DESCRIPTION OF THE MENOMINEE QUADRANGLE.

INTRODUCTION.

This account of the geology of the Menominee iron-bearing district of Michigan will be followed by a more detailed report, in which the figures of two new maps of the Lake Superior district are based upon the field work of the year $1890$, and upon the survey of the Lake Superior district made under the direction of Dr. A. G. Harriman. The work of the present year has been carried on under the superintendence of Dr. C. E. Wright, in the field, and of Dr. E. D. Mead, in the office. The field work of the present year has been under the superintendence of Dr. C. E. Wright, in the field, and of Dr. E. D. Mead, in the office.

The reason for presenting this account at the present time is to give to the public an account of the work of the recent year, and to warn against further waste of money in the search for new ore deposits. Every nook and corner of the Menominee district was of much use to us in our field work, since it was possible to make systematic plans for the survey of the district, and to get a better idea of the extent of the deposits that might otherwise have been overlooked.

Many of the large and prosperous companies and many independent explorers are now actively engaged in a search for new ore deposits in the Menominee district, because these deposits are already exhausted, and new work is needed. The work that has been done is not useless, since it is possible to make use of the data that have been collected. Unfortunately, some of the explorers are apparently ignorant of the results of the work already done, and are experimenting with new methods and new ideas. In the Menominee district the work of the present year has been under the superintendence of Dr. C. E. Wright, in the field, and of Dr. E. D. Mead, in the office.

The present report will suffice to give the main conclusions of the work, but not on the map. The names of the formations and their relations to general geologic systems are shown on the map, and the interpretations of the data are given in the text. The map shows the distribution of the greenstone-schists, and the distribution of the iron bearing formations.

The greenstone-schists comprise chlorite-schists and sericitic-schists, schistose dolomites, schistose limestones, and basic rocks. The greenstone-schists are associated with the basic rocks, and are characterized by the presence of iron and magnesium minerals. The basic rocks are characterized by the presence of iron and magnesium minerals, and are associated with the greenstone-schists. The greenstone-schists and the basic rocks are interbedded, and form a complex which is known as the Menominee schist.

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granulation of the original components and partly through recrystallisation. The particles of some of the newly formed minerals developed with a parallel arrangement giving a schistosity. The coarse-grained rocks were also made schistose by the same processes, but the grains of these were so much stronger that the ordinary schists were formed by the weathering away of a pre-existing land surface by the joint action of the air, rivers, and waves, and consequently they are not formed from the ordinary schists as to leave no visible projecting ledges above the drift, whereas, in the central and northern portions of the trough they are locally massive. This is the principal reason why the absence of these formations be confirmed by future explorations, the fact may indicate that two such resistant formations as the Sturgeon quartzite and the Randville dolomite could have been so completely planed down in those places as to leave no visible portion of the area from which they were deposited in whole or in part and eroded during Huronian time.

STURGEON QUARTZITE.

Distribution, character, and position.—The Sturgeon quartzite forms a continuous border of bare hills on the southern side of the northern complex. The formation lies between the Archean complex and the northern belt of dolomite. Prominent bluffs of the typical quartzite may be conveniently studied northeast of the Loretto mine.

At many places the base of the Sturgeon quartzite there is a conglomerate made up of boulders and fragments of granites, gneisses, and hornblende-schists, identical with the corresponding rocks in the adjacent Archean complex. The matrix in which these are embedded is in some places a quartzite; in other places it is an arkose composed of the fine-grained debris of granitic rocks. In many places this matrix is schistose, and in these cases a large quantity of a micaceous mineral has been produced by alteration of thefeldspar of the original sediment, so that the matrix is now lithologically a sericite-schist.

The major portion of the formation consists of massive beds of a very compact, vicious quartzite, usually white or creamy, but occasionally with some shade of pink or green. In their upper portion the contact between the quartzite is often calcareous. This calcareous constituent increases in quantity as the overlying dolomites are approached, until the rock becomes a calcareous quartzite and finally a quartz-dolomite. The change from the quartzite to the dolomite is thus a transition. This indicates a gradual deepening of the waters during the later part of the Sturgeon epoch.

The upper member of the Sturgeon quartzite is a nearly vertical southward-dipping monocline. The outcrop of this monocline varies in width; this does not, indicating that cross folding has taken place to some extent. At the western end of the district the quartzite turns northward, wrapping around the northeastern edge of the Archean complex, and then passing eastward into the area of the Cabot syncline. (Fig. 1.) On the turn to

**LOWER NEMOMINE SERIES.**

**Succession and distribution.—** The Lower Nemomine series is divided into two separate formations: the Lower Lower Nemomine and an Upper Nemomine series, equivalent to the Lower Huronian and the Upper Huronian elsewhere in the Lake Superior region.

From the above brief outline of the Archean geology it will be seen that the Lower Nemomine series is exposed throughout the district and that the Upper Nemomine series is observable only in certain portions of the northern members of the district. The formations belonging in the Lower Nemomine series are exposed only in the central and southern parts of the district. They are not found in the north part of the trough, and it is only in the central portion of the area that any evidence of the existence of the Upper Nemomine series is observable, and then only in the north part of the trough. These two formations are therefore both very restricted in extent, and in many places the rocks are subdivided into two separate formations: the Lower Lower Nemomine and an Upper Nemomine series, equivalent to the Lower Huronian and the Upper Huronian elsewhere in the Lake Superior region.

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first is the impossibility of deducing how much of the apparent thickness of the many rock layers in a closely folded district, like the Menominee, is due to the folding and how much to the thickness of the beds resulting therefrom.

The other difficulty is to fix the upper limit of the formations. There is everywhere a thinning of the quartzites and the lowest ledges of the overlying dolomite, and this thinning has been accounted for by the erosion of the upper beds of the dolomite. In consequence of close folds, it is not possible to determine the exact amount of duplication of beds resulting therefrom.

In the mines and the open pits a similar conglomerate or a coarse quartzite is frequently found lying upon the dolomite. Jaspilite fragments can not in all places be detected in it, but they can be observed in so many localities that the only acceptable interpretation of the phenomena is that the dolomite and the quartzite are separated by an unconformity. The contact between the two rocks is sharp. There is no gradation of any kind between them. The dolomite is almost completely or almost completely disappeared, while the jaspilite is preserved. It is possible that much of the jaspilite is due to the erosion of the dolomite, but it is probable that there is a considerable thickness of jaspilite in the district.

The dolomite formation is nowhere seen in actual contact with the Sturgeon quartzite, nor are ledges of the two formations seen in close proximity. It is known, however, that in many places the upper layers of the quartzite are obliterated and that the lower beds of the dolomite are exposed. In other places continued until it also was removed. The dolomite is dominant. With the pure dolomite is associated siliceous dolomite, calcareous quartzite, and breccia of quartz.

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### Subdivision into members.---The Vulcan iron-bearing formation embraces three members; those above the base of the member, the member, the Brier slate, and the Curry iron-bearing beds. The Brier slate is so named

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---the upper, the Hanbury formation, comprises the great upper slate member of the Meminone series. vulcan formation. Subdivision into members.---The Vulcan iron-bearing formation embraces three members; those above the base of the member, the Brier slate, and the Curry iron-bearing beds. The Brier slate is so named because the Curry Hills is located in this horizon. Stratigraphic position and distribution.---From the position of the Vulcan formation immediately upon the Hanbury slate. This member is named after the district in which it is found. This member is named after the district in which it is found. The principal area of the Vulcan formation is the iron-bearing formation. The belt follows the sinuosities of the adjacent quartzite is extremely sharp, and in many places the contact is alkali-olived. Occurrence and correlation.---The Negaunee iron-bearing beds are to be expected in that area in which a blank schist is exposed south of Slate River. The Negaunee formation is known to extend for only a few miles on both sides of the Cuff mine, and the smaller components of the quartzose matrix. The areas of the iron-formation in particular, and bordering the areas of Quinnesec schist. In several places, however, it is seen that these relations do not always hold. It is known that in various parts of the district the iron-formation is absent from the position it would naturally be present, but in the cases where it is so present, the belt is so long as to make it evident that the iron-formation is present in the areas in which it is not shown on the maps. The occurrence of the iron-bearing formation, summarized in Table 1, is based upon the fact that the lower layers of the Vulcan formation, both the upper slate member of the Menominee series and below the Hanbury slate. But at some places within the district where we naturally expected to find the Vulcan formation, the dolomite is in immediate contact with the Hanbury slate, or is separated from exposures of the latter formation by later intrusions of granite. This result is to be expected since the lower and metamorphic formations that affected both the Lower Menominee and Upper Menominee series. The contact between the schist and the super­jacent quartzites is extremely sharp, and in many places the contact is alkali-olived.

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The associated iron oxides usually occur in beds or large, nearly continuous layers in various places, however, especially in the basins produced by the folding of the strata. Where the ore is well developed, it replaces the quartzose slate along its strike, forming beds which may be sufficiently large to warrant mining. The thin-bedded ores are usually gray specular in thin section, and the ferruginous quartzose slate, from a gray to a dark gray color, are noticed to occur particularly in areas of disturbance, such as scarps and troughs of folds. Where the rocks have been crushed or jointed, the water that is constantly circulating through the rock has removed silicic and deposited hematite. New hematite has built up the plates of the original ore into grains. The jaspilites, which have been filled or partly filled with ore, are those that have been produced during the process of the ore, whereas the thin-bedded ore is usually a mass of small fragments. The beds of the Brier slate consists of interbedded jaspilites and ferruginous quartzose slates.

The jaspilite bands in many cases are in approximately parallel and then again unite to form largesized quartzose slates. The jaspilites occur in beds which are formed largely by metasomatic changes from an iron-bearing carbonate; those of the latter consist of the ferruginous material derived from the quartzose slates by the same process. The explanation of the intimate association of the two kinds of sediments is very probably somewhat as follows: The formation originally consisted of ferruginous quartzose sand grains and of hematite in the interstices of the Lower Menominee formation. The specular hematite is considered to be the result of changes in the iron oxides and the hematite is considered to be the result of changes in the iron oxides of the ore beds. The hematite and the jaspilite are similar in composition, but differ in texture and in the amount of the constituents that are slates.

The iron ore of the Curry member is of two varieties of the Brier slate. The first kind of ore is hard, dense, and very flinty. It occurs in very thin layers, separated by equally thin layers of jaspilite. The layers, therefore, have a direct relation to the depositional surface. The phenomena wherever studied appear to be controlled by the relations between the two members. The Brier slate is usually determinable within a few miles of the Upper Menominee series, as described in Mineralogical Survey of the United States Geological Survey, except that the concretionary or oolitic structure of the Brier slate is usually determinable within a few miles of the Upper Menominee series. In exploring operations it is important to determine the difference between the two rocks and the ore deposits in the Upper Menominee series. The ore beds, where they are known to exist, are about 5 or 6 feet in thickness, and are especially abundant in the southern part of the state. They are usually separated from the ore beds by thin layers of specular hematite and are not marketable. They are then known as the hematite ores.

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the iron-bearing formation stretches as a narrow belt which for much of the distance appears to rest upon the Negaunee iron-bearing formation. If the Vulcan formation exists in the southern iron-bearing belt west of Negaunee and in the central iron-bearing belt north of Lake Antonia, its thickness is about 600 feet. In both of these areas folding is more prominent than it is in the southern belt east of Negaunee, and where folding is not prominent exposures are lacking. In the Pewabic mine a measured section along a drift in the first level under shaft No. 1 gave 195 feet and 200 feet for the Brier and Curry shafts respectively.

At the Indiana mine the measured thickness of the entire Vulcan formation is about 550 feet. At a number of sections the thickness of the individual members comprising the formation is easily measured. The Brier slates have been measured at seven places, yielding results between 150 and 225 feet. Measurements of the Traders member have given results varying between 150 and 225 feet. Six of these falls between 160 and 195 feet. The thickness of the Vulcan formation is given as 550 feet, divided as follows: Traders member, 150 feet; Brier slates, 330 feet; Curry member, 225 feet. Six of these falls between 160 and 225 feet. Where the Vulcan formation rests upon the cherts or dolomite it is commonly noticed that the contact between the rock and the iron-bearing formation must be guessed at. Only three measurements have been made on the surface, the thickest zone is 500 feet, the dolomite to the known top of the Traders member. These give 175 feet, 85 feet, and 35 feet.

The opportunities for accurate determinations of the thickness of the iron-bearing formation east of Quinnesec are very poor. In this area the iron-bearing formation is usually 500 feet thick, and at the Arvon mine its thickness is about 675 feet. If the Vulcan formation exists in the southern iron-bearing belt west of Negaunee and in the central iron-bearing belt north of Lake Antonia, its thickness is about 600 feet. In both of these areas folding is more prominent than it is in the southern belt east of Negaunee, and where folding is not prominent exposures are lacking. In the Pewabic mine a measured section along a drift in the first level under shaft No. 1 gave 195 feet and 200 feet for the Brier and Curry shafts respectively.

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The opportunities for accurate determinations of the thickness of the iron-bearing formation east of Quinnesec are very poor. In this area the iron-bearing formation is usually 500 feet thick, and at the Arvon mine its thickness is about 675 feet. If the Vulcan formation exists in the southern iron-bearing belt west of Negaunee and in the central iron-bearing belt north of Lake Antonia, its thickness is about 600 feet. In both of these areas folding is more prominent than it is in the southern belt east of Negaunee, and where folding is not prominent exposures are lacking. In the Pewabic mine a measured section along a drift in the first level under shaft No. 1 gave 195 feet and 200 feet for the Brier and Curry shafts respectively.

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were still above the sea during Vulcan time. The gradual approach of the base of the Huronian to the lower formation at such places and the presence of conglomerates at the base of the Huronian slate to the lower formation at such places and were still above the sea during Vulcan time. The explanation that of unconformity between the fore, with great confidence, we hold to the second Menominee sea, the deposits of which slowly series, with a gradual advance of the Upper series. There are therefore in this district all the evidence of a great unconformity between the Upper Menominee and Lower Menominee found in the Huronian of the Marquette district and other districts of the Lake Superior region, except that of marked discordance in strike and dip between the upper and lower series. This lack of discordance does not in the least invalidate the conclusion that a great time gap separates the two series. It has been shown by the senior author that an apparently minor unconformity may mark as great a time interval as the most startling discordance. The relations of the two series in the Menominee district are very similar to those existing in the Penokee district between the obtry limestones of the Lower Huronian and the Upper Huronian parquartular member.

**Fig. 1.** General relations. — The iron ores of the Menominee district occur in two members, from the base upward as follows: (1) the Traders member of the Vulcan formation, and (2) the Curry member of the Vulcan formation. The iron ores may occur at any horizon within these members. However, other things being equal, they are more likely to occur at lower and higher horizons than at middle horizons in each of the members, but a number of the large ore bodies extend entirely across the members in which they occur.

It will be explained that the iron ores deposits occur at places where downward-moving waters are converging. Of these places, pitching troughs with impervious basements are the most important. Therefore, the iron ores deposits of large size rest upon relatively impervious formations, which are in such positions as to constitute pitching troughs. A pitching trough may be made (a) by the dolomite formation underlying the Traders member of the Vulcan formation, (b) by a slate constituting the lower part of the Traders member, and (c) by the Beleau slate between the Traders and Curry members of the Vulcan formation. The dolomite formation is especially likely to furnish an impervious basement, since its upper horizon has been transformed into a talc schist, as a consequence of folding and shearing between the formations.

While all the larger iron bodies are confined to the pitching troughs with impervious basements of dolomite or slate, smaller ore deposits occur at contacts between the different members. These contacts are favorable places for the concentration of ore, because they are horizons along which important slipping or differential movement has occurred during the folding of the district. Wherever a set of beds are folded there must be differential movement among them. This is well illustrated by the slipping of the leaves of a flexible book over one another when the book is bent. In nature the contact planes between formations of different characters are always places of weakness, hence at such places the major movements take place. These movements are sure to make the formation porous and thus produce main channels of percolating water; hence the frequent presence of ore bodies along such plan. Still smaller ore deposits are found where faulting has occurred or where close faulting has occasioned the Vulcan formation. Such formations furnish zones or areas where percolating waters are converged into trunk channels and thus favor the concentration of the iron oids.

The combination of two or all of these conditions is more favorable than any one of them alone. Where the conditions are such as to combine pitching troughs with impervious basements, the ore deposits are of two main kinds—toughs or folds of the third order, and s separation of formations from the limestones with an intervening siltstone, and even these folds have folds of a higher order superimposed upon them. If one were to follow a geographical

**Fig. 2.** Horizontal section of the Walpole mine at the third level. Scale: 1 inch = 100 feet.

**Fig. 3.** Horizontal section of the Walpole mine at the third level. Scale: 1 inch = 100 feet.

**Fig. 4.** Vertical north-south cross section of the Chapin mine. Scale: 1 inch = 100 feet.

**Fig. 5.** Vertical north-south cross section of the Chapin mine. Scale: 1 inch = 100 feet.

**Fig. 6.** Vertical north-south cross section of the Chapin mine. Scale: 1 inch = 100 feet.

**Fig. 7.** Vertical north-south cross section of the Chapin mine. Scale: 1 inch = 100 feet.
The slate and dolomite ore here again found on the north, east, south, and bottom of the ore body. Here, however, on the south limb of the fold the ore-bearing member does not appear between the dolomite and Brier slate. It has therefore been squeezed out by the very great pressure, or else tightly appressed. A close looking at the first level from the Traders ore-bearing bed on the south limb of the fold the ore-bearing are here again found on the north, east, south, and bottom of the ore body. The reduplications are regarded as due to very close subordonate folding.

At the present time the workings of the Chapin mine have not extended sufficiently far to show beyond question the relations of the ore bodies (fig. 4). As yet they have not been connected with the ore deposits of the Walpole in such a manner as to show the continuity of the Walpole folds with those of the Chapin. However, two main belts of ore have been developed at the Chapin, and it is believed that these two belts will be found to correspond with the two closely appressed, westward-pitching folds of the Walpole. North of the northern ore body is a succession of slates, quartzites, and thin belts of iron-bearing formation similar to that on the south side of the Pembridge mine. Immediately north of this ore body is a slate similar to that of the Walpole and Pembridge. Slate also occurs between the two ore bodies. Further, slate forms the southern lens of ore on the south of the Chapin. It is probable that the compression was so severe that the center of the soft oxide of ore at the top was actually squeezed out, the slate on each side of the ore coming together.

It is impossible at present to be absolutely sure as to the horizontal plane of the ore bodies. Since, however, the relation of the ore bodies to the surrounding rocks near the Chapin are parallel in many particulars to the occurrences at the Walpole mine, it is thought that the two ore body have been the Trapper member of the iron-bearing formation, that member being repeated by close folding. According to this explanation, such ore lenses would constitute an isoclinal syncline, and the slates between them would be albacades; also the slate between the southern lens of ore and the southern belt of iron-bearing formations would be an anticline. This slate would be the southern iron-bearing belt, in which no ore bodies have been found, as Traders. The slates and quartzites south of this would be Brier. Therefore, the synclinal fold (fig. 5).

While it is freely admitted that as yet this intercalation, the one which appears to the entire ore body the whole appears to correspond most closely with the facts, the two lenses of ore would correspond to two emplacements in the outer parts of the dolomite east of the Walpole mine. The isoclinal folds at the Chapin mine are overturned, the axial plane dip to the north, and the isoclinal belonging structurally below the Vulcan formation really rest upon it with a sharp dip about 80° at the surface, but bending so as to be as low as 70° deep in the mine. For a long time it was a question with the miners which of the two formations was geologically the higher. However, the occurrence of undoubted dolomite bowl-shaped bodies in the Traders member, and the continuity of the dolomite from the vicinity of Iron Mountain to the east end of the district have shown beyond question that the dolomite is the lower formation. With the possible exception of the Quinnesec, the Chapin mine shows the main mass of ore being repeated by close folding. The Millie mine is not sufficiently developed to enable us to make definite statements as to the relations of this ore deposit, but the probability is strong that it belongs to the Traders member of the Vulcan formation. The most important point to the east of the Pembridge mine where ore is produced is that of Quinnesec. The Quinnesec ore bodies are closely appressed, probably a somewhat narrow, northward-pitching fold, and the dolomite and the quartzite at this locality apparently overlie the ore, the dip being about 70° to the north.

The ore is bounded by the talc-schists on the north and by slates on the south. South of these slates is iron-bearing formation. The ore in this area is longitudinal section passes into iron-bearing formation of this area to the west, and if there is a pitching trough here it does not clearly appear. However, the sharp embayment in the dolomite is immediately adjacent renders it highly probable that a pitching trough really exists. North of the old Quinnesec to the Culley mines, but it yet developments have not gone far enough to show the relations of the ore body.

Another very important ore center is at Norway, where are found the Norway and Aragon mines. Here are two important folds in the dolomite, both pitching to the west and to the north. The said to be the eastern member of the ore body and the northern ore body, respectively.

The next important point to the east of the Aragon mine is a sharp embayment in the dolomite which has been mined for some distance along the strike of the rocks, the position of the mounds being marked by a long row of open pits. The position of the ore deposits in the vicinity of Vulcan, therefore, fully correspond to the general principles laid down. They occur at places of differential movement between different formations or members, where, therefore, circulating downward-moving waters are effective, but it was at the top of the Traders member of the ore formation, just below the bottom of the Brier slate (see fig. 6). At this time no one could have predicted that this ore body is really related to the impervious talc-schists of the dolomite below.

However, as mining continued, the ore deposit was found to extend along both limbs of the ore. From the fifth level downward this relation has continued, the main mass of the ore body being found at the apex of the trough, and long a small amount of ferruginous and siliceous slate, which, until the demands for low-grade, it was the top of the Traders member of the ore formation, just below the bottom of the Brier slate (see fig. 6). At this time no one could have predicted that this ore body is really related to the impervious talc-schists of the dolomite below.
wide ore bodies have not yet been developed, apparently because impervious basements are still lacking.

East of the East Vulcan mine the dolomite formation appears to extend as a continuous straight belt to the eastern end of the district, no subordinates being indicated by reentrants in the southern border of the dolomite. Corresponding with this, no

location is that adjacent to Loretto, where are found the Loretto mine and the Appleton shaft. Here the northern and central belts of dolomite probably join (see map), giving continuous dolomite from the Sturgeon quartzite on the north to the southern iron-bearing belt on the south. East of this bridge of dolomite, the northern and southern belts of dolomite, the Vulcan iron formation.

The iron ore deposits of the Vulcan formation, in thedistrict have the following characters: (1) They are above an impervious basement; (2) this

The ores have been developed directly from the surface. Hence it follows that the Vulcan formation, or its ore bodies developed. It has been seen that the ore bodies are large, and the ore bodies have been developed in their present position after the troughs were formed. No igneous or sedimentary rocks as originally produced has such forms as exhibited by most of the ore bodies. They are closely set, being original sedimentary rocks, such as the iron-bearing formation as a whole, is that the

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The iron formation extends for some distance to the north of the dolomite. It is highly probable that the iron-formation extends for some distance to the east and west of the area which is definitely known to the Menominee formation, but how far it is impossible to state.

The belts in which the iron formation may possibly exist are determined, to a close magnetic survey with dial compass and dip needles. For the most part, the iron-bearing formation of the eastern district is not strongly magnetic, but it is generally somewhat so, and it is thought that it is probable that a sufficiently close magnetic survey will determine whether or not the iron-bearing formation has any considerable extent in these areas. After magnetic surveys have been made, if indications of the bearing formations are found in various areas, these should be further examined by judicious test pitting.

Where the iron formation is known to exist, the rule for explorations are very clear. All, or nearly all, of the ore deposits do not extend to the surface. Moreover, the surface of the ore-bearing formations is not always at the same level, but changes from place to place, and it is generally somewhat so, and it is thought that a sufficiently close magnetic survey will determine whether or not the iron-bearing formation has any considerable extent in these areas. After magnetic surveys have been made, if indications of the bearing formations are found in various areas, these should be further examined by judicious test pitting.

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ocher. In a few cases, however, mixtures of chert and iron oxide have been found that resemble some of the mixed cherts and ores from the Michigan slate district. Thus far nothing has been discovered that would lead to the belief that large ore bodies exist at any of these places. Unfavorable results reached by explorations, the conclusion that the large ore bodies exist in the slate, and the fact that these slates have not been generally deplored by geologists, have led to the belief that the slate has been generally eroded from the area. Nevertheless the examination of any of these possibilities should be closely examined with a view to securing the most favorable sites. If possible, the slate should be underlain by these rocks, which when altered to their alteration products. Under favorable conditions some rocks are known to exist only in the slate. For instance, the Curry ores, some of which were later mined by Walcott as *the heads of small trilobites, probably Dicranophorus minor*; also frag. of carbonates, and these are known to exist only in the slate. In any case it is highly probable that the different formations were not deposited in uniformly thick layers throughout the district. If all the carbonaceous shales, in which the minerals were deposited, had been pierced at only a few places, and at these places there had not been any deposits, then the slate has furnished large quantities of iron ore.

Under the lithology of the Hanbury slate formation the evidence was found for the presence of iron carbonates in the carbonaceous slates and dolomites in the lower portion of the formation and to their alteration products. Under favorable conditions some rocks are known to exist only in the slate. For instance, the Curry ores, some of which were later mined by Walcott as *the heads of small trilobites, probably Dicranophorus minor*; also frag. of carbonates, and these are known to exist only in the slate. In any case it is highly probable that the different formations were not deposited in uniformly thick layers throughout the district. If all the carbonaceous shales, in which the minerals were deposited, had been pierced at only a few places, and at these places there had not been any deposits, then the slate has furnished large quantities of iron ore.
formation. The deposition of the Huronian slate required a long time, during which the physical conditions varied, for mingled with the ordinary elements of sediments large amounts of clastic slate, dolomite, and chert, making brief stages of partial or complete non-clastic sedimentation. Following the deposition of the Lower Huronian member the district was again raised above the sea and was subjected to erosion. So far as known, this erosion period continued for a time, as there are no deposits of the Lower Huronian member in the district. It is furnished by the great Keweenawan series in the Penokee district, which is entirely absent in the Menominee district.

Describing succession in the Penokee, Marquette, Crystal Falls, and Menominee districts.

Penokee district: Lake Superior sandstone.

Marquette district: Lake Superior sandstone.

Crystal Falls district: Lake Superior sandstone.

Menominee district: Lake Superior sandstone.

Upper Huronian.

1. Upper Huronian.

2. Ishpeming formation of Upper Huronian, consisting in lower portion of quartzites and detrital material, in the middle of this series are found the so-called Negaunee iron formations. These are the most important in the district, as they contain large amounts of iron. In the Marquette district the non-detrital material is represented by the Curry member, which is apparently a thick sequence of quartzites and slates, and is therefore more than one formation was deposited. In the Penokee district it is a continuous, almost completely non-clastic formation, which extends from the western part of the district nearly to the eastern end. In the extreme eastern part of the district the upper fragmental member is represented by a great volume of contemporaneous volcanic rocks. In the Marquette district the non-detrital material is also represented by a great volume of contemporaneous volcanic rocks. In the Penokee district it is a continuous, almost completely non-clastic formation, which extends from the western part of the district nearly to the eastern end. In the extreme eastern part of the district the upper fragmental member is represented by a great volume of contemporaneous volcanic rocks. In the Marquette district the non-detrital material is also represented by a great volume of contemporaneous volcanic rocks.

In all the districts the upper fragmental member is represented; in the Penokee by the great upper slate member, in the Marquette by an equally great upper slate member, in the Crystal Falls by the lower fragmental member, and in the Menominee by the Huronian slate. The largely non-detrital, iron-bearing member is also represented in all the districts. In the Penokee district it is a continuous, almost completely non-clastic formation, which extends from the western part of the district nearly to the eastern end. In the extreme eastern part of the district the upper fragmental member is represented by a great volume of contemporaneous volcanic rocks. In the Marquette district the non-detrital material is also represented by a great volume of contemporaneous volcanic rocks. In the Penokee district it is a continuous, almost completely non-clastic formation, which extends from the western part of the district nearly to the eastern end. In the extreme eastern part of the district the upper fragmental member is represented by a great volume of contemporaneous volcanic rocks. In the Marquette district the non-detrital material is also represented by a great volume of contemporaneous volcanic rocks.

The absent member in the Penokee district is absent in a similar manner in the Marquette district, but not until upper Cam­}

...
the Brier slate and the Traders iron-bearing member. Here the detrital ores appear because of the encroachment of the sea before the Negaunee iron-bearing formation was removed. However, thick beds of quartzite are generally absent, and this is explained in the same manner as in the Crystal Falls district—that is, the formation was deposited upon a dolomite rather than upon siliceous formations.

If it were possible to map in each of the four districts each member which is recognized, the apparent discrepancies in the succession of the Upper Huronian would be much less prominent. Indeed, where volcanic rocks are absent the succession would be found to correspond almost exactly. However, a given formation would be very important in one district and comparatively unimportant in another. Moreover, where volcanics have disturbed the succession, as in the eastern end of the Penokee district and in the Crystal Falls district, the orderly succession is not readily recognized.

The discrepancies in the successions in the Lower Huronian series are greater than those in the Upper Huronian. As already noted, in the Penokee district all the members above the Cherty limestone were removed during the time of inter-Huronian erosion. In the Menominee district the Negaunee formation was all but removed at the erosion period. In the Menominee district only one formation, the Randville dolomite, has been discriminated between the Negaunee formation and the Sturgeon quartzite; whereas in the Marquette district four formations, the Siamo slate, Ajibik quartzite, Weve slate, and Kona dolomite, are found; and in the Crystal Falls district two, the Hemlock volcanic formation and the Randville dolomite. The formations which are present in the Marquette and Crystal Falls districts and are not found in the Menominee district are all clastic and volcanic formations. The inference is that in the Menominee district quiescent physical conditions favorable to limestone deposition were long continued. The Randville dolomite was there laid down during the time of the deposition of the limestone formations and the fragmental and volcanic sediments between the limestone and the Negaunee formations in the Crystal Falls and Marquette districts. This is shown to be highly probable by the relations within the Crystal Falls district. In the eastern part of that district the Randville dolomite is a thick formation, and there no volcanics are found, whereas in the western part of the district the limestone deposit is very thin and there is a great volcanic formation standing in an equivalent position. In the Marquette district, also, changing physical conditions combined with volcanism explain the deposition of the clastic sediments and volcanic formations between the Kona dolomite and the Negaunee iron formation. The attempt to correlate the various formations of the two Huronian series in the four different iron-bearing districts south of Lake Superior shows very significantly that the geologic history of pre-Cambrian time was extraordinarily complex. From Archean to Cambrian time, in the Marquette, Crystal Falls, and Menominee districts, the areas three times emerged from the sea and were three times overridden by the sea. In the Penokee district there was a fourth emergence and transgression of the sea. The erosive forces at periods when the districts were land areas found rocks of very different characters. Here they were resistant, there easily denuded. As a consequence, when the sea encroached at the close of Archean, Lower Huronian, and Upper Huronian times, the country in detail was very irregular—was in fact bluffy, but not mountains. Therefore certain areas were covered by the sea, while other immediately adjacent areas were above the water and were being actively eroded. As a consequence of all these complex conditions we have unconformity, overlap, changes in the characters of contemporaneous sediments along the strike and across the strike, disturbances in the successions due to volcanism, close folding and attendant metamorphism, and all of these phenomena in a region which is largely covered by glacial drift.

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WILLIAM SHIRLEY BAYLEY,
March, 1900.
Geologists.