ore-bearing beds at this place in an anticline and beneath the Paleozoic beds to the east by another syncline. Thus the formation must be affected by three broad anticlines and three broad synclines with north-south axes.

Within the major folds the slates are crowded together in many close minor folds, here pitching in one direction, and there in another. No definite system has been discovered in the minor folds, chiefly, perhaps, because outcrops are so scarce. In general, however, the pitch of these folds in the western portion of the district is to the west, and in its eastern portion toward the east. On one or two of the hillocks on which exposures are fairly plentiful it was observed, moreover, that, as a rule, the little folds at the east ends of the hillocks pitch to the west, and those on the west ends to the east, at angles varying between 20° and 45°. These hillocks thus constitute open cross synclines with approximately north-south axes, corresponding to the broad north-south folds of the formation as a whole.

The east-west minor folds, on the other hand, are extremely close folds. Frequently on ledges that show cross sections 10 or 12 feet across several small anticlines or synclines may be plainly seen, so closely compressed that the dips of their opposite limbs vary but a few degrees. Frequently, too, the folds are overturned so that the dips of the limbs are in the same direction. On horizontal exposures these close folds are often very difficult, if not impossible, to detect, so that in many cases the closely folded beds appear to be consecutive. The strikes of the folds are usually a little north of west, and, consequently, the strike of the bedding is approximately in the same direction, and this is also the direction of trend of the Menominee trough. Departures from this strike are noticeable in many instances, but the variations are not great except in a few restricted areas where the pitch due to cross folding is marked. Small folds with dimensions of an inch or two are present everywhere. These often cause flutings and puckerings of the strata to such an extent that even approximate strikes and dips can not be obtained. In some places lens-shaped deposits of quartz have been found between the layers of the slate at the apices of the little anticlines and in the troughs of the little synclines.

The strong north-south compression of the slate beds, producing the close east-west folds, also impressed upon all the weaker members of the slate formation a perfect slaty cleavage with a nearly east-west strike and a dip that varies but a few degrees on either side of the vertical. In addition to this cleavage there was also often produced a set of fracture planes or joints at right angles to the cleavage. These latter intersect the rocks at approximately equal intervals of several inches. In some places they are bordered by narrow shear zones in which the total displacement of the slate beds is an inch or more. On flat horizontal surfaces two sets of these joints are sometimes seen cutting each other at acute angles, and about each slight faulting has occurred. All of the phenomena presented by the slates indicate that they were subjected to powerful north-south stresses acting nearly at right angles to the axis of the Menominee trough and producing the close east-west folds, the cleavage, and the jointing; and that at the same time they were influenced by less powerful east-west stresses acting along the axis of the troughs, and producing the open north-south cross folds.

THICKNESS.

No approximately correct estimate of the thickness of the Hanbury slate is at present possible. The similarity of the beds and their reduplication in consequence of the close folding render it impossible to determine what proportion of the apparent thickness of the formation is due to folding and what proportion is due to successive deposits. There can be no doubt that the Hanbury slate is much thicker than any of the other formations in the district, but that it is as thick as the corresponding formation in the Penokee district—12,000 feet—is not probable. Indeed, it is extremely doubtful whether its maximum thickness is more than 2,000 or 3,000 feet, though, as has been said, this estimate is not founded on sufficient data to make it of much value.

RELATIONS TO PALEOZOIC BEDS.

The relations of the Hanbury slate to the underlying Vulcan formation, the Randville dolomite, and the Archean schists have already been fully discussed (pp. 289, 365-372). The relations of the formation to the overlying Paleozoic sediments are those of a much-deformed, closely folded, highly tilted set of beds to a set of undisturbed horizontal deposits laid down upon them. No actual contacts of the slates with the overlying sediments have been seen, but from the nature of the structural differences exhibited by them there is no doubt as to the existence of a profound unconformity between the two. During the interval represented by the break the Upper Huronian beds were raised above the sea, closely folded, deeply eroded, and again lowered beneath the water's surface.

INTERESTING LOCALITIES.

The most interesting points at which to study the Hanbury slate are (1) those at which the formation is exhibited in its typical development, and (2) those at which its unusual cherty and ferruginous phases occur. The latter are of interest because of the light they may throw on the problem of the origin of the jaspilites and ores of the Vulcan formation, and because they suggest the possible presence of ore deposits in the slates like those in their western extension across the Menominee River.

TYPICAL LOCALITIES.

Exposures of the Hanbury slates are so scarce that only in a few places may more than one phase be seen. In several places, however, all the lithological types of the formation are well exhibited. Two such localities are described below and two others in which the slaty phases are best shown.

Sec. 13, T. 40 N., R. 31 W.—The exposures along both sides of the Menominee River in sec. 13, T. 40 N., R. 31 W., have already been referred to on a former page (p. 289), in discussing the relations between the Quinnesec schists and the Huronian sedimentaries. The slates form the banks of the river and the bottom of its channel for a distance of about 300 paces. Between the slate exposures and the nearest ledge of green schist, which is immediately under the railroad bridge of the Florence branch of the Chicago and Northwestern Railway, is an interval of about 150 paces free of exposures of any kind. The slates are cut through by the stream, leaving little perpendicular walls about 8 feet high bordering both sides of the channel. The rocks in these walls are silvery-gray sericitic slates with a well-marked cleavage dipping high (80°) to the north, and a jointing at right angles to this direction. Their strike is nearly east-west across the stream, the water of which flows across their upturned edges in a little rapids.

At about the middle of the exposure on the Michigan side of the river the slates are fluted in a series of small wave-like folds and are crossed by joints at right angles to the general dip of the fluting. Near the joint cracks there has been movement in a narrow shear zone which has produced a distinct schistosity which is inclined to the joints at angles of about 60°.

Hanbury Hill.—Hanbury Hill, situated just south of Lake Hanbury, furnishes the best exhibition of the Hanbury slates and their associated greenstones found anywhere in the district. The hill is the most marked topographic feature within the slate area. It rises about 140 feet above the surrounding plain, its apex reaching an altitude of a little over 1,040 feet above sea level. From a physiographic point of view it is a monadnock, which has resisted erosion because there are associated with the soft slates at this place large dikes and sheets of intrusive basic rocks which are now represented by greenstone-schists.

The predominant rocks exposed on the hill, in addition to the greenstones, are dark-gray argillaceous slates, light-gray calcareous slates, graywackes, and quartzites. These are folded in a most intricate manner in the central portion of the elevation, but on its east side the pitch of the folds is uniformly toward the west and on the west side toward the east. Where folding it not pronounced the strike of the beds is about N. 78° W., but there are many places where the strike departs widely from this, especially on the higher points of the hill. In one place near the west end of the top of the hill a strike was measured and found to be nearly north-south. At this place the folding is very distinct. The little folds, where the proper observations could be made, were found to pitch east at 20° and to strike N. 85° W. In other portions of the hill near its west end the folds are very close. Their axes usually pitch east at angles varying between 20° and 45°, but in a few instances the angle of pitch is much higher, reaching 90° in a few cases. The general dip of the beds in the hill approximates 70° S., showing that the folds are frequently overturned to the north, but of course dips of all angles and in all directions are met with, as must be the case in a series of folded beds. Northern dips are, however, rare, and where observed they are always much steeper than the southern ones.

All the beds are crossed by a schistosity that strikes about N. 75° W. and dips from 80° S. to 90°, irrespective of the folding. It therefore sometimes corresponds with the bedding of the slates, but more frequently the two structures are discordant.

The greenstone-schists are limited almost exclusively to the northern part of the hill, although a few ledges have been observed on its south side, especially where the hill is widest, i. e., near the section line between secs. 15 and 16. The relation of the schists to the surrounding slates is not always easy to ascertain. In most instances the greenstone appears to intrude the bedded series in the form of large dikes, but in the northwest part of the hill the igneous rock appears to underlie slates, both on the north and on the south sides of a minor elevation; consequently the rock in this case may be an intruded sill. In all cases the greenstone is strongly schistose in the same direction as the neighboring slates. In composition it is an aggregate of fibrous hornblende and the decomposition products of feldspar. None of the original constituents remain. In structure the rock was apparently granular, although the presence of small white spots sprinkled over the dark-green weathered surfaces of some of the schists may indicate that these were originally porphyrinic. The greenstone occupies some of the higher peaks of the hill and forms a little cliff about 20 feet high with a northern face overhanging the lake.

The various phases of the slates, the quartzites, and the graywackes are interbedded. The quartzites and graywackes are usually in comparatively thin beds, but in one case at least a quartzite bed measures 20 feet in width. These quartzites are nearly all calcareous, and gradation phases between them and the calcareous slates or impure dolomites are common. The slates, as before stated, predominate over all other rocks. They form not only thicker beds but more numerous ones.

The calcareous phases occupy distinct horizons toward the north side of the hill. They are interbedded with the argillaceous phases, but the former greatly predominate. The argillaceous phases, on the other hand, are more common to the south. Near the center of the hill thin beds of the calcareous slates may alternate with the argillaceous ones, but farther south on its southern slope the calcareous forms are entirely lacking. Here the gray slates exclude all other rocks. While the exact stratigraphical position of the calcareous slates is not certainly known, on account of the complicated folding of the series, it is nevertheless believed that, together with the graywackes and the quartzites, they occupy low horizons and that the argillaceous phases occur above them.

Under the microscope the gray and black argillaceous slates are seen to be typical clay slates, composed of fine quartz grains, spicules of chlorite and sericite, flakes of kaolin and the usual accessory particles. Some of the quartz is plainly in fragmental grains, but most of it has been recrystallized. Near the contacts with the greenstones a little brown biotite has been developed in them, otherwise the contact phases are not essentially different from the normal ones. Where most contorted, both normal and contact varieties, more particularly the latter, are traversed by an intricate system of veins and veinlets of quartz.

The argillaceous slates pass into the quartzites by increase in their quartzose components. The most distinct quartzites are dark-gray or black varieties that are usually covered on their weathered surfaces by a crust of brown, earthy limonitic material that indicates the presence of siderite in the fresher portions of the rock. Here and there they are cut by quartz veins, and near contacts with the greenstone they are gashed and jointed into polygonal blocks, many of which are bounded by curved surfaces. The quartzites are much less schistose than the other rocks in the hill, but all specimens show some indications of the structure. Under the microscope the rocks present two types. In both types the quartz grains have more or less ragged outlines in place of the sharp ones characteristic of clastic quartz, as though they had been partly dissolved and new quartz had added itself to the undissolved nuclei. The two types differ in the amounts and character of their matrices. In one type the matrix is in comparatively large quantity, constituting perhaps 50 per cent of the rock. It has the usual character of the matrix of the argillaceous slates, except that it contains a great deal of a light-brown carbonate in small grains and groups of grains, and in large pieces that look as though they might be pseudomorphs after some other mineral, or the fillings of pores or cavities. In the second type the matrix is sparse. It consists of an occasional plate of chlorite and sericite and many small rhombohedra of a yellowish-brown carbonate that is locally changed into limonite. The carbonate crystals in this type of quartzite are plainly ferruginous. The carbonate in the first type seems to be partly a ferruginous carbonate and partly calcite or dolomite.

The calcareous slates differ from the quartzites mainly in the absence of the large quartz grains and the presence of more abundant carbonate. They are essentially like the matrices of the quartzites of the first type, except that they contain even more of the carbonate. This mineral often makes up by far the greater portion of the rock. It is an aggregate of granules, many of which have a rhombohedral habit. When the texture is extremely fine the rocks resemble slates more than they do quartzites; when coarser they graduate into the latter rocks.

Sturgeon Mills.—East and southeast of Sturgeon Mills, in sec. 13, T. 39 N., R. 29 W., are several small knobs of black slates that are easily accessible from the railroad track east of Sturgeon Mills station. On the east side of the mill pond (see map, Pl. XLI) the slates form a considerable knoll in which the most typical phase of the black variety is beautifully exposed. The rocks are dense and homogeneous and are crossed by a well-marked cleavage that is vertical. No bedding is noticeable. Farther south, alongside the railroad track, the same rock occurs in two flat ledges with a vertical schistosity striking east-west. In the northern ledge the bedding is much contorted, the little folds in every instance pitching about 55° E.

On or near the banks of the river are other ledges in which slates and quartzites are interlaminated. Here, too, the bedding is much folded, and again the folds pitch to the east, the angle of pitch being between 30° and 40°. Greenstones are associated with the slates in the southern ledges, and in several instances the knobs rising above the plain expose only the intrusive rock.

Secs. 29 and 30, T. 39 N., R. 28 W—In the central portion of sec. 29 and the eastern part of sec. 30, in T. 39 N., R. 28 W., the slates of the Han-bury formation are well exposed in a number of little knobs and flat ledges on both sides of the road running southwest from Waucedah. In sec. 30 the slates are calcareous in part, and in part sericitic, and are associated with schistose greenstones of the usual types. In nearly all the ledges folding is very apparent. The axes of the sharp, close folds strike N. 75° W. and pitch. 15° E. The slates are also schistose, with the schistosity striking parallel to the axes of the folds, and consequently in some places across the bedding, and in other places parallel with it. Farther east, in sec. 29, the gray argillaceous slates predominate, although a few beds of calcareous slates are interbedded with them. Here, too, the rocks are contorted and schistose. The schistosity strikes east-west, crossing the numerous little folds at inclined angles. The strike of the axes of the folds is about N. 45° W. and their pitch is to the east.

LOCALITIES AT WHICH CHERTS OCCUR.

The second group of localities within the Hanbury area that are of special interest are those in which cherty and ferruginous rocks occur. Comparatively only a few of these are known at present, all of which are briefly referred to below.

Sec. 15, T. 40 N., R. 30 W.—In the southeast quarter of the southwest quarter of sec. 15, T. 40 N., R. 30 W., near the point where the road crosses the little stream flowing north, are two deep test pits or exploring shafts, from which a large quantity of material was taken many years ago. The rocks on the dump piles are much weathered, but there can be distinguished among them various slates, cherts, and lean ores. At the pit about 200 paces west of the stream the material on the dump is principally a sheared pink ferruginous slate, containing considerable talc or serpentine along the shearing planes between the laminæ. It looks extremely like the talcose slates lying between the Randville dolomite and the base of the Vulcan beds. The other pit is about 200 paces south of the same stream. Here the principal

material on the dump is a ferruginous slate not very different from that at the western pit. In addition to this, however, there are many fragments of a red and gray cherty quartzite, some fragments of a well-characterized jasper, and a few pieces of a very heavy brecciated jasper in which the fragments are cemented by a porous crystallized mass of hematite. The cherts or jaspers are very much more like some varieties in the Vulcan formation than like those in the Hanbury slates. There are no exposures of any kind in the vicinity of the pits, and consequently there is no way of learning what the relations of these rocks are to those north and south.

The nearest rocks outcropping to the north are the Quinnesec schists of the western area. Those to the south are the sandstones covering the hill north of the Cuff mine. If, as has been reported, a drill put down in the northeast corner of sec. 21 penetrated the Randville dolomite, then the dolomite is but a short distance south of the southern pit. If this latter condition is true, the jasper and ores reached by the pits may belong in the Vulcan formation and the talcose slates may be the slates on the top of the Randville formation. In this event there would be a narrow syncline of Vulcan beds between the Quinnesec schists on the north and the Randville dolomite on the south. There is no possible method at present of deciding whether this view of the case is correct or not, and so, in the interests of conservatism, the jaspers and ores are regarded as portions of the Hanbury formation and the general map (Pl. IX) is colored accordingly.

Sec. 11, T. 39 N., R. 30 W.—Another place within the area of the Hanbury slate at which cherts are found is near the center of sec. 11, T. 39 N., R. 30 W., on the top of the terrace just west of the point where the railroad to Little Quinnesec Falls crosses the highway running from Quinnesec to the same point. Here there are several exposures of typical Hanbury slates and several test pits. The pit nearest the railroad is in the normal clay slates of the formation. These strike east-west, as shown by exposures near by. About 150 paces east and 150 or 200 paces north is another pit, south of a large ledge of slates striking also east-west. The slate is strongly schistose, and this structure strikes in the same direction. Its dip is vertical.

On the dump of the pits are rocks some of which are unlike anything else seen in the district. A few of the pieces seem to be a network of quartz veins, with its meshes filled by a mass of hematite and chlorite. A few others are slate. The greatest number consist of a streaked and mottled red and dark-green chert. The dark portion has the texture and the general appearance of flint. The red portion differs from jasper in having a duller luster. Both the red and the green portions are composed principally of a very fine-grained crystalline aggregate of quartz, but the former contains, in addition, a large quantity of hematite and the latter a large amount of chlorite. The hematite is in small granules between the quartz grains and the chlorite is in streaks forming a matrix in which the quartz grains are embedded. Here and there a quartz vein traverses the chert, and the rock is moreover incipiently schistose. The near proximity of the slate ledges to the pit showing these cherts would appear to indicate that these rocks were formed in some vein-like crevice, but of course no proof of this conclusion is at hand. The cherts, however, are clearly in the Hanbury slates.

Southeast quarter of sec. 7 and southwest quarter of sec. 8, T. 39 N., R. 29 W.—West and a little north of Hanbury Hill, i. e., nearly on the general strike of the bedded rocks forming this elevation, is a little hillock on which are exposed not only the siliceous and calcareous forms of the Hanbury slates, but also dolomites and cherts better developed than anywhere else in the Hanbury formation. In the southeast quarter of sec. 7 the rocks form a distinct hill 80 feet high, overlooking a swamp which lies to the north, east, and west. On the top of the hillock the various slaty phases of the formation are well exposed in a complicated series of small folds. Between the slate layers there is occasionally a thin layer of coarse grit or conglomerate, containing granite, chert, and quartz pebbles, and in the trough of some of the folds the slates are brecciated. In some places the rocks are cut by ramifying veins of white quartz, but usually veins are absent. The bedding of the slates in the western part of the hill strikes fairly uniformly N. 65° to 75°, but the dips vary from 63° S. to 65° N., indicating the presence of a syncline. Farther east the bedding is much more contorted and small folds are numerous. Moreover, in some cases a few of the layers constituting the larger folds are folded within themselves into minute crinkles and crumplings. Near the east end of the hillock the little folds are well enough defined to enable one in several instances to determine the direction of their pitch. In one case noted the pitch of a small fold near the center of the elevation was found to be east at 20° to 30°. Farther east the pitch is almost uniformly to the west at widely different angles. This hill, thus, like Hanbury Hill, is a synclinorium with the axis of the fold transverse to the axis of the elevation. Its presence as a hill is undoubtedly due to the close folding to which its rocks have been subjected and their consequent compactness.

All the slates, whether sharply folded or not, are markedly schistose, but the direction of the schistosity is uniformly N. 80° to 85° W. and its dip is 75° to 80° S. Thus the secondary structure is inclined to the bedding at all angles. It is parallel with the same structure in the slates of Hanbury Hill, and departs only slightly in direction from the corresponding structure observed in nearly all the sedimentary rocks of the entire district. Hence this structure is not of local origin, but is probably connected with some general cause which was active throughout the entire Menominee trough. The only general cause capable of producing the effect was that which at the same time produced the major folding of the district and gave rise to the great synclinorium that constitutes the Menominee trough.

Nearly all the slates composing the hill contain iron carbonate to some extent, as is shown by the almost universal existence of a brown, earthy limonitic weathering crust. On its north slope the carbonate is especially abundant, some of the beds consisting of a well-characterized ferruginous limestone 10 feet or more thick. This limestone is dark gray in color and finely granular, and is covered by a limonitic skin or crust one-tenth inch in thickness. Under the microscope can be detected a few grains of quartz, a number of small plates of brown mica, an occasional flake of muscovite, and a few spicules of kaolin. The major portion of the section consists of an intricately interlocking mass of carbonate and crystallized quartz.

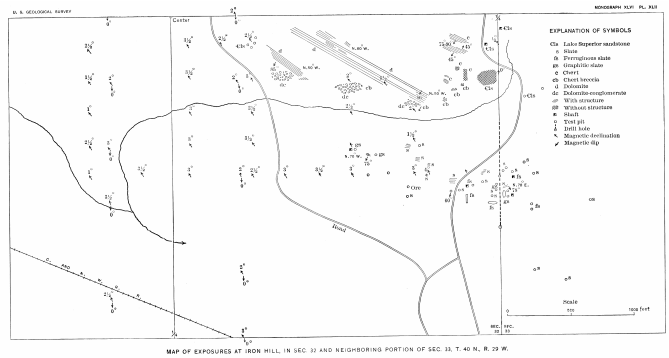
An analysis of one of the best specimens of the ferruginous limestones from this place was made by Mr. George Steiger, of the Survey laboratory, with a view to the determination of the nature of the cementing carbonate.

Analysis of ferruginous dolomite in Hanbury formation.

	Entire rock.	Soluble in HCl (dil.).
SiO_2	36.71	2.28
Al_2O_3	5.34	1.27
Fe_2O_3	.35	3.61
FeO	3.37	
MgO	10.78	[illegible].83
CaO	15.11	15.20
Na_2O	.12	.....
K_2O	2.40	.....
H_2O at 105°	.55	.....
H_2O above 105°	1.61	.....
TiO_2	.27	.....
CO_2	23.22	.....
P_2O_5	.05	.....
MnO	.23	.....
Total	100.11	.....

The soluble portion includes the carbonates and a small portion of some aluminous silicate. If all the iron, magnesia, and lime are assumed to be in the form of carbonates the proportions of these in the rock are 5.43 $FeCO_3$, 18.54 $MgCO_3$, and 27.15 $CaCO_3$, which require the presence of 23.72 per cent CO_2. The total amount of the carbonate present must be about 51 per cent of the entire rock and its composition must be about as follows: $FeCO_3$, 4¾ $MgCO_3$, 5¾ $CaCO_3$—-or the carbonate is a dolomite in which about 17 per cent of the $MgCO_3$ is replaced by $FeCO_3$.

In some places the limestone bears layers of chert several inches wide. This chert is a dark-gray variety clouded with irregular patches having a light-gray or white color and marked by bedding lines. In some places the chert grades on both sides into the limestone. In others it forms a distinct band separated from the limestone by a very sharp line. In the latter cases the siliceous rock appears to occupy a fissure and to partake somewhat of the nature of a vein. In both cases the composition and structure of the chert are simple. The major part of those phases that are most intimately related to the limestone is an aggregate of finely granular, interlocking silica. In this there are embedded abundant little rhombohedra of a light-yellow carbonate, probably siderite, an occasional grain of hematite or magnetite, and a few flakes of biotite. The bedding observed in the banded specimen is due to the greater richness in carbonate of some portions of the sections than others; the darker bands containing a greater proportion of carbonate and the lighter ones a greater excess of quartz. Tiny quartz veins intersect the rock, sometimes forming a complicated network traversing the thin sections in all directions. The quartz in these veins is much coarser grained than that in the mass of the chert, and through it are interspersed little nests of calcite or other carbonate, streaks of a black substance that may be carbonaceous, and a few wisps of muscovite. The carbonate is usually near the walls of the vein and frequently when in this position it occurs in rhombohedra. Those varieties of the chert that are distinctly separated from the limestone, and that have been said to be vein-like in character, differ from the cherts just described in being almost free from carbonate except on the selvages of veins. In many places the slates near the chert bands are highly ferruginous, and in one or two instances distinct veins of hematite can be seen penetrating them.



MAP OF EXPOSURES AT IRON HILL, IN SEC. 32 AND NEIGHBORING PORTION OF SEC. 33, T. 40 N., R. 29 W.

[Plate XLII. Map of exposures at Iron Hill in sec. 32 and neighboring portions of sec. 33, T. 40 N., R. 29 W.]

About a quarter of a mile east of the east end of the hill the same kinds of rocks outcrop in little ledges scattered through the swamp. Black slates, quartzite, and impure limestones occur interbedded with one another in such a way as to show that the general strike is N. 85° E. and the dip about 55° S., but the beds are affected by minor folding, which naturally causes many departures from these directions in both strike and dip. In the midst of the slate outcrops is one of greenstone-schist, in which the schistosity is parallel to the cleavage in the slates, which, of course, is not always coincident with the bedding in these rocks.

Iron Hill, southeast quarter of sec. 32, T. 40 N., R. 29 W.—Near Iron Hill, in the southeast quarter of sec. 32 and the adjoining portion of sec 33, T. 40 N., R. 29 W., is the most extensive exhibition of ores and cherts seen anywhere in the Hanbury slate area. The ledges and pits in which they are exposed are dotted over a plain lying south and east of the end of the central dolomite belt, from which they are separated by a narrow swamp (see Pl. XLII). The dolomite has been described on a previous page. The fact that a drill hole cutting under the pits along the east line of the section encountered

only gray slates, like the typical clay slates of Hanbury Hill, indicates conclusively that none of the cherts and ores are in the Vulcan formation.

On the little terrace south of the swamp, and hence south of the dolomite ridge, are numerous outcrops of well-defined slaty rocks striking about N. 70° W. and dipping approximately 70° S. Some of these are clay slates, others are graywackes, and others are impure quartzites. Most of the slates are like the argillaceous Hanbury slates, but some of them are slightly ferruginized. Graphitic varieties have also been met with in test pits sunk in this portion of the area, and here, as elsewhere, they are associated with heavily ferruginous beds. In one pit a fairly good lean ore was encountered.

North of the dolomite exposures, near the north quarter post between secs. 32 and 33, are three or four deep shafts and a tunnel leading from the bottom of one of them to the side of the hill on which they are situated. These shafts are all in sandstone. A large quantity of ocher is found on their dumps, but this it is believed must have come from a ferruginous bed at the base of the sandstone. Indeed, on some of the dumps pieces of conglomerate were seen that resemble strongly the ore conglomerate found at the base of the sandstone at many places within the district.

The pits and shafts southeast of the dolomite bluffs are plainly in a heavily ferruginized zone. They are at the base of a high hill on which no exposures have been found, but which is probably composed mainly of the Lake Superior sandstone. The pits have disclosed a great variety of rocks. Red ferruginous schistose slates predominate, but in addition to these there are also on the dump heaps graphite-slates, cherts, thin beds of hematite, interbanded cherts and ores, and a few specimens of conglomerate. The latter is from a thin bed interlaminated with slates.

In places the slates approach graywackes in composition and structure, and in other places they approach quartzites. In some places shearing has been so severe as to produce fissility. The slates nearly all contain visible quartz grains. On fracture surfaces their original color can be seen to be green. Their present red color is due to a stain that started along the fissility planes and extended inward from these. In composition the slates of this kind are very near to graywacke. Their quartz grains are often crushed into mosaics or mashed into long, flat lenses. These are embedded in a schistose aggregate of chlorite, muscovite, and crystallized quartz. The brown stain is due to the decomposition of the micaceous constituents and the development within them of limonite and hematite. Others of the red slates contain considerable dolomite. These on a fresh fracture are light-yellowish gray. They are schistose and stained in the same manner as are the quartzose slates.

The cherts and ores are naturally the most interesting of the rocks encountered in the explorations. Indeed they look so promising in a number of instances that the general view as to the existence of a narrow belt of the Vulcan formation at this place is not to be wondered at. However, the cherts are all sandy textured and the ores are very dense, hard, brownish-red varieties unlike anything seen in the Vulcan beds. Most of them are also porous. In some specimens the pores are little, irregularly shaped, vug-like cavities, lined with tiny hematite druses. In other specimens narrow, crack-like cavities, with druse-covered walls run through the centers of the bands as do the longitudinal cavities so often seen in veins. All the ore layers are minutely banded and many of them are divided longitudinally into two or more parts by very fine lines, as though the ore material had grown from both sides of the band inward until the opposite portions joined. The only conclusion as to the origin of the ore that can be reached from a study of the fragments thrown out on the dumps is that they are vein fillings in a fragmental rock which has been partly silicified, and which, therefore, has lost some of its fragmental features. Some of the siliceous bands associated with the ores are distinct cherts, but these may be veins. All the cherts and ores are jointed, and along some of the joints slight faulting has taken place.

Again, there is no opportunity to study the relations between the different rocks because of the impossibility of seeing them in place. It can scarcely be doubted, however, that the jointing and ferruginization of the beds is connected in some way with the folding that terminated the central dolomite belt.

Sec. 17, T. 39 N., R. 29 W.—In about the center of the southeast quarter of the northeast quarter of sec. 17, T. 39 N., R. 29 W., several test pits have been put down in low ground near a swamp. Most of the pits have exposed the normal black siliceous slates of the Hanbury formation, but a few of them, apparently along a crushed zone in the slates, have yielded a red, porous mass of hematite and chert that might be regarded as a lean ore. On the dumps of several other pits fragments of a brecciated chert are also noticed. In these the cement is a red, earthy hematite, and the fragments are small angular pieces of light-gray chert, very similar to the chert on the hill in sec. 7 of the same township. The relations of the cherts and ore to the slates are not known. No exposures are visible in the vicinity, and the pits are now partially filled with débris. The location is referred to simply because it is one of the places within the Hanbury slate area at which cherts have been found.

Northwest quarter of sec. 26, T. 39 N., R. 29 W.—The only place near the southern Quinnesec schists at which cherts and ferruginous beds have been seen is in the southwest quarter of the northwest quarter of sec. 26, T. 39 N., R. 29 W., near Sturgeon Falls, on the Menominee River. On the north side of a little hillock not more than 200 feet north of the State road (see map, fig. 22) running east from the New York farm are exposures of fissile slates containing layers of white, gray, and pink chert, and bands of dense black and dark-purple ores. The rocks are jointed, and in the joint cracks are often thin deposits of hematite. Some of the slates are

graphitic. Northeast of this again, at a distance of about 300 feet, is another very similar ledge on the escarpment of a terrace, and this deflects the compass needle to a very noticeable extent. Still farther north, about 250 paces north of the last-mentioned ledge, is a third low ledge in which the rocks are plainly distinctly fissile slates interbedded with bands of chert. In this ledge the beds are contorted. In all these cases the slates are undoubted members of the Hanbury formation, and the cherts and ores are secondary deposits.

Sec. 21, T. 39 N., R. 28 W.—In the center of the south half of sec. 21, T. 39 N., R. 28 W., is another group of pits which show the presence of 'ferruginous bands in the slates. The pits are comparatively old, but quartzites, graywackes, and slates can be recognized on their dumps. All the rocks are more or less ferruginized, and some of the slate presents the appearance of a very lean banded ore. Reference has already been made to this ore-like slate in another place (p. 467). The relations of the (different rocks to one another are not known. There is little doubt, however, as to their being a part of the Hanbury formation.

Sec. 19, T. 39 N., R. 28 W.—In sec. 13, T. 39 N., R. 29 W., the Hanbury formation is represented by exposures of black slates cut by greenstones (see p. 471). Between this place and the center of sec. 19, T. 39 N., R. 28 W., there are no exposures except here and there a small knob of greenstone. Within the last few years, however, the formation has been opened up by a series of test pits and shafts extending along the east-west quarter line of the last-named section for a distance of about 2,000 feet. (See map, fig. 54.)

This exploration, which was made under the direction of Mr. Turner, of Vulcan, has shown the presence of a ferruginized belt inclosed between normal Hanbury slates, extending in an east-west direction entirely across the explored region. Associated with the slates at several places is a greenstone which is occasionally fresh and dense, but which usually is much decomposed. On the north side of the ferruginized belt the slates dip north at high angles. On the south side they apparently dip high to the south. On both sides the slates are light-gray, much-sheared clay slates, cut by many gaping joint cracks. With these are interbedded a few layers of quartzite or graywacke, the thickness of which has not been determined. Nearly all of the quartzite is sheared, and in one instance considerable muscovite or other light-colored mica has been developed. One of the pits on the south side of the ferruginized belt has also disclosed the presence of a well-defined graphite slate. The existence of this material so near the ferruginous beds recalls the presence of similar material in association with the ore-bearing beds of the Curry member of the Vulcan formation, and suggests the interesting possibility that it may signify that the same processes were active here, which, in the Vulcan beds gave rise to the ore deposits.

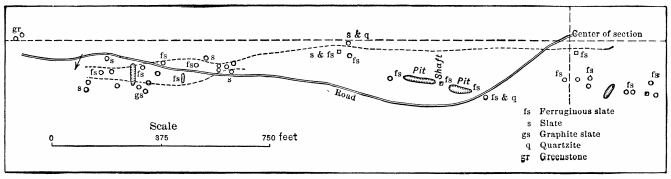


FIG. 54.—Sketch map of explorations at Turner's location, near center of sec. 19, T. 39 N., R. 28 W.

The ferruginous band averages about 60 feet in width. In many pits the material of the bands looks as though it were a brecciated chert or fine-grained quartzite, cut by numerous quartz veins and by thin veinlets of dense hematite. At other places it is a porous, cherty, ocherous mass containing crystalline hematite, forming druses on the walls of its pores and on the sides of joint cracks. In the deepest shaft the ocherous mass seems to be a superficial layer covering a bed of hard hematite ore. This ore appears in two varieties. In one it is a dense black or dark-red hematite, interlaminated with thin layers of yellowish-gray chert, or a dense, banded ore, made up of layers differing slightly in texture. The second variety is porous and crystalline, and the pores are studded with crystals of hematite. The ore that has been seen differs in character from that of the great ore deposits in the Vulcan formation, but is similar to that of the vein-like material that sometimes occurs in the jaspilites as narrow bands, which are interpolated parallel to the bedding. While it is not possible to see the relations of the ferruginous belt to the slates on both sides, it seems probable that the ferruginous zone is along a line of crushing and fracture, and that the hematite was deposited within it in the same manner as that in which the ores were deposited in the brecciated zones within the Vulcan formation.

POSSIBLE IRON-ORE DEPOSITS.

From very early times in the exploration of the Menominee district there has been much speculation as to the possibility of discovering workable ore deposits in the great slate area between the Chicago and Northwestern Railway and the southern area of Quinnesec schists. The discovery of valuable ore beds at Commonwealth and Florence, in Wisconsin, in slates resembling those of the Hanbury formation, has given rise to the belief that similar ores will sometime be found in the slates east of the Menominee River. That so few explorations have been made in this area is explained by the fact that few clues have been available to guide the explorer in locating drills and test pits. Exposures are scarce, and the mantle of drift is so thick that explorations can not be intelligently undertaken. Even if ore bodies exist, they would be very difficult to find. Nevertheless, as has been indicated above, at a number of places within the slate area groups of test pits have been sunk, and from these lean ores have been obtained. In some cases the material is only ferruginous slate, and in other instances it appears to be red 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 Michigamme slates of the

Marquette district, and in several cases these are banded. Thus far, however, nothing has been discovered that would lead to the belief that large ore bodies exist at any of these places. But notwithstanding the unfavorable results hitherto reached by explorations, the conclusion that no ore bodies exist in the slate areas should not be assumed. The slates have been pierced at only a few places, and at these places there has unquestionably been deposited some ore material. That ore bodies of workable size have not been discovered may be due to the fact that the explorations were not made in situations that presented conditions favorable to the accumulation of the ores, or it may be due to the absence of sufficient ferruginous material in the slates at these places to furnish large quantities of iron oxide.

In describing the lithological features of the Hanbury slate reference was made to the presence of iron carbonates in the calcareous slates and dolomites in the lower portion of the formation and to their alteration products. Under favorable conditions these carbonates have partially or completely changed into oxide. Crusts composed largely of the hydrated oxide, limonite, are noticeable on all their exposed surfaces, and gradations between the dolomites and ferruginous cherts are observable in several places. Under favorable conditions of environment and with suitable basins furnished in which to accumulate the ore produced, there seems to be no valid reason why there should not be formed in the Hanbury slates of the Menominee district ore deposits of equal size to those formed in the slates of the Florence and Iron River districts. It is probable, however, that the ores would be non-Bessemer, and therefore quite unlike those in the Vulcan formation.

The same rules to be followed in exploring the Vulcan beds for ore deposits should also be followed in exploring the Hanbury slates. In the latter case, however, there is much greater difficulty in selecting favorable sites for the location of the explorations than in the case of explorations in the Vulcan area. In the latter area the possible positions of the ore deposits are in a narrow belt limited on the one side by the Randville dolomite and on the other by the Hanbury slate. Moreover, marginal folds in the dolomite are comparatively easily detected.

The Hanbury areas on the other hand are broad, and the folding of the slates is of an exceedingly complicated character. Before locating exploring plants in this area the ground should be closely examined with a view to securing the most favorable environment possible, for it is a well-established fact that it is only in exceptionally favorable situations within the slate area that ore deposits of workable size have been developed, and that explorations in any other than the most favorably situated locations will result in a waste of money and energy. If possible, the following conditions should be met by the sites selected:

First. Since the ore material is derived from iron carbonates, and these are known to exist only in the dolomites, cherts, and calcareous slates, the explorations should be confined to areas near those known to be underlain by these rocks, which, when exposed to the weather, may be identified by the coating of limonite that covers their weathered surfaces.

Second. The most favorable situations for ore concentration are the troughs of pitching synclines with impervious bottoms. Hence search should be made for pitching folds. If such folds can be found, and it can be further determined that the folding involves beds of argillaceous slates or other impervious rocks, these furnish conditions favorable for ore concentration.

Third. In the Crystal Falls district carbonaceous shales are often associated with the ore bodies, and in the Menominee district graphitic slates are often associated with the Curry ores, some of the material of which is almost certainly original. Therefore, if situations can be found where carbonaceous slates occur in pitching synclines below rocks containing iron carbonate, the conditions may be regarded as exceptionally favorable for the accumulation of ore deposits.

Fourth. Percolating waters are the agents of the process of concentration; consequently localities at which the rock masses have been shattered, thus affording easy passage to the water, are places particularly desirable for testing.

In a set of slates as closely folded as are the Hanbury there may somewhere be found places where the conditions outlined are fulfilled, and in such places ore bodies will be found, if they exist anywhere in the slate area.

Thus it appears that, although no ore bodies of value have thus far been discovered in the slates, the possibilities of the formation have not by any means been exhausted. A more extensive exploration of the slate formation is, perhaps, warranted before the field is finally abandoned as worthless.

CHAPTER VI.
THE PALEOZOIC SYSTEM.

Limited areas of Paleozoic sediments in approximately horizontal sheets are found to lie on the eroded edges of the Huronian and Archean rocks within the Menominee trough, and a wide expanse of the same sediments is known to cover all the older rocks at the eastern border of the trough and to extend uninterruptedly eastward to Green Bay.

The Paleozoic rocks may be divided into two formations. The lower beds are mainly red sandstone, which is known in the region as the Lake Superior sandstone. The upper beds are porous arenaceous limestones, identified by Rominger as corresponding to the Chazy and Calciferous formations of the Ordovician in the Eastern States. This formation is designated the Hermansville limestone on the map forming Pl. IX. The sandstones and possibly the limestones at one time must have spread continuously over the entire

Menominee district, as they now do over the region to the east. West of Waucedah, however, they have been generally eroded from the valleys, leaving remnants as isolated patches on the tops of the higher hills. East of Norway both the sandstones and the limestones can still be found at many points, but west of this place the limestone has been identified at only one locality. The apparent absence of the limestone from the western portion of the district may, however, be due to the fact that exposures are rare, indeed practically unknown, on the tops of the hills where the limestone would naturally occur.

SECTION 1. LAKE SUPERIOR SANDSTONE.

CHARACTER AND RELATIONS.

The Lake Superior sandstone, according to Rominger, consists of a lower portion, partly cemented by an iron oxide and consequently red in color, and an upper portion, in which the cement is partly calcareous and the color white. Its total thickness is estimated at 300 feet.

The relations of the sandstone to the underlying formations are always practically the same. Whether on the tops of hills or in the depressions between the hills the horizonal beds of the younger rock always rest imconformably upon the upturned and truncated layers of the older series. In the mines and open pits visible contacts between the sandstone and the underlying rocks are numerous, and in every case the contact is an unconformable one. Perhaps the best of these is at the west end of the Quinnesec pit (see Pl. XLIII), where the shore-line conditions that prevailed at the time the sandstone was deposited are very clearly exhibited. Similar contacts are to be seen at several places within the Pewabic and the Cuff mines and in the open pits of the Norway and the Cyclops mines.

Moreover, not only is the sandstone separated from the Huronian rocks by a discordance in bedding, but its basal layers always contain a great deal of material derived from the immediately subjacent formations. Where the underlying rocks are those of the Randville formation the inclosed fragments consist of bowlders of cherty quartzite and dolomite. Where the underlying rocks belong to the Vulcan formation the basal member of the sandstone is an ore and jasper conglomerate, composed of huge, rounded bowlders of ore and large sharp-edged fragments of ferruginous quartzose slate and jasper in a matrix consisting of quartzose sand, numerous small pebbles and fragments of ore-formation materials, quartzite, and occasional pebbles of white quartz, of granite or of other members of the Archean system. Some of these conglomerates are exceedingly handsome.

In a few instances the proportion of ferruginous material is so great that the conglomerates have been utilized as sources of iron ore. A deposit of this kind was formerly worked by the operators of the Quinnesec mine, and another has recently been worked by the Pewabic company. The latter was reached by the open pit in the southeast quarter of sec. 32, T. 40 N., R. 30 W., known as the Pewabic pit. Although at this place the rock immediately underlying is dolomite, the amount of iron ore in the conglomerate is so great that the company operating the pit felt warranted in erecting concentrating works on the property for the separation of the ore from the sandstone (Pl. XXII, *B*). In the summer of 1898 the yield of ore from the concentrator was 5,000 tons.

PLATE XLIII.
VIEW OF UNCONFORMITY BETWEEN THE TRADERS JASPILITES AND THE LAKE SUPERIOR SANDSTONE.

West side of Quinnesec open pit. The rocks to the left are even-banded Traders jaspilites dipping north. Above these, and to the right, is the Lake Superior sandstone. Its top layers are practically horizontal, but near the contact with the jaspilites the dip is steep to the north, conforming with the dip of the surface of the underlying rock. The lower layers of the sandstone series consist of coarse conglomerates containing abundant angular fragments of the jaspilites. Interlaminated with these are layers of fine sand. All beds thicken with increasing distance from the contact, and their included fragments become less angular. Cross bedding can be detected in the sandstone layer beneath the heavy bed of conglomerate.

VIEW OF UNCONFORMITY BETWEEN THE TRADERS JASPILITES AND THE LAKE SUPERIOR SANDSTONE. WEST SIDE OF QUINNESEC OPEN PIT.

AGE OF LAKE SUPERIOR SANDSTONE.

Although Rominger states that there is no record of any recognizable fossils from the sandstone, nevertheless, because of its position beneath the limestones, he correlates it with the Potsdam of New York. Since the publication of Rominger's report several pieces of fossil-bearing sandstone have been obtained, which, according to reliable authority, came from the ledge through which the Pewabic mine shafts near Iron Mountain were driven. One of these contains numerous fragments of trilobites, some of which were determined by Dr. Walcott as "the heads of small trilobites, probably *Dikellocephalus misa;*" others are "fragments of a large species of *Dikellocephalus*." According to Walcott, "these indicate the Upper Cambrian horizon of the Mississippi Valley section." Other pieces are filled with fragments of brachiopod shells. In most cases these are ground up into very small portions, but occasionally a

layer is found in which whole valves, and indeed entire shells, are abundant. In every case seen the shell-bearing layers are interbedded with coarsely conglomeratic layers, indicating that they must have been formed in shallow water near a shore line. Mr. Schuchert, of the United States National Museum, has been kind enough to examine some of the best preserved of these shells and has pronounced them to be *Lingulepis pinniformis*.

The discovery of these fossils in the sandstone at Iron Mountain is particularly interesting, since they furnish the data by which the rock is identified as a portion of the St. Croix series of the Upper Mississippi Valley, which in turn is stratigraphically equivalent to the Potsdam sandstone in the Adirondack region. Through the Menominee rock is likewise established the age of the sandstone bordering the south side of Lake Superior, since the Menominee sandstone is traceable directly by almost continuous exposures into the sandstone at Ashland, Marquette, and other points on the south shore of the lake. Therefore this sandstone likewise must be the equivalent of the St. Croix sandstones. This view has been consistently maintained by nearly all writers on the geology of the Lake Superior region, but it was based exclusively on stratigraphical arguments, since the rock had nowhere been seen to contain fossils that it was possible to identify. Walcott, in his review of the literature of the Cambrian series,[a] concluded that the Lake Superior sandstone "occupies the exact stratigraphic position of the fossiliferous St. Croix or 'Potsdam' sandstone of Wisconsin." He continues: "Although not considering it proved that the two sandstones are exactly contemporaneous, I think that for all practical geological classification they may be considered equivalent deposits." The discovery of a portion of the St. Croix fauna in these sandstones removes the doubt as to their contemporaneity with the St. Croix beds and enables us to correlate the two sandstones without much fear of error.

[a]Walcott, C. D., Correlation papers—Cambrian: Bull. U. S. Geol. Survey No. 81, 1891, p. 338.

SECTION 2. HERMANSVILLE LIMESTONE.

The general character of the Hermansville limestone "is that of a coarse-grained sandstone, with abundant calcareous cement, in alternation with pure dolomite, or sometimes oolitic beds." The limestone may be seen near the top of Hughitt Bluff, east of Iron Mountain, on the north side of the road between the Pewabic and the Walpole mines, and also on the bluff northeast of Norway and at several places on the hills north of Waucedah. Its maximum thickness, according to Rominger, is about 100 feet, but this maximum is rarely reached in the Menominee district. Only a few fossils have been reported from it. Rominger states that it has yielded a few fragments of molluscan shells. To these may now be added a broken *Orthoceras*, a fragment resembling a piece of a *Cyrtoceras*, a gasteropod, and several other fragmentary forms found in the top layer on the bluff northeast of Norway.

The areas within which the limestone is known to occur are so small that no attempt has been made to differentiate them from the Cambrian areas on the general map.

CHAPTER VII. OUTLINE OF GEOLOGICAL HISTORY.

RÉSUMÉ OF FORMATIONS.

Before giving a brief outline of the history of the district it may be well to recall the general succession of formations and their distribution. The district is bordered by areas of Archean schists and granites. The Huronian sediments of the district are in a trough between these older rocks. Structurally this trough is a synclinorium, composed of several important anticlines and synclines. The Lower Menominee series comprises 1,050 to 1,250 feet of quartzites and conglomerates that have been called the Sturgeon quartzite, 1,000 to 1,500 feet of dolomites, with subordinate amounts of calcareous slate and chert, designated the Randville dolomite, and possibly small patches of the iron-bearing Negaunee formation. The Upper Menominee series comprises the Vulcan formation, 650 feet thick, and the Hanbury slate. The Vulcan formation includes three members, the iron-bearing Traders member, consisting largely of detrital ores and jaspilites, but having basal layers of slate, quartzite, and conglomerate; the Brier member, composed of ferruginous and siliceous slates; and the Curry member, consisting of quartzites, ferruginous quartzose slates, jaspilites, and ores. The Hanbury slate is mainly argillaceous, but in places is calcareous, and includes small beds of dolomite and ferruginous chert.

SUCCESSION OF EVENTS.

Archean.—The history of the Archean rocks is an extraordinarily complex one, which will not here be analyzed. It is sufficient to say that the ancient Quinnesec schists, wholly of igneous and largely of volcanic origin, were intruded in a most complex fashion by various igneous rocks, of which granite was the most abundant. This complex of rocks went through a long series of epeirogenic and orogenic movements, with attendant metamorphosis and deep denudation, before Algonkian time.

Lower Menominee deposition.—By transgression of the sea, due to subsidence of the land or rise of the sea, or both, the Menominee district was finally covered by water, and Lower Menominee Algonkian deposition began. Originally the sediments were laid down as a set of approximately horizontal beds on a basement composed of Archean rocks similar to, if not identical with, the material constituting the rims of the trough. The

first deposit of the advancing sea was the basal conglomerate of the Sturgeon quartzite. Following this conglomerate was a thick layer of sandstone, which later was consolidated into quartzite. The deposition of a considerable thickness of sand, which at several horizons is ripple marked, shows that the district must have continued to subside during Sturgeon time. Apparently toward the end of the Sturgeon epoch the water became too deep for sandstone formation, and the nonclastic sediments of the Randville dolomite were deposited. These are now cherty crystalline dolomites and marbles, but there is every reason to believe that the original form of the material was an ordinary siliceous magnesian limestone. The time represented by the Randville dolomite was probably long, for the thickness of limestones deposited was 1,000 feet or more. Possibly, as a result of upbuilding with shallowing of the sea, or other unknown conditions, the carbonates being deposited changed in character and bore a large amount of iron. At this time the cherty iron-bearing carbonates and greenalite nodules were produced. Later these were transformed into the ferruginous cherts and jaspilites of the Negaunee formation. Whether or not later formations were deposited during Lower Menominee time upon the Negaunee formation is uncertain.

The formations of the Lower Menominee series were certainly deposited over a considerable area in the Menominee district, and the equivalents of these formations were deposited north of the Menominee district in the Crystal Falls and Marquette districts. Whether or not the Lower Menominee formations were deposited upon the Quinnesec schists is uncertain. It is possible that the Quinnesec schists were land areas during a large part of Lower Menominee time and that the iron for the Negaunee formation was derived from these heavily ferruginous rocks within and bordering the district mapped. The apparent entire absence of the Lower Menominee formations about the western area of Quinnesec schist is difficult to understand. The most plausible explanation for this area, and possibly for the southern area, is that the Lower Menominee formations were there deposited and were subsequently removed by erosion. These formations, resting upon the Quinnesec schists, might have been composed of softer material than the resistant formations adjacent to the granite area on the north side of the trough, and therefore may have been more easily erodible.

In any case, it is highly probable that the different formations were not deposited in uniformly thick layers throughout the district. If all the formations, or the lower ones, were not deposited upon the Quinnesec schist, each higher stratum overlapped the one next below it in passing toward the land areas of Quinnesec rocks.

Inter-Menominee unconformity.—Following the long-continued deposition of Lower Menominee time the district was raised above the sea. Apparently this uplift was accompanied by only very gentle folding. The reason for this belief lies in the apparent conformity of strike and dip of the Upper and Lower Menominee series. However, it is explained in another connection that such an erosion interval, with no great discordance in strike and dip, may mark a very great hiatus, and such is believed to have been the case in the Menominee district. The evidence that such a hiatus exists between the lower and the upper iron-bearing series is not found in the Menominee area, but in other areas south of Lake Superior. In the Marquette district, for instance, the inter-Huronian orogenic movements and denudation were of a most profound character. As soon as the Menominee area rose above the water, erosion began and continued until all the Negaunee formation was removed through the central and northern parts of the district, and probably also all of the Lower Menominee formations from that part of the district adjacent to the areas of the Quinnesec schists. However, as has already been said, these schist areas may have been above water during much of Lower Menominee time, in which case it would not be necessary to suppose that denudation removed from them the Lower Menominee formations.

Upper Menominee deposition.—During the later stages of the inter-Menominee denudation the sea again gradually overrode the district. Evidently at this time the area was uneven, though not mountainous, for the first formation laid down by the Upper Menominee sea does not extend over the entire district. These first deposits constitute the iron-bearing Traders member of the Vulcan formation. The material of which this member is composed was largely derived from the iron-bearing Negaunee formation, although material was furnished by other formations, and a portion consisted of iron carbonate and greenalite. Therefore the basal layers are composed of quartzites and conglomerates, the bowlders and smaller detritus of which consist largely of iron oxide and jasper, with some quartzite and dolomite. Since these bowlders could have come only from a land mass, it is certain that the Lower Menominee beds at this time had already been consolidated and were at least partly above the sea. Following the deposition of the basal, somewhat coarse, clastic member of the Vulcan formation, there came a time of relative quiescence, during which the muds that afterwards solidified into the Brier slate were laid down. Following the deposition of the Brier slate the mingled fragmental and nonfragmental sediments of the Curry member were deposited. At the end of the time of the deposition of the Vulcan formation-—that is, at the close of the deposition of the iron-bearing Curry member—the sea had not as yet spread over all of the district. The area covered has not been accurately determined, and the Vulcan formation may have a wider distribution than that shown on the map, but it is certain that the sea had not covered the entire district and that some areas were still land, especially those occupied by the hard, resistant dolomite. This is shown by the fact that the Hanbury slate, the next deposit of the advancing sea, at various places rests directly upon the Randville dolomite, there being no intermediate belt of Vulcan formation. The

deposition of the Hanbury slate required a long time, during which the physical conditions varied, for mingled with the ordinary slates are subordinate amounts of calcareous slate, dolomite, and chert, marking brief stages of partial or complete nonfragmental sedimentation.

Folding and metamorphism.—Following the deposition of Upper Menominee time the district was again raised above the sea and was subjected to very great orogenic forces. The major compressing force was nearly north-south. As a result of compression in this direction the areal extent of the mass of Menominee sediments was shortened considerably, probably as much as one-half. Consequent on this folding two great anticlinoria were formed, bordering the northern and southern sides of the area, and a great central synclinorium constituting the Menominee trough. The northern and southern anticlinoria naturally expose the oldest, or Archean, rocks. The intermediate synclinorium is occupied by the Huronian sediments. This central synclinorium consists of three synclines and two anticlines. Superimposed on these folds of the first order is a set of folds of the second order, on these a set of folds of the third order, and on these folds of higher orders to those of microscopical dimensions. The major folds of the Menominee synclinorium are illustrated by the anticlines of dolomite; the folds of the second order by the synclines within the Vulcan formation, in which such mines as the Walpole, Pewabic, and Aragon occur; the folds of the third order by the two separate ore deposits of the Walpole. From an economic point of view, therefore, it is necessary to take into account at least the three major orders of folds.

In addition to the intense north-south compression there was very strong compression in an approximately east-west direction, or, to speak more exactly, parallel to the direction of the trough. This compression produced folds at right angles to the longitudinal folds, so that the east-west folds of the various orders have a pitch. In some cases this pitch is comparatively slight, but in other cases it is very steep, as high as 40°, 50°, 60°, or even 70° or more. It is therefore clear that the east-west compression was of great importance. While the north-south compression produced the subordinate synclines holding the ore bodies, the east-west compression gives these folds a pitch, and thus supplies the chief final condition for the production of the ore deposits.

During the uplifting and folding of the rocks of the Menominee series the harder formations were fractured in a most complicated fashion, and all were profoundly metamorphosed. The sandstones were transformed to quartzites, the limestones to crystalline dolomite or marble, the iron-bearing formation to ferruginous slates, jaspilites, and ores, the muds to slates.

Post-Huronian unconformity.—Contemporary with the uplifting and folding of the district, which must have produced mountain masses, denudation was steadily going on. It was during this complex series of transformations that iron oxide was concentrated in the pitching troughs and the ore deposits were produced. The period of post-Huronian folding and erosion occupied the great length of time represented in other parts of the Lake Superior region by the unconformity between the Upper Huronian and the Keweenawan, the formation of the entire Keweenawan series, and the great unconformity between the Keweenawan and the Cambrian.

Paleozoic deposition.—During the later stages of this great period of denudation the Cambrian transgression was slowly making its way in North. America from the southeast toward the northwest. Finally the Cambrian sea reached the Menominee district, but not until Upper Cambrian time. At this time the topography of the Menominee area was rough, even bluffy. The Cambrian deposits filled the depressions in the preexisting rocks and capped even the highest hills of the district. Where the sandstone lies adjacent to or upon the Vulcan formation the basal member of the Cambrian contains quantities of iron-ore pebbles, and where the topography furnished depressions for concentration of the heavy material these beds are so strongly ferruginous as to furnish detrital iron ores. Sandstone deposition continued to the end of the Cambrian period, at which time the water had become sufficiently deep for limestones to be deposited, and at this stage of the history the Hermansville limestone was laid down. Whether Paleozoic rocks later than the Hermansville limestone were deposited in the Lake Superior region is uncertain.

Post-Paleozoic history.—Following the Paleozoic period of deposition the area was again elevated above the sea, and then another long period of denudation began. So far as known, this erosion period continued until late in Cretaceous time. Possibly later Cretaceous sediments were laid down over the Menominee areas; but in any case, following Cretaceous time the region was again elevated, and, so far as we know, denudation has since continued. Nearly all of the Silurian limestone has now been removed from the district, and only a subordinate amount of the Cambrian sandstone remains capping the higher hills and filling the depressions in some of the subordinate valleys. During this period of erosion the present topography of the district was largely produced. The exact extent to which this topography follows the pre-Cambrian topography can not be accurately determined, but apparently the pre-Cambrian topography has had an important influence upon present topography. As the result of the removal of the greater part of the Paleozoic rocks, the Huronian and Archean rocks were again brought to the surface.

The final important episodes in the history of the Menominee district were the successive advances of the North American ice sheet, which modified the topography of the district by erosion and by deposition. The glacial deposits constitute a mantle which subsequent river erosion has only partially succeeded in removing, and which has prevented fully satisfactory

determination of the distribution of the Vulcan and other formations.

CORRELATION WITH OTHER IRON-BEARING DISTRICTS OF THE LAKE SUPERIOR REGION.

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 geological history of pre-Cambrian time was extraordinarily complex. From Archean to Upper 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 epeirogenic or land-making movements were accompanied by orogenic movements, or mountain growths of varying power, but some of them exceedingly intense. In Huronian time, in all the districts except the Menominee, there were important and long-continued periods of volcanism. 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 mountainous. 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.

A more precise correlation of the Menominee formations with those of the other iron-bearing districts south of Lake Superior as well as with those to the north of the lake is left for discussion in another monograph which will treat of the geology of the entire Lake Superior Basin.

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January, 1904