causes in the majority of cases of the production of crystallization, not age and depth of burying, although these may be contributory causes and at times the predominant ones. A stratum which is strongly conglomeratic at the axis of a fold, within a short distance upon the legs may have become so completely crystalline as to obliterate every trace of original fragmental character, because of the movement of the particles over each other, as for instance, in the Cambrian at Hoosac mountain. In strong contrast to this may be mentioned the occurrence of quartzites in the lower part of the Upper Huronian of lake Superior, which show no evidence whatever of dynamic action, the particles of quartz not even being arranged with their longer axes in the same direction, and the induration being wholly due to the process of renewed growth and cementation. Yet this and the adjacent rocks have been buried under the entire thickness of the Upper Huronian and the Keweenawan series many thousands of feet and subjected to a pressure beyond the crushing strength of any rock, a condition in which they must have been latently plastic. Rocks as late as Devonian in the Appalachians have become so completely crystalline that not one vestige of the original fragmental material remains. Contrasting with this occurrence are the Chuar, Grand Canyon, and Keweenaw series, all wholly unaltered, yet pre-Cambrian.

No one would think of maintaining that in post-Cambrian time a rock of a certain composition is of a definite age; neither would any one think of referring a rock to the Devonian, Silurian, or Cambrian upon the degree of its crystallization. To suppose that the plane of the basal Cambrian is a *magic* one, below which new conditions of sedimentation prevailed and an entirely different set of principles apply in stratigraphy, is to assume a revolution in the conditions of the world at this time for which there is not one particle of warrant. Those who believe in evolution must believe that for eras of time before the Cambrian there were cycles of deposition of the various classes of sedimentary rocks and the slow evolution of life to the high degree of perfection and the great variety of types including all important branches except the vertebrates found in the Olenellus fauna.

It may be said that the foregoing applies equally well to the separation of the Algonkian and Archean. Revolutionary methods can not be applied here more than elsewhere. To this it can only be said that this plane is the most remote and difficult to define of any. It may be that it is wrongly defined. Without question it will in the future be much more accurately defined. Rocks now placed in the Archean will be found to be Algonkian, just as series are being found to be Cambrian, Silurian, or Devonian in the Appalachians which have commonly been regarded as Huronian or Laurentian. While the distinctions made may not be complete, they are based upon the knowledge available, are not dogmatic, and do not, it appears to the writer, contradict the laws of geology. The law of uniformity, if rightly understood, does not imply that the causes now at work have always had the same relative value. When the laws of geologic forces are fully comprehended, it will be found that each is not absolutely uniform in power, but that each involves variables. These variables may be so small that the cumulative change in the effect in any case may not be discoverable in an epoch or even in a period; but that the amount of this effect perceptibly changed in eras, can not be doubted. A standard clock if observed for a day may seem to run with an invariable and correct rate, but if observed long enough it is found to lose or gain, and this not regularly. The law of its variation may finally be partly ascertained, but usually it is too complex to be fully covered by a formula. Just so each geological force when more accurately known will be found to involve an irregular rate of change. The increment in an individual case for a certain length of time may be added or substracted, but it is not probable in any case that the addition or substraction will fully cover the real law, although this may be a second approximation to the truth as the so-called law of uniformity was a first approximation. If we go far enough back a geological force may have been multiplied or divided by two or three or a larger number. Igneous rocks are now a far less abundant geological product than are sedimentary rocks. That these relations are true for all past time can no more be assumed than it can that organic and mechanical sediments have the same relative volume for the pre-Cambrian that they have for the Cretaceous or Tertiary. If the generally accepted hypothesis as to the origin of the globe represents the facts, in all probability rocks of igneous origin must become relatively more important in very ancient times. If we but go back far enough they may become predominant; and in still earlier time for continental areas they may be the only rocks.

The problem then of the stratigraphy of the pre-Cambrian clastics is a problem to be treated precisely as that of the Paleozoic. It is, upon the whole, a more difficult problem; for, while in any particular locality it can not be premised from the degree of crystallization that the rocks are pre-Cambrian or post-Cambrian; taking the world as a whole, the rocks become more crystalline in passing to lower series; so that it is to be expected and is the fact that a greater proportion of pre-Cambrian rocks than of the Paleozoic are highly crystalline. This, however, is not the most serious difficulty with which pre-Cambrian stratigraphy has to contend; it is the sparseness of the remains of life in definitely recognizable forms. It has been seen that a beginning of a pre-Cambrian fauna has already been found, and when it is remembered how rapidly definite paleontological knowledge has extended downward in the past decade it may be reasonably hoped that before long assistance will be derived from paleontology in the classification of the pre-Cambrian rocks, but it can not be expected that fossils will ever be so important and controlling a guide as in the post-Cambrian; for probably the farther we go back from the Cambrian the sparser and sparser will the recognizable life-remains become.

As a result of the average greater crystalline character of the pre-Cambrian rocks, and the frequency in them of secondary structures, the principles of working out stratigraphy in regions in which cleavage foliation occurs with partial or total obliteration of stratification are of the utmost importance. The failure to clearly recognize and apply these principles has left the crystalline Cambrian and post-Cambrian series of the Appalachians in a state of confusion for many years. Within the last decade, by a recognition and a close application of them a new start has been made in the study of this difficult region.

That it will not do to regard slaty cleavage or foliation as bedding has long been recognized, although it has often occurred that in regions in which this has been distinctly stated it has also been said that bedding and cleavage do correspond without any evidence of such correspondence being given. If tangential thrust be assumed as the cause of foliation, unless the resultant folding be close, bedding and cleavage will usually not correspond for any considerable area; for cleavage and foliation have a tendency to develop transverse to the lines of pressure, while bedding is initially in the lines of pressure. In the closely folded series in which it may be said that resultant foliation and sedimentation correspond throughout, the use of the term bedding ought to be dropped, as there is no longer a basis upon which to estimate thickness, because in this case there must have been such an amount of movement of the particles within the beds over each other as to render it doubtful if bedding does still exist.

By the foregoing it is not meant to imply that the foliation of thoroughly crystalline rocks may not widely correspond with bedding, but only that this is not usually the case when tangential thrust is the cause of the foliation. However, Smyth (H. L.) has discovered when there is an alternation of beds of different degrees of massiveness that these often control the movements of accommodation during the folding of the series, and that the slipping of the particles over each other parallel to the bedding develops schistose structure along the same planes. It is not impossible that deeply buried beds may become thoroughly crystalline, with foliation and bedding parallel when superincumbent pressure and metasomatic changes are the predominant forces. A sufficient degree of heat for recrystallization may be engendered by very deep burying or by laccolitic intrusions. In such cases the structure of the recrystallized rock will naturally conform to the bedding, and it is probable that differences in the original characters of the layers will be preserved in the metamorphosed rock. A mica-schist or gneiss thus derived from a shale or an arkose, now showing in its interior structure no evidence of clastic character, might be underlain by a quartzite which was produced by the cementation of a quartzose sandstone. The quartzite at the present time would reveal its detrital origin, while the mica-schist or gneiss might not. Some such explanation seems to fit the thick beds of mica-schist (the structures of which unmistakably correspond with bedding) which overlie the quartzites of the Penokee series of Michigan and Wisconsin. A crystalline series of the origin suggested, which subsequently reached the surface by denudation, might be folded, but not sufficiently to produce a new secondary structure, when the different bands of different characters would truly represent sedimentary beds. Some such explanation seems to fit the gently folded thoroughly crystalline mica-schists and gneisses of the Blue ridge west of Old fort, North Carolina. In the Adirondacks, where the schistose structure and bedding of the Algonkian rocks appear to correspond, the great laccolites or batholites of gabbro are probably the chief cause of the metamorphism.

In crystalline series, when but one structure can be found, it is safe only to assume that it is foliation. Not only will it not do to use cleavage for working out structure, but an actual regular alternation of mineral constituents in schistose and gneissoid rocks can not be regarded as any evidence of sedimentation. The great series of regularly banded gneisses in which alternate zones of nearly pure quartz and feldspar and other zones in which the bisilicates are concentrated, if taken as due to sedimentation would result in the conclusion that the thickness of the beds in which these structures occur is incredibly great. In thoroughly schistose rocks it is manifest that the best and most reliable means upon which to base a conclusion as to strikes and dips is to find contacts between thick beds of rocks of a fundamentally different character, as a layer of quartzite, quartz-schist, or mica-schist, with limestone, or either of these with gneiss.

The clearest, briefest, and most comprehensive enunciation of the principles applicable to a formation in which are cleavage foliation and stratification foliation known to the writer is that of Dale and Pumpelly (see pp. 768–770), which is here quoted in substance, slight modifications being made to fit the change of setting:

I. Lamination in schist or limestone may be either stratification foliation or cleavage foliation, or both, or sometimes "false bedding." To establish conformability the conformability of the stratification foliations must be shown.

II. Stratification foliation is indicated by: (*a*) The course of minute but visible plications; (*b*) the course of the microscopic plications; (*c*) the general course of the quartz laminæ whenever they can be clearly distinguished from those which lie in the cleavage planes.

This statement was made with reference to a particular district. It is of course wholly possible that some other substance should play the same rôle as quartz. In the application of these criteria it must be premised that the parting is not a second or third cleavage. If an earlier cleavage existed the criteria might give the direction of this first one rather than the bedding, which might have become obliterated at the time of the development of the first cleavage.

III. Cleavage foliation may consist of: (*a*) Planes produced by or coincident with the faulted limbs of the minute plications; (*b*) planes of fracture, resembling joints on a very minute scale, with or without faulting of the plications; (*c*) a cleavage approaching slaty cleavage in which the axes of all the particles have assumed either the direction of the cleavage or one forming a very acute angle to it, and where stratification foliation is no longer visible; (*d*) a secondary cleavage, resembling a minute jointing may occur.

IV. The degree and direction of the pitch of a fold are indicated by those of the axes of the minor plications on its sides.

V. The strike of the stratification foliation and cleavage foliation often differs in the same rock, and are then regarded as indicating a pitching fold.

VI. Such a correspondence exists between the stratification and cleavage foliations of the great folds and those of the minute plications that a very small specimen properly oriented gives, in many cases, the key to the structure over a large portion of the side of a fold.

It is to be noted that the statement of these principles has been inspired by a study of formations which have proved to be wholly Cambrian or post-Cambrian.

The principles of lithological correlation enunciated by Irving are as follows, except that series is here substituted for group and Algonkian for Huronian so as to make the terminology correspond with that here used:

Lithological characters are properly used in classification:

(1) To place adjacent formations in different series, 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 together in a single series adjacent formations because of lithological similarities when such similarities are used as confirmatory evidence only.

(3) To correlate series 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 series 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 series 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 series 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, i. e., those which underlie the clastic series here called Algonkian, at least until very much more definite evidence of the existence of such subdivisions be gathered than has hitherto been done.

In applying these principles it must not be forgotten that a bed of one character may thin out and disappear; may gradually change from a limestone to a shale, from a shale to a sandstone or conglomerate; and that sometimes the change may be abrupt, as perhaps upon the opposite sides of an axial ridge, one side of which faces toward the ocean and the other toward an interior sea. All formations, however widespread, terminate somewhere. A single formation of a certain lithological character can only be assumed to be the same bed in a district when it has been demonstrated to be persistent over a wide area. When several characteristic formations occur in a definite order in different parts of the same district the probability that they are of identical age is greater than with single beds found to be lithologically alike at separate points.

The principles applicable to correlation by unconformities are given by Irving as follows:

The structural breaks called unconformities are properly used in classification:

(1) To mark the boundaries of the rock series 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 series 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.

Irving's discussion leading to these principles shows that oftentimes unconformities are the most widespread and important of any of the means available to obtain starting planes for comparisons and that they have the place of first importance in making the major subdivisions for the origin of the pre-Cambrian clastic rocks. An erosion interval can only occur as a result of the raising of a district above the sea, a time of degradation, and then a depression below the sea; and if there is a true unconformity there must also have been an orographic movement and erosion long enough continued to truncate the folds. The erosion interval, if extended over a large area, implies a considerable time break; while the unconformity, if it is marked, can hardly be less than regional in extent. When the newer series is undisturbed, an unconformity is one of the easiest of phenomena to detect, but more frequently than not among the pre-Cambrian rocks the older and newer series have again been folded, and this folding has oftentimes gone so far as to produce a cleavage or foliation, which cuts across both older and newer series and makes their most prominent structure in absolute conformity. Even if this degree of folding has not occurred and the process has not gone far enough to produce prominent secondary structures, the discordance in angle of inclination is more likely to be overlooked than when the series are in an undisturbed condition.

Since unconformities are so valuable in structural work, it is important that the principles be clearly recognized upon which they may be established in disturbed regions. This subject has been discussed at length by Irving, and from his paper the substance of much which follows is taken. An unconformity between series implies a difference in number of orographic movements with intervening erosion. This difference in number may be one or more than one. Even when the difference of orographic movements to which the series have been subjected is but one the time gap between the two must have been very considerable, and it may have been of vast duration. Consequently discordant series may differ in degree of consolidation, in the development of cleavage and foliation, and in their relations to eruptives. At the beginning of the deposition of the newer series basal conglomerates are often formed.

Hence, as guiding phenomena in the discovery of unconformities, we have (1) ordinary discordance of bedding; (2) difference in the number of dynamic movements to which the series have been subjected; (3) discordance of bedding of upper series and foliation of lower; (4) relations with eruptives; (5) difference in degree of crystallization; (6) basal conglomerates; (7) general field relations.

(1) In cases of ordinary discordance of bedding nothing need be said, except to state that unconformities should not be inferred from a single small contact where the apparent discordance may be due to false bedding or to local currents or very local minor disturbances. Also, the discordances caused by faulting may be mistaken for an unconformity if care is not taken. The amount of evidence for the unconformity should be sufficient to show a real discrepancy of bedding for a considerable area. Within a short distance the amount of discordance of bedding between two series may vary greatly. Frequently a dynamic movement mainly relieves itself along a comparatively narrow zone. This zone is one of uplift and consequently of great denudation. The adjacent plain may be little folded and not deeply eroded. When a new series is deposited upon this older series the former lies approximately parallel to the bedding of the older upon the plain, but along the zone of disturbance the first may lie directly athwart the bedding of the second.

(2) Difference in the number of dynamic movements to which the series have been subjected is often an important means of determining unconformities. In order that an unconformity shall occur the older series must have been subjected to at least one more orographic movement than the newer. In the most favorable case the older series has undergone two or more orographic movements while the newer series has undergone but a single one. When the lines of these movements are in the same direction and result in folding the only difference between the two series consists in steepness of inclinations; but in case the earlier movements were in a different direction from the last the older series will show a compound series of folds due to the resultant effect of the two or more movements, while the newer series will be simply folded. As a matter of course, in this discrimination, bedding must be used rather than foliation. Oftentimes it will happen that the latest movement has produced a prominent cleavage or foliation which is common to both older and newer series; and under these circumstances the real discordance which may exist between the two series is particularly apt to be overlooked, and a district will be described as having a simple monoclinal structure, or one in which the series is reproduced by faulting, when evidence is at hand for two or more discordant series.

The orographic movements, instead of producing folding, may cause jointing or faulting, these results, as suggested by Willis, being perhaps due to insufficient load. These phenomena are, however, serviceable in discovering an unconformity, for the sets of faults or joints produced in the older series before the newer series was formed are not found in the latter. When there have been later orographic movements which have produced faults or joints in both series the unconformity will be shown by the presence in the older series of two sets of joints or faults in different directions, provided the directions of thrust were different, while the newer series will be affected by joints or faults only in a single direction. If the jointing or faulting is in the same direction in both the newer and older movements they will not be of much service in detecting an unconformity, the only difference being their greater frequency in the older series.

When one of the orographic movements has resulted in folding and the other in faulting or jointing, the combination of phenomena are as easily used to detect an unconformity as when effects of the same kind are produced by both movements.

(3) Discordance of the bedding of an unfoliated series with the cleavage or foliation of an adjacent series may be taken as evidence of unconformity, if the former is such that it would take on cleavage or foliation as readily as the latter; for whatever the origin of the altered series the development of cleavage or foliation, which must have developed before the new series was deposited, required much time. An unconformity could not be inferred from the fact that a heavy formation of quartzite or of limestone cuts across the cleavage or foliation of an argillite or mica-schist, for clayey rocks very much more readily take on secondary structures. In the same series it often happens that more massive beds escape foliation, which may be prominently developed in other members. But if a formation with slaty or schistose structure is overlain by another formation without secondary structure which from its composition is as likely to take on foliation as the underlying formation, a discordance, while not demonstrated, is a probability for which other evidence should be sought.

(4) Eruptive rocks are often an important guide in determining structural discordances. These are valuable when the older series has passed through an epoch of eruptive activity before the newer series was deposited. In such cases bosses, contemporaneous or intrusive beds, volcanic fragmental material or dikes may occur in the older series, which nowhere are associated with the newer. It is possible, of course, that eruptives may penetrate the inferior members of a series and never reach the higher formations; but if it is found that the supposed inferior series is associated with abundant material of igneous origin which never passes beyond a certain plane, it is almost demonstrative evidence of the later age of the newer series. A notable instance of this is found in the Doe river section of eastern Tennessee, where the granitic rocks supposed to be older than the associated clastics are cut by very numerous schistose dikes which never

intrude the latter. It might be reasonably inferred, if it were not for these dikes, that the granitic rock is an eruptive later than the clastics (although the absence of contact phenomena would be against this), but as the basic dikes are unquestionably intrusives of later age than the granites, and yet never cut the slates, this explanation can not possibly apply. Evidence of this kind is particularly decisive if the dikes are traced up to the plane of contact and have been found to be eroded or disintegrated, as is the case in the Stamford dike at Clarksburg mountain, Massachusetts, described by Pumpelly, which enabled this author to determine positively what had been believed before, that the granitoid gneiss is unconformably under the Cambrian quartzite.

(5) Closely connected with (3) and (4) is degree of crystallization as a guide to unconformities. It has been seen that crystalline character is often taken on in proportion as dynamic action occurs. When the folding, which has affected only the older series, has been severe, it as a whole will be more crystalline in character than the newer. Also the presence of igneous material is often a potent factor in the production of crystalline character. As, however, recrystallization is also produced by metasomatic change, this criterion must be used with caution and as a cause to search for other evidences of an unconformity rather than alone as a basis upon which to infer an unconformity. But even difference of amount of metasomatic change, if the rocks are equally likely to be affected by these processes, may be evidence of difference in age. In determining degree of crystallization the modern petrographical methods serve one of their most useful purposes, since many rocks which in exposure or in hand-specimen appear to be about equally crystalline, are shown in thin section to be of a fundamentally different character. A completely crystalline rock sometimes can not be discriminated macroscopically from one which is merely indurated by cementation. For instance, a thoroughly crystalline granite and a recomposed rock built up of the débris of this granite, especially when the particles are in the form of individual minerals, rather than pebbles, present much the same appearance in mass, but a glance at sections of the two under the microscope shows the thoroughly crystalline interlocking character of the one and the clastic character of the other. Another case quite as marked is the discrimination between much foliated eruptive rocks which have passed over into fissile schists and ordinary argillaceous slates and graywackes. In the latter class the particles of quartz and feldspar may be seen with their oval forms as regular as the day in which they were deposited, while in the other case an entirely different appearance is presented.

(6) Basal conglomerates are one of the most important means of determining a plane of unconformity, but it must be clearly shown that the conglomerate is really a basal one. Conglomerates may occur in other positions than at basal horizons, and it will not do to assume

that an unusually conglomeratic layer is basal. A conglomerate is likely to be basal when the major portion of the débris is derived from the immediately subjacent member; but even here the exception must be made that in case this subjacent member is a surface igneous rock the presence of the conglomerate is no evidence of a time break. If, however, the igneous formation is of such a character as does not originate except as a deep-seated rock, the fact that it is at surface and yields fragments to the overlying formation is evidence of a time gap. Also evidence of a break is just as decisive when the underlying rock has a foliation which has been produced prior to the deposition of the conglomerate. This may be determined from the fact that fragments broken from a foliated rock are apt to be longer in the direction of lamination, and when deposited in the overlying series they naturally lie with their foliation at an angle to that of the underlying series. It matters not whether the foliated rock of the inferior series be of sedimentary or of igneous origin. If sedimentary, a long time has been required to obliterate evidence of its fragmental character; if igneous, its foliation shows the effect of long-acting forces. While basal conglomerates are often found they are also often absent where other evidence shows that there are discordant relations between two series. This absence is explained, at least in some cases, by Pumpelly's disintegration theory, the encroaching shore line finding a set of disintegrated rocks in which the mass is ready to yield particles of the constituent minerals rather than pebbles.

(7) General field relations are often sufficient to establish discordant relations between series when all other lines of evidence are lacking. When in a region immense stretches of rocks of one series are always found in an undisturbed condition, while an adjacent series is always disturbed, discordant relations may be inferred. This is particularly evident when the horizontal series fills bays in the older rocks, or is found as inliers surrounded by the other rocks. Again, the general field relations may establish an unconformity even if both series are disturbed. One case of this is the occurrence of a uniform belt of stratified rocks which, perhaps with a monoclinal structure and a somewhat uniform strike and dip, runs for great distances, the rocks of the adjacent unconformable series being here of one kind and there of another kind. The evidence for the unconformity in this case is still further emphasized if the lower series, instead of having a simple structure, is folded in a complex manner. General field relations may betray unconformity even when the newer series has been folded in a more complex manner, as, for instance, having been subjected to two orographic movements, the first of which placed it in a monoclinal attitude, and the second of which, at right angles to this first force, gave it a fluted structure. The lower series, instead of having this regular structure, being subjected to still earlier orographic movements, would be more irregular in its foldings and faultings, and the difference

in simplicity of structure of the two series would increase in proportion to the number and intensity of the earlier movements. However, as the movements which have affected the newer series increase, the difficulty of discovering discordances by general field relations is increased. These and other cases of general field relations which show unconformity may not appear to the observer while doing detailed work, since no contacts or other ordinary indication of unconformity is found, but strongly appear when the work is platted. To the mind of the writer general field relations of the kinds above cited are sometimes more decisive evidence of unconformity than almost any kind of local relations. When the local proofs above considered, combined with general field relations, unite as evidences of unconformity, as is generally the case if the worker takes advantage of all the facts available, the accumulated evidence for discordant relations, even in difficult and folded regions, is often decisive.

Unconformities have been frequently inferred on insufficient ground. This has sometimes resulted from regarding surface igneous rocks as sedimentary, and the basal conglomerate overlying such a formation as evidence of unconformity. More frequently the misinterpreted evidence of unconformity is a discordance in foliation; sometimes cited as occurring in actual contact, but at other times being a discordance only in the strike and dip of foliation at some distance. A contact discordance of foliation or bedding may occur as a result of faulting. The strikes and dips of banded and contorted schists and gneisses often vary so greatly within short intervals that a difference of this kind can not be taken as an indication of discordances. This error has occurred because it has been assumed that cleavage foliation accords with sedimentation. When it is practically, not theoretically, recognized that this structure is secondary—may be produced in either sedimentary or igneous rocks—and that it generally does not correspond over large areas with bedding, such evidence will cease to be used as indications of structural discordance.

The application of the foregoing principles demands that in working out the structure of the crystalline formations the ground must be gone over in detail. No single section will be adequate to give a proper idea of the structure, nor will it do to consider that as a result of several or a dozen sections the structure of a large district may be worked out and the formations mapped, as has been too frequently done. Formations which outcrop in one section may not be exposed in another, or a formation between one section and the next may entirely change its character or disappear altogether. If the district is a difficult one the only safe way is to take advantage in the field of all available overground and underground facts, and to collect abundant material for supplementary office work. When only one structure is present and the character of that the least doubtful, it must not be assumed to be bedding. In regions in which the exposures are infrequent it may be impossible to work out the structure of crystalline rock series which have a true detrital succession, but it is better for the present and the future that no structure be presented than a false one.

After working out the structure of one district in a geological basin, adjacent districts may be mapped much more rapidly. Under proper checks the lithological character of individual beds may be assumed to remain the same. Sets of like formation occurring in the same order may be assumed to be the same group of formations. And perhaps most useful of all are discordant relations between series. In correlations from region to region, without the assistance of paleontology it will probably not be possible to carry the analogy further than series; and in far distant regions even the general lithological likeness and similarity of position of series is not sufficient warrant for placing them opposite each other in the time column.

If the foregoing principles are true, it is plain that in working out the structure of a new region local names should be applied to the formations and series. When the time comes that fuller knowledge enables them to be safely correlated with the series to which classical names have been applied, this may be done, and the local names will not be less serviceable to designate particular parts of these general series.

The area in North America in which detailed mapping has been done with a resultant proper understanding of the structural relations of the pre-Cambrian is surprisingly small. Scarcely a crystalline area on the continent has escaped the rapid geologist who has passed over a region and upon a few facts of uncertain value publishes structural conclusions which are not to be verified by future work. The districts carefully studied include the original Huronian of lake Huron, several small areas about Ottawa and between the Ottawa river and lake Ontario, a few small areas about the lake Superior region, a small part of western Massachusetts and a part of Maryland. Even in these districts the work at many points is rather old and to a certain extent unsatisfactory. Before reliable maps can be obtained this old work must be thoroughly revised in the light of the recent advances in the methods of study of the crystalline rocks. By this it is not implied that the more general work done is not of superlative value and of necessity must precede the more accurate accounts. A beginning has been made in American pre-Cambrian stratigraphy, but the great mass of work remains for the future.

RESULTS IN AMERICA AND EUROPE COMPARED.

This volume has already become too long to attempt to make a detailed comparison between America and Europe as to the results reached in pre-Cambrian stratigraphy. Also, I am wholly unfamiliar with European ground and am but imperfectly acquainted with the literature; hence I would not be warranted in making the attempt, even if space permitted. It may, however, be well, without giving any detailed facts or reviews of literature, to mention the opinions which appear to be prevalent in reference to the pre-Cambrian of Europe.

In the first place, it is not universally held that in Europe there are pre-Cambrian clastics. It is probable that this difference of opinion results in part because it is not agreed as to the lower limit of the Cambrian. If this could be settled it would be comparatively easy to decide as to the existence of pre-Cambrian sedimentaries.

Nowhere has there been in the past a wider difference of opinion on this question than in Great Britain, but now the consensus of opinion appears to be that pre-Cambrian clastics, either water-deposited or volcanic, or both, occur at various places. The officers of the official survey have, until very recently, denied that such rocks occur; but the Director-General states, in a late paper, that in western Scotland, associated with the fundamental gneiss, are small areas of schist and limestones which are possibly sedimentary; that within the complex of rocks in Scotland, for which the term Dalradian is proposed, there are probably pre-Cambrian clastics both of sedimentary and volcanic origin, and that Callaway is correct as to the pre-Cambrian age of the Uriconian volcanics. Still more recently it has been announced that the Torridon sandstone, 8,000 or 10,000 feet thick, which contains traces of annelids and other obscure organic remains, lies unconformably below the Olenellus Cambrian and must therefore be classed as pre-Cambrian.

The head of the official survey of France, Michel-Lévy, states that in the pre-Cambrian are placed only those rocks which are completely crystalline and which antedate all the clastic series. The Cambrian is delimited below by the appearance of the first layers, which are incontestably clastic. It passes insensibly into the crystalline rocks regarded as pre-Cambrian. The Cambrian is delimited above by the overlying accordant or discordant strata-bearing fossils. The rocks placed in the Cambrian are for the most part nonfossiliferous, and, while clastic as a whole, are locally much altered by contact action and are more crystalline than the later formations. The foregoing positions are very different from those held by Barrois, another of the official geologists. This author holds that in France there is at least one series of pre-Cambrian rocks of clastic origin to which he has applied the term Huronian.

In Germany there is a radical difference of opinion between the leading geologists as to whether pre-Cambrian clastics exist, although a large majority maintains that belonging here are the Obermittweida conglomerate and similar rocks in other localities. Others hold that these rocks are in folded parts of the Cambrian or post-Cambrian. The commonly accepted classification of the pre-Cambrian rocks, according to Lossen, is as follows: (1) Urgneiss or fundamental gneiss, which in places is rather a granite than a gneiss. Toward the top, the formation takes in beds of limestone, quartzite, and amphibolite, generally, however, without any vestige of clastic character. Above the Urgneiss follows (2) the Urglimmerschiefer, which passes into (3) the Urthonschiefer or Phyllit, and this contains younger gneiss formations. This classification has a structural basis to a certain degree, but seems to be primarily lithological. Credner, in the last (seventh) edition of his Elemente der Geologie, places the Urgneiss as the equivalent of the Laurentian and the Urschiefer, including here the Urglimmerschiefer and Urthonscheifer as the equivalent of the Huronian of North America.

In Norway the director of the official survey, Dr. Reusch, considers that it has been shown that there are in that country pre-Cambrian clastics which are overlapped by the Cambrian. De Geer maintains that there are pre-Cambrian rocks in Sweden which are unconformably below the Cambrian. Reusch is inclined to exclude these rocks from the Archean, the latter being restricted to the fundamental complex. If these results be accepted it follows that in Scandinavia there are rocks which take a position represented in America by the Algonkian.

The inclination to limit the term Archean to the fundamental complex is rather widespread in Europe, without reference to whether pre-Cambrian clastics exist or not. Many of those who hold that pre-Cambrian clastics occur are disposed to give them distinctive names. As in America, no structural methods have been applied to the fundamental complex.

Rigidly defining the Archean to cover the basal crystalline complex and excluding from it all clastic rocks, we have in England, France, Germany, and Scandinavia equivalents of the Algonkian of America, if those geologists are right who maintain the pre-Cambrian character of the clastic rocks mentioned.

No attempt has been made, except in Great Britain, to subdivide into series the rocks equivalent to the Algonkian. The review of the facts in America has led to the conclusion that it is not practicable to make correlations over the whole continent of a more definite nature than Algonkian and Archean. If this be true, it is evident that correlations can not be more definitely made between European and American rocks. The application of such American terms as Huronian and Keweenawan to European series is wholly unwarranted.

If the suggestion be correct that the Archean is of a different character from any succeeding formation and has a continental extent in America, it may be safe to regard the fundamental complex of Europe as its equivalent. If this be done and Cambrian be delimited below by the Olenellus fauna, it would be safe to say that the intervening series of rocks occupy some position in the great Algonkian system. But any given series of the Algonkian of Europe can not safely be placed opposite a definite series in this country until there shall be found paleontological evidence for so doing.

Even if the Cambrian in Europe were rigidly delimited below by the

Olenellus fauna and all doubtful series barren of fossils were regarded as pre-Cambrian, it would still be true that the rocks thus referred to the Algonkian system would be insignificant in amount and extent as compared with the great areas and volumes here included in America. It would also be true that the structural work upon such series has not progressed so far. This is probably in large measure due to the non-occurrence of such volumes of Algonkian rocks in Europe as exist in America; but it is also due in part to the fact that in that portion of Europe which has been most closely studied there have been since Cambrian time repeated powerful dynamic movements and periods of great eruptive activity. The conditions are much the same as in the eastern United States, where a study of pre-Cambrian stratigraphy has barely begun. In the interior of the American continent the conditions have been far more favorable for a structural study of the pre-Cambrian rocks.

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INDEX.

B.

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L.

T.

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