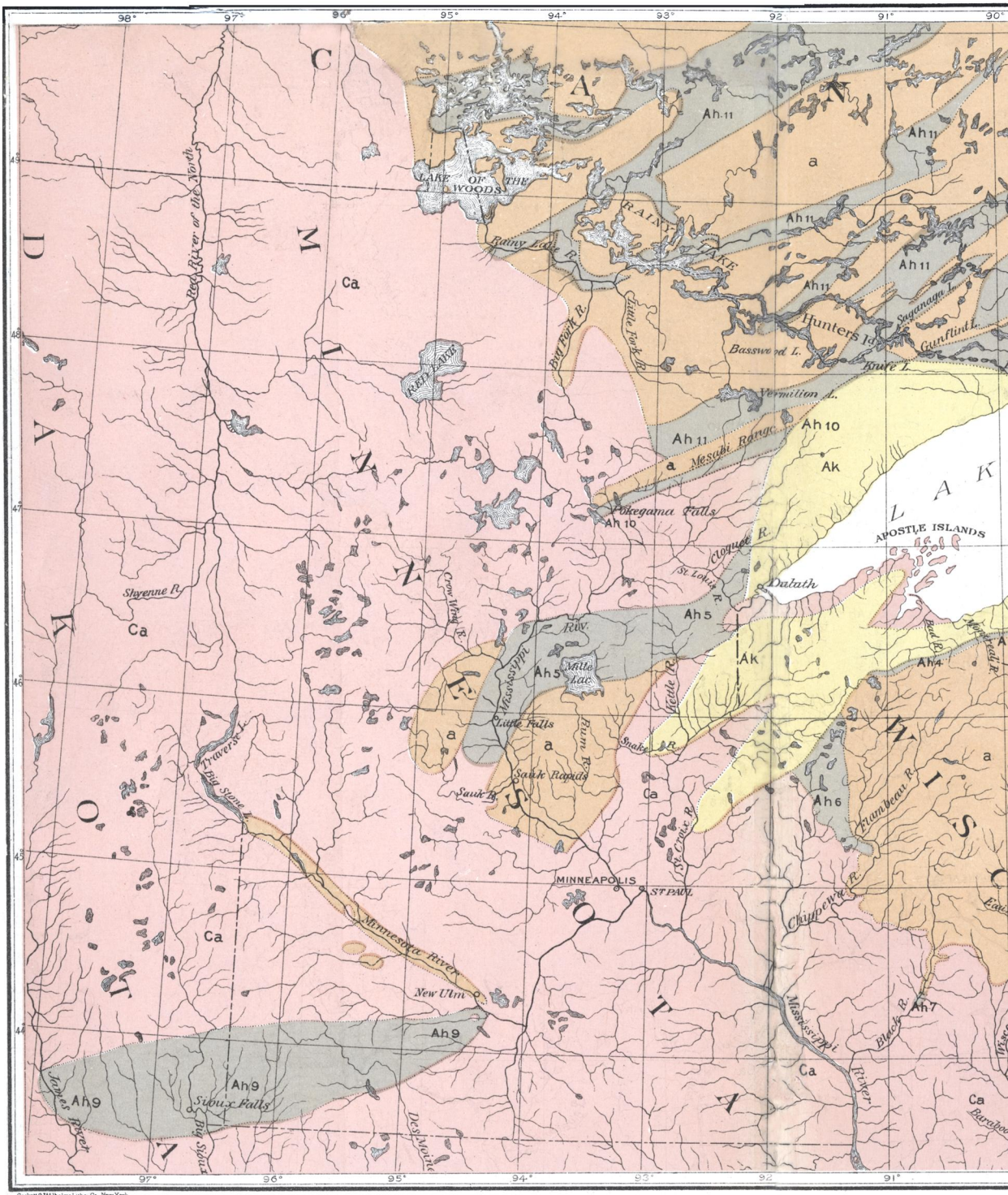


ARCHEAN | ALGONKIAN | Huronian | Keweenawan

a | Ah | Ak

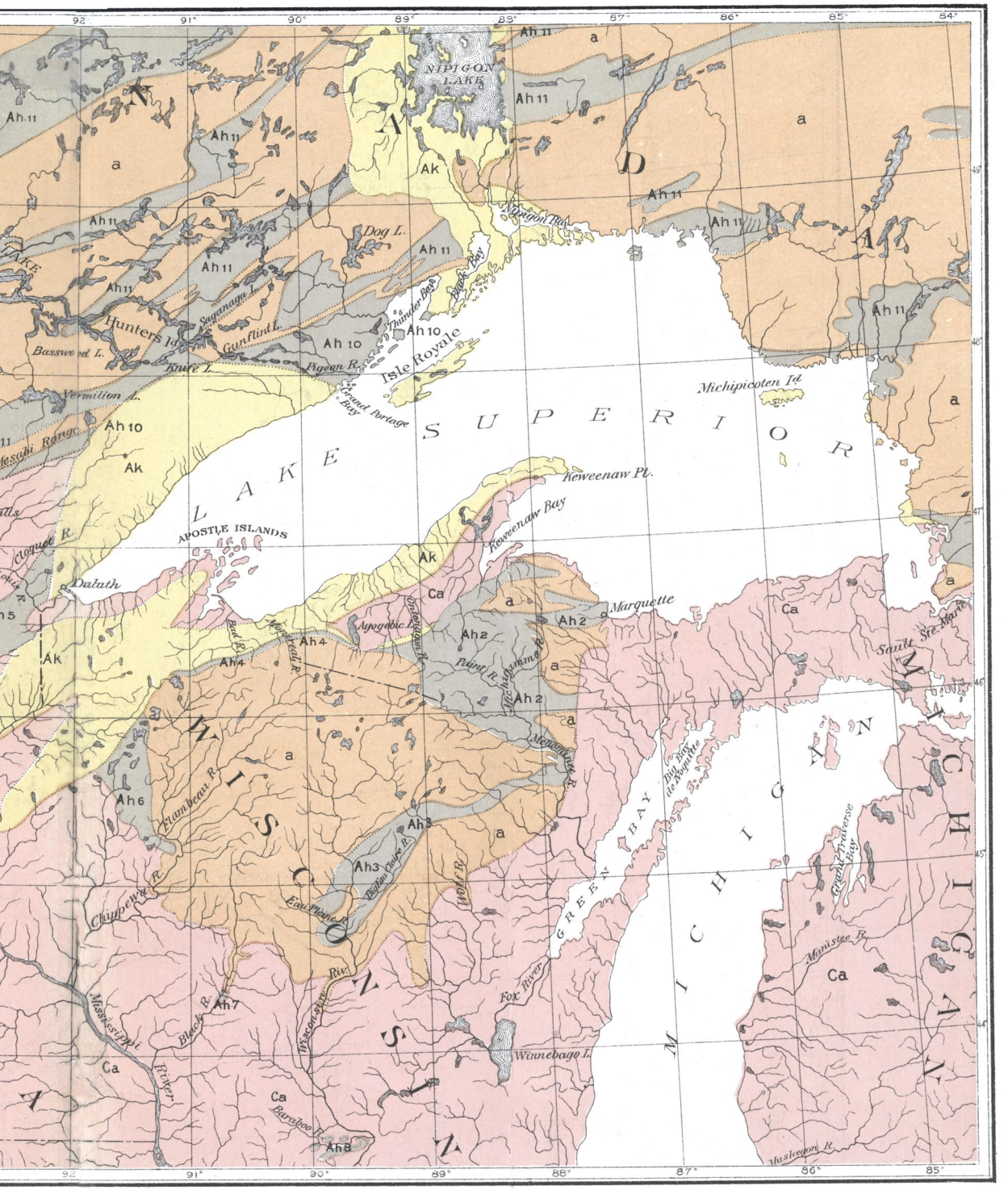
GEOLOGICAL MAP OF THE LAKE SUPERI

SHOWING PRE-CAMBRIAN AND CRYSTALLIN

Compiled from Official Maps of U.S. and Canadian Surve

Scale

0 50 100



ALGONKIAN

Huronian — Ah

Keweenawan — Ak

POST-ALKONKIAN — Ca

MAP OF THE LAKE SUPERIOR REGION

PRE-CAMBRIAN AND CRYSTALLINE ROCKS.

Compiled from Official Maps of U.S. and Canadian Surveys.

Scale

50 100 150 STAT. MI.

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.

THE

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AN HISTORICAL SKETCH OF THE LAKE SUPERIOR REGION TO CAMBRIAN TIME.[1]

(WITH PLATE I.)

THE ancient formations south of Lake Superior may be grouped into five great divisions: the Basement Complex, the Lower Huronian, the Upper Huronian, the Keweenawan, and the Lake Superior Sandstone. These five divisions are separated by unconformities of great magnitude, two of them at least being of the first order. According to the classification adopted by the United States Geological Survey, the Basement Complex is Archean; the Lower Huronian, Upper Huronian and Keweenawan constitute the Algonkian for this region; and the Lake Superior Sandstone is Cambrian.

The Basement Complex.—The characteristic rocks of the Basement Complex are (1) light colored granites and gneissoid granites, and (2) dark colored finely foliated or banded gneisses or schists. These are cut by various basic and acid intrusives, many of which are not different from eruptives

[1]In this very general article no attempt will be made to give references to the many authors from whom facts are taken. To give full credit for all information used would require citations from scores of papers. The writer gives a summary of the literature of the Lake Superior Region in Bulletin 86 of the U. S. Geol. Survey.

Many of the problems considered have no definite answers as yet. The aim of the article is to give a summary of the very limited knowledge available on a subject that has not before been considered, because the data were not at hand upon which to base any reliable conclusions.

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found in the later series, with which they are doubtless in part continuous.

The granites and gneissoid granites are placed together, because between the two are constant gradations. If one speaks accurately and includes among granites only those rocks which are completely massive, the gneissoid granites include the greater part of the granitic rocks; for in large exposures it is usually possible to find some evidence of foliation. The granitoid areas are of greatly varying sizes, running from small patches to those many miles in diameter. When everywhere surrounded by the schistose division of the Basement Complex, they frequently have oval or ovoid forms. In nearing the outer border of the granitoid areas, the foliation often becomes more and more prominent, and near the edge of an area the rock frequently passes into a well laminated gneiss.

The schistose rocks include fine grained hornblende-gneisses, mica-gneisses, chlorite-gneisses, and various green schists, formerly supposed to be sedimentary, but now known to be greatly modified basic and acid igneous rocks. These schists have usually a dark green or black color, are strongly foliated, and the variations in strike and dip of this foliation, within small areas, is very great. Not infrequently the schistose rocks are traced by gradations into massive igneous rocks.

The contacts between the schistose division and the granitoid division of the Basement Complex are usually those of intrusion, the granitoid rocks being the later. In passing from a schistose to a granitoid area, small pegmatitic looking veins of the granite are first found. In going onward these veins become more numerous and, after a time, unmistakable dikes of granite appear, which multiply in number and size in approaching the granite area, until the granite is found in great bosses. Here we have perhaps a nearly equal quantity of schistose and granitoid rocks, and in this intermediate zone the schists may be found as a mass of blocks within the granite, sometimes at but small distances from their original positions, the whole having frequently a somewhat conglomeratic appearance. However, these pseudo-

conglomerates, so well described by Lawson, grade more or less rapidly on the one hand into the schists, and on the other into the solid gneissoid granite. The complete change may occur within a short distance, or it may take a mile or more.

The Basement Complex is then composed of intricately interlocking areas of granitoid rocks and schistose rocks. Moreover, all of these rocks are completely crystalline. None of them show any unmistakable evidence of having been derived from sedimentaries, but many can be traced with gradations into massive rocks, and therefore the greater proportion of them are igneous, if a completely massive granular structure be proof of such an origin.

The Basement Complex is the most widespread of any of the Lake Superior systems, and it doubtless runs under all later formations to a greater or lesser distance. That it is continuous under all such formations can not be asserted, for while it was once so, it is possible, perhaps even probable, that in places, as a consequence of sedimentation and folding, the Basement Complex has been so deeply buried, that fusion has locally resulted. It is even possible that such fused material is a partial source of the later volcanic eruptions.

Before the earliest sedimentary rocks were deposited, the Basement Complex was subjected to enormous orographic forces, which folded and sheared the rocks in a most intricate manner. Accompanying the great orographic movements, which undoubtedly occupied a vast period of time, were intrusions of various deep seated igneous rocks, and also doubtless their volcanic equivalents were extruded. Subsequent to, and during the orographic movements, atmospheric forces were at work. Erosion continued long after the mountain-making folding had ceased, and, for much of the Lake Superior region, reduced the Basement Complex nearly to a plain or base level. As evidence of this may be cited the fact that, at the end of the erosion interval, the Basement Complex, consisting of differing lithological materials, and therefore having a variable resisting power, did not vary in altitude more than a few hundred feet for long dis-

tances. Whether this denudation extended everywhere deep enough to remove all surface volcanic material, and to leave only deep seated igneous material, is undetermined. At the beginning of the Lower Huronian time, the Basement Complex was, in the Lake Superior region, a universal system.

The Lower Huronian.—After the forces of erosion had nearly exhausted themselves, there was the first advance of the sea over the Lake Superior region of which we have any evidence, as a result of which the Lower Huronian was deposited.

The well-known characteristic rocks of the Lower Huronian, are (1) conglomerates, quartzites, quartz-schists and mica-schists, (2) limestones, (3) various ferruginous schists, (4) basic and acid eruptives, which occur both as deep seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward.

The inferior formation is usually a quartzite or a feldspathic quartzite. Where metamorphism has been severe it passes into a quartz-schist, mica-schist or gneiss. The lowest horizon of the formation is in places a coarse conglomerate, and this when metamorphosed may become a conglomerate-schist. This conglomerate is of two types, depending upon the character of the underlying formation, which is here granitic and there schistic. The limestone formation, when at its maximum, is of very considerable thickness. The limestone is magnesian and so very crystalline as to make the name marble appropriate. It frequently contains a considerable amount of chert. In places it may be divided into two horizons, one of which is nearly pure marble, and the other nearly pure chert. At other times the limestone becomes very siliceous by a mingling of fragmental quartz, while zones of wholly fragmental material may occur. These impure phases are often at the lower part of the limestones, where they may be considered as a transition from the underlying formation. The formation overlying the limestone is usually known as the iron-bearing member, since it contains all the ore bodies of the Lower Huronian. It has varied aspects, but the different varieties grade into one another both vertically and

laterally, so that when one becomes familiar with them, the rocks of the formation may invariably be recognized. Here are included hematitic and magnetitic schists, cherts, jaspers, ferruginous carbonates, and other forms. The formation always differs from the limestone in carrying a very considerable amount of iron, and it differs from the quartzite in being largely, and sometimes wholly, a chemical or organic sediment, rather than a mechanical one.

The three members of the Lower Huronian are not often seen in a single section. This may be due to lack of exposures, but in some cases is undoubtedly due to the absence of one or more of the formations themselves.

In the Lower Huronian, basic eruptive rocks are abundant, and locally cover considerable areas. Not infrequently acid eruptives also occur. These eruptives include both contemporaneous volcanics and subsequent intrusives. If the Keewatin of Lawson about Rainy Lake and the Lake of the Woods is Lower Huronian, great granitic masses have been intruded into this series northwest of Lake Superior.

Equivalent to the Lower Huronian series of the north shore of Lake Huron are placed the following iron-bearing districts: Lower Vermillion, Lower Marquette, Felch Mountain, in large part, Lower Menominee, the cherty limestone formation of the Penokee district; and probably the Kaministiquia series of Ontario, and the Black River Falls series of Wisconsin. Whether all of these detached basins were once connected by continuous sediments is unknown, but probably they were.

The fragmental material of the Lower Huronian was derived from the Basement Complex. This fragmental formation is usually thin. This doubtless means that the advance of the sea over the Lake Superior region was comparatively rapid. The directions from which the Lower Huronion sea entered, and the extent of its trangression, is at present unknown. By certain of the Canadian geologists it is held that the structural break which exists between the Basement Complex and the Lower Huronian, south of Lake Superior and north of Lake Huron, does not exist

in the region of Rainy Lake and Lake of the Woods, northwest of Lake Superior. If this conclusion be true, the sea did not advance as far as the Lake of the Woods, this district perhaps being above the ocean, and one of the sources of detritus throughout Lower Huronian time.

The extent of the Lower Huronian deposits is also uncertain. If the series of the districts above placed in the Lower Huronian, are correctly correlated, Lower Huronian basins occurred in various places over a great triangular area extending from Black River Falls in Wisconsin, to northeastern Minnesota, and thence east to the north shore of Lake Huron. Doubtless Lower Huronian rocks also occur in the great northern region of Canada, and they may have had a much wider original extent than this, but no data are now available to locate such a possible extension.

Of the original thickness of the Lower Huronian deposits we are also ignorant. The present thickness has not been determined south of Lake Superior, but according to Logan, on the north shore of Lake Huron, including the interstratified volcanics, the thickness is five thousand feet.

At the end of Lower Huronian time, the Lake Superior region was raised above the sea, folded, and subjected to erosion. The orographic movements of this time were very severe, closely crumpling in places the rocks of the Lower Huronian, and inducing in them in many places a schistose structure. In other localities, away from the axes of great disturbance, the Lower Huronian rocks were but gently tilted, as is shown by the small discordance in places between them and the succeeding series. In certain localities the areas of great disturbance are but a short distance from those of comparative quiet. The denudation was deep enough to wholly remove the entire series over wide areas, and to cut to unknown depths into the Basement Complex itself. As has been stated, the Lower Huronian has an estimated thickness of about one mile on the north shore of Lake Huron, and in different localities varies from this thickness to entire absence, depending mainly upon the differing deundation. This variabil-

ity may possibly be due in part to highlands of the Basement Complex, which were not covered by the Lower Huronian sea until the period was well advanced. Of the extent of the series at the end of the erosion preceding Upper Huronian deposition, little has been determined, since later erosions have undoubtedly removed large areas of the series, and therefore its present distribution is not a safe guide to its distribution at the close of the erosion interval referred to.

The Upper Huronian.—At the close of the long period of erosion which followed the Lower Huronian deposition, the water once more advanced upon the Lake Superior region, and the Upper Huronian series was deposited.

Lithologically this series consists of conglomerates, quartzites, graywackes, graywacke-slates, shales, mica-schists, ferruginous slates, cherts, jaspers, ferruginous schists and igneous rocks, including both lava flows and volcanic fragmentals, as well as basic and acid intrusives. The series, as a whole, is very much less crystalline than the Lower Huronian, although locally the shales and graywackes have been transformed into mica-schists, and even into gneisses.

The Upper Huronian immediately about Lake Superior is divisible into three formations, a lower slate, an iron-bearing formation, and an upper slate, the basis of separation being that of mechanical and non-mechanical detritus. The inferior formation is mainly a quartzose slate or shale, but locally it passes into a quartzite, while the basal horizon is frequently a conglomerate. The nature of this conglomerate varies greatly, depending upon the character of the underlying formation, which, in some areas, is the Basement Complex, and in others the Lower Huronian. In the first case the slates may rest upon the gneissoid granite, upon the schists, or upon the junction of the two. The basal conglomerate corresponds in its character, being a recomposed granite or granite-conglomerate, a recomposed schist or schist conglomerate, or finally a combination of the two.

When the lowest member of the Upper Huronian rests upon the Lower Huronian series, the underlying formation may be

any one of the three formations of the Lower Huronian. As a consequence the basal conglomerate may consist mainly of the fragments of any one of these formations, or of all of them together. Not infrequently detritus, derived from the Basement Complex, is mingled with that of Lower Huronian origin. However, as a consequence of the resistant character of the jaspery iron-bearing formation of the Lower Huronian and of mining operations, the discovered contacts are most frequently between the Upper Huronian and this iron-bearing formation. In the basal conglomerate or recomposed rock at these points, the characteristic fragments are chert, jasper, and other ferruginous materials, and it is locally so rich in iron as to bear ore-bodies. The uppermost horizon of the lower slate of the Upper Huronian in the Penokee district is a pure, persistent layer of quartzite. The central mass of the formation is a graywacke or graywacke-slate, passing in places into a shale or sandstone.

Above the lower slate is the iron-bearing member, consisting of various ferruginous rocks, including cherts, jaspers, magnetite-actinolite-schists, iron ores, and ferruginous carbonates. It has been shown that all these varieties have been mainly derived directly or indirectly by transformation from an original lean, iron-bearing carbonate, which was of chemical or organic origin, or a combination of both. Mingled with these non-mechanical sediments is a greater or lesser quantity of mechanical detritus.

Above the iron-bearing formation is the upper slate formation. This is mainly composed of shales frequently carbonaceous or graphitic, slates, graywackes and mica-schists, often garnetiferous and staurolitic. The mica-schists are usually toward the upper part of the formation. The stages of the transformation between these crystalline rocks and plainly fragmental detritus have been somewhat fully made out.

The lower slate formation is of variable thickness, but is usually less than a thousand feet. The iron-bearing formation is also of very variable thickness, its maximum being perhaps about the same as that of the lower slate, and from this it varies to disappearance, the horizon being usually represented, however, by

carbonaceous and ferruginous shales and slates. The upper slate formation includes the great mass of the Upper Huronian series. Its maximum thickness is more than ten thousand feet.

In certain areas, during Upper Huronian time, there was great volcanic activity, as a result of which, peculiar formations were piled up, wholly different from any of the ordinary members of the series. Also this volcanic activity greatly disturbed the regular succession, so that for each of the volcanic districts an independent succession exists, the sedimentary and volcanic formations being intimately interlaminated. The two areas which are best known are the Michigamme iron district north of Crystal Falls and the east end of the Penokee district. Similar volcanics also occur in the Marquette district. In the Michigamme iron district is an extensive area of greenstones, greenstone-conglomerates, agglomerates and surface lava flows, many of which are amygdaloidal. In the Penokee district the materials are almost identical. The typical succession for this district extends in unbroken order for fifty miles or more, but east of Sunday Lake this is suddenly disturbed by the appearance of the volcanics. The character of the rocks and their order soon becomes so different that if one were not able to trace the change from one into the other, there would be a great temptation to regard the part of the series bearing volcanics earlier than or later than the Penokee series proper. But the continuity of the two cannot be doubted. Thus this occurrence well illustrates that lithological character in pre-Cambrian, as in post-Cambrian time is no certain guide as to relative age. Finally, associated with the Lake Superior Upper Huronian rocks are many later intrusive dikes and interbedded sills, chiefly diabases, gabbros and diorites, but local granitic intrusives also occur, particularly in the Felch Mountain and Crystal Falls districts, and possibly also in the Menominee district.

The typical districts in which the Upper Huronian series can be best studied are the Penokee, Marquette, Mesabi and Animikie. Remote from the Lake Superior region proper, the rock series

which are correlated with the Upper Huronian have not the same successions of formations as in these districts. The Upper Huronian north of Lake Huron has a set of formations which can not be correllated with the formations above given; the same is true of other series to the south which are here placed. The position of these latter as a part of the Upper Huronian must not be considered as a question finally determined, but rather as representing the probability, from the weight of evidence at the present time. It can not be expected that in a great geological basin the same subordinate succession of formations will be everywhere found.

However, for the present, regarding all these series as Upper Huronian, this is the most widespread of the Lake Superior pre-Cambrian sedimentary series. It includes a great area, extending from the Sioux quartzites of Dakota on the southwest, to the Huronian rocks north of Lake Huron on the east, and thence far to the north, and from Lake Huron to the Animikie series of the National Boundary west of Lake Superior. Within this area are included the major portion of the Baraboo quartzites of Wisconsin; the major portion of the large area in the Upper Peninsula of Michigan, the eastern arms of which are the Menominee, Felch Mountain, and Marquette iron-bearing districts; the greater part of the Penokee-Gogebic iron-bearing series of Michigan and Wisconsin; the Chippewa quartzites of Wisconsin; St. Louis slates of Minnesota including the newly developed Mesabi range of Minnesota, and the Animikie series of Thunder Bay, Lake Superior and its westward extension. That most, and perhaps all of these areas were once connected, there can be no reasonable doubt.

This broad semicircular zone of Upper Huronian rocks, extending from the National Boundary west of Lake Superior through Ontario, Minnesota, Michigan and Wisconsin, to the north Channel of Lake Huron, and thence north to the east side of James Bay, suggests that the transgression of the sea was from the south and east, and that the source of the mechanical detritus is the great expanse of so-called Laurentian rocks west of Hudson

Bay and north of Lake Superior. How far the sea transgressed over this area, and whether it also advanced toward it from the north and west, is unknown. It is probable as the sea advanced from the south, that the great mass of fragmental detritus, making up the Baraboo and Sioux quartzites, was laid down before the sea had transgressed to what is now the north shore of Lake Superior, and thus would be explained the discrepancy in the parallelism of formation between the Sioux quartzites, Baraboo quartzites, etc., and the districts of Upper Huronian rocks adjacent to Lake Superior.

In this case the advancing ocean was perhaps making its progress by cutting a terrace quite as much as by subsidence. However, there is reason to believe that the area included within the west end of the Lake Superior Basin, *i. e.*, from the Animikie series to the Mesabi range, and thence to the Penokee series was submerged practically at the same time. For here we have three great formations of like character in identical order. The lowest formation, the quartzite and quartz-slate with conglomerates derived from the Basement Complex and the Lower Huronian, are the first deposit of the advancing sea. After this came a deepening of the water, when the calcareous and ferruginous formation, now constituting the iron-bearing member, was laid down. Then perhaps as a consequence of the upbuilding of this formation, came a shallowing of the water and the deposition of the great thickness of clayey sediments of the Upper Huronian. Since the last formation must have been deposited in shallow water, and yet is of great thickness, the bed of the ocean was probably subsiding during the remainder of Upper Huronian time.

At the end of the deposition of the Upper Huronian rocks, the Lake Superior region rose above the sea, and the atmospheric forces once more set to work. The orographic movement following the Upper Huronian, like that following the Lower Huronian, was locally intense, but in general the folding was of a gentle character. Along narrow axes the plications were so severe as to give the Upper Huronian rocks a foliated structure and com-

pletely crystalline schistose or gneissic character, but for the most part the changes in the Upper Huronian rocks are those of cementation and metasomatism. As with the Lower Huronian areas of intense plication, they are sometimes but short distances from those in which the rocks have been merely tilted.

How deep the Upper Huronian denudation went it is impossible to say. We only know that at a maximum, the Upper Huronian rocks are now 13,000 feet thick, and in certain other places are entirely absent, the higher members disappearing first and the lower members last. Thus the difference of the Upper Huronian denudation is measured by 13,000 feet. To this must be added the unknown thickness of the Upper Huronian rocks, which have been wholly swept away, and the thickness of the Lower Huronian and Basement Complex, which were cut at this time. The thickness represented by these three elements is unknown, but it is probably great.

Of the outer limits of the Upper Huronian transgression, we are as ignorant as of the preceding ones, but certain it is that it had an extent to the outer areas mentioned as belonging to this series. Beyond these limits no knowledge is available. The original extent to the east, south and west of the Upper Huronian will probably never be determined, since the ancient rocks are covered by the Cambrian and post-Cambrian sediments. Whether the transgression extended over the Great Northern area of Canada to the Paleozoic deposits will doubtless be ascertained when this vast region is studied in detail.

The Keweenawan.—Again a change of conditions occurred, and a great flood of basic volcanics, in beds of enormous thickness were poured out. Later these were followed by more thinly bedded volcanics. At about the same time a portion, at least, of the Lake Superior region became immersed in the sea, since in places the basement lavas of the Keweenawan are interstratified with sandstone and conglomerates.

The Keweenaw series is composed lithologically of gabbros, diabases, porphyrites, amygdaloids, felsites, quartz-porphyries, etc., and of sandstones and conglomerates. The basic and acid

rocks constituting the series are mainly surface flows. The gabbro flows are often of immense thickness. The diabase flows are usually much thinner, and frequently pass in their upper parts into porphyrites and amygdaloids. Many flows are porphyritic or amygdaloidal throughout. The beds of quartz-porphyry and felsite are abundant in certain districts, but usually have no great lateral extent, but while a single flow may be traced but a little way, frequently a group of flows of the same general character may have a great extent and thickness. But even the groups of flows cannot be regarded as general formations for the whole of the Lake Superior basin.

Since the number and thickness of the volcanic beds as well as the detritals vary greatly, the Keweenaw series as a whole is widely variable in different districts in its character and thickness. Structurally, Irving has divided the series into two parts, a lower division, in which eruptives are present, and an upper division, in which eruptives are absent. In any one section of the Keweenawan, at the lower part of the lower division, are generally found numerous volcanic flows, with few or no detrital beds. In passing toward the middle of the series the sandstones and conglomerates become more and more numerous and of greater thickness. Still higher the sandstones and conglomerates become predominant, and finally volcanic products disappear, the upper ten or fifteen thousand feet of the Keweenaw series being wholly composed of mechanical detritus. A given detrital bed varies from a mere seam of narrow local extent to thick beds of sandstone and conglomerate, one of which has been traced by Marvine for more than one hundred miles. The most general detrital formation is the upper sandstone and conglomerate.

The Keweenawan rocks extend about the entire area of the Lake Superior basin. They appear upon the east shore of Lake Superior, cover a large area of Keweenaw Point, northern Wisconsin, eastern and northeastern Minnesota, and a great area about Lake Nipigon. A similar set of volcanics, occupying a like stratigraphical position, is also known adjacent to Hudson Bay, and this may be a contemporaneous series.

The Keweenawan is the thickest of the series about Lake Superior, its maximum being estimated by Irving at the Montreal river to be fifty thousand feet. From this thickness it varies to nothing. This vast quantity of material does not, however, of necessity mark a period longer or perhaps even as long as the Lower Huronian or Upper Huronian, for the greater part of it is of igneous origin. The lava flows in their extent and thickness are to be compared with the great volcanic plateaux of the far West, rather than with local volcanoes such as Vesuvius, or the local volcanoes of the Upper Huronian and Lower Huronian. Associated with the lavas no volcanic fragmental material has been as yet discovered.

The source of the lavas of the Keweenawan is beyond the scope of this paper. It was, however, suggested that the fusion of a portion of the Basement Complex, and even Lower Huronian, may have in part produced the deep-seated magmas, the extrusion of which produced the Keweenawan lavas.

In large measure the sandstones and conglomerates derived their materials from the volcanics of the series, but a lesser quantity came from earlier series. This latter is particularly true of the great detrital formation constituting the topmost member of the Keweenawan. Partly because fragments derived from the felsites and porphyries are more resistant than those from the basic rocks, acid pebbles are relatively abundant in the conglomerates.

The fact that erosion was contemporaneous with eruption for much of Keweenawan time is to be noted. Certainly, when the period was well inaugurated, most of the Lake Superior basin was normally below the sea or near tide water. Many of the eruptions may have been sub-aqueous. Here and there volcanic masses of such magnitude were built up as to rise above the water, and upon such areas, the sea at the base, and the air and rain above, immediately began their course of destruction. The acid and more viscous lavas may have formed the more prominent elevations, and thus the attack was here more vigorous. This may partly explain the predominance of the acid pebbles in the conglomerates.

This great volcanic period was doubless one of unstable equilibrium, the lithosphere falling here and rising there. One of the final movements was the production of the Lake Superior synclinal. This synclinal movement affects not only the Keweenawan rocks, but the lower series, and in areas in which the unconformity between the Upper Huronian and the Keweenawan is not great, there is such a likeness in strike and dip of the two series as to suggest, at first, that the two are conformable. It is only as the contacts between them are followed for some distance, and the Keweenawan is seen to be now in contact with one member of the Upper Huronian, and now with another, that it is perceived that between the two there is an unconformity.

What proportion of the Keweenawan had accumulated before this Lake Superior synclinal began it is impossible to say. Possibly somewhere near the center of the Lake Superior basin were the larger foci, from which the great extrusions of lava occurred, and here a simultaneous sinking went on, such as is usual as a result of the upbuilding of a mountainous mass of volcanic material. This suggestion, if true, would also partly explain the apparent absence of volcanic fragmental material which naturally would accumulate near these foci.

Nowhere are the Keweenawan rocks so closely folded as to give them a schistose structure or a metamorphic character. Their induration is almost wholly a process of cementation.

The Cambrian Transgression.—At the close of Keweenawan deposition the Lake Superior region was again raised above the sea, and the pre-Cambrian erosion continued until the enormous thickness of Keweenawan deposits was wholly truncated. What must have been mighty mountains were reduced to mere stumps, or to base level. Following this denudation, the sea once more transgressed upon the land, and the horizontal Lake Superior sandstone was deposited. It now occupies many of the bays about Lake Superior. It once was much thicker, and perhaps covered all but the highest points of land. Certainly it or an overlying formation once was at least one thousand feet higher

than the level of Lake Superior, but it has since been almost completely removed, so that it occurs only in patches within the depressions of the older rocks.

Since Cambrian time no important orographic movements nor outbursts of volcanic material have occurred in the Lake Superior region, consequently the rocks have received little subsequent alteration. To these facts is due the possibility of outlining the pre-Cambrian history of this area with greater fullness than has been done in areas in which later disturbances have obscured the early history.

C. R. VAN HISE.