Iron amphibole is noticeably absent at this locality. In general, the formation is soft, somewhat porous, and shows no evidence of having been subjected to severe metamorphism but it is lean and shows little concentration of iron oxide.

The formation of the south limb of the fold, so far as known, contrasts sharply with that of the north limb just described. It is an

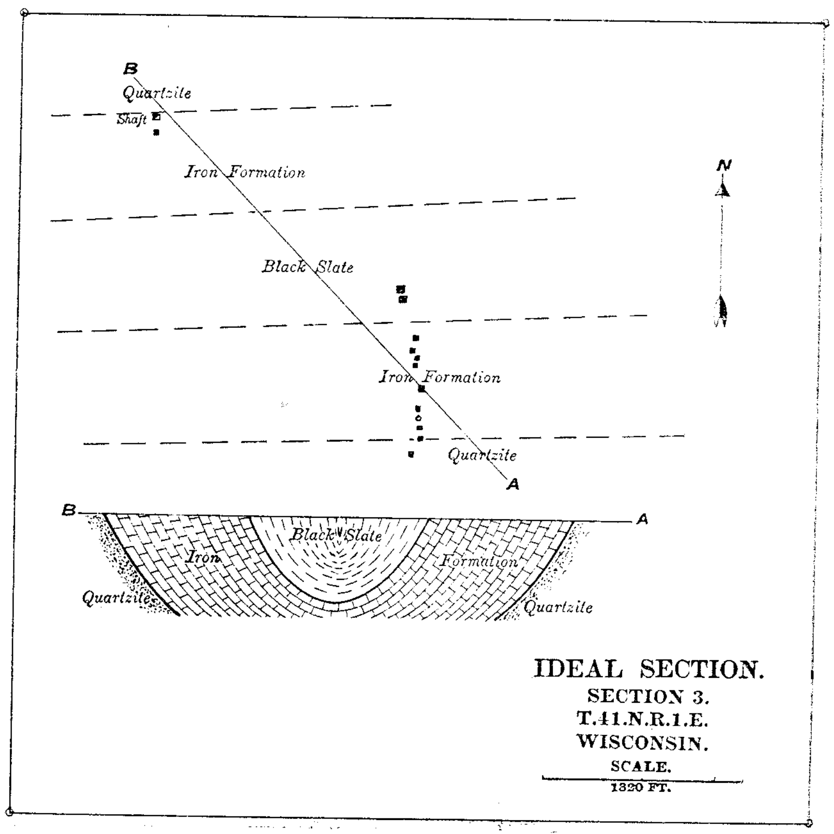


Figure 5.

amphibole magnetite schist similar to that at the Ford-Lucas exploration. The chief minerals are amphibole (mainly grunerite with subordinate actinolite), quartz, magnetite, carbonate and brown iron oxide, the latter apparently the result of surface weathering of the grunerite. It is needless to add that the formation in this vicinity is unpromising from an economic standpoint. The thickness here is apparently the same as at the Ford-Lucas locality, namely, in the neighborbood of 650 feet

The cross section, (*Fig. 5*), is in part ideal. It is probable that the fold is much deeper than represented in the drawing. The boundary between the iron formation and quartzite on the north limb of the syncline is placed just north of the shaft on the basis of statements made by residents of the locality who worked here at the time exploration was active. Such information is not considered reliable.

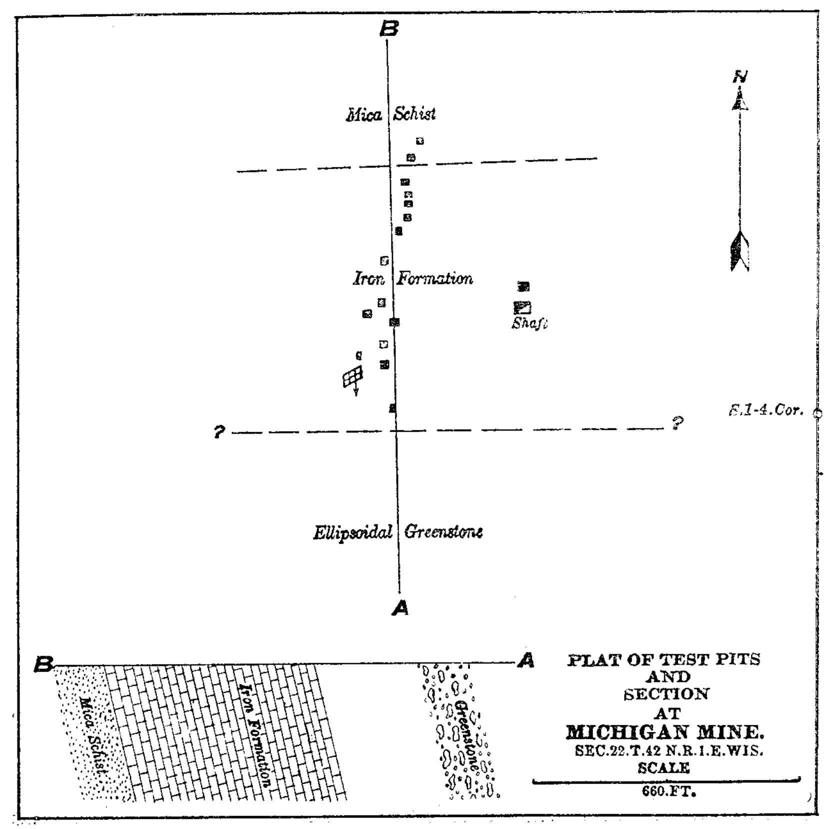


Figure 6.

Michigan Mine. (*Fig. 6.*) The old Michigan mine is located in the SE¼ of the SW¼ of section 22, T 42 N, R 1 E. The workings consist of a number of test pits and a shaft. The dump adjacent to the shaft contains about 2,000 tons of iron formation but none of the other workings show very extensive exploration.

The rock exposed in the northernmost pits is a soft, gray, rather fine grained *muscovite schist* which in thin section is observed to be composed mainly of quartz and muscovite with considerable graphite; accessory minerals are biotite, epidote and hematite. The muscovite, biotite and graphite flakes possess a decided schistose structure, and even the individuals of quartz forming the crystalline mosaic filling the spaces between the micaceous minerals show a tendency toward elongation parallel to the alignment of the muscovite crystals. The epidote seems to have formed after the development of the schistosity as it occurs in fairly large, fully formed crystals whose growth has pushed aside the schistose ground mass. Although no traces of sedimentary structures or textures remain there can be little doubt from consideration of the mineral content, and especially the presence of graphite, that the schist is a metamorphic sediment.

As to the question of the position of the schist with reference to the iron formation no direct evidence is available. The dip of the rocks in this vicinity, as revealed by the single known outcrop of iron formation, is toward the south at an angle of about 85 degrees. If the schist is regarded as belonging to the upper slates, overturned folding is indicated. The presence of graphite in the schist renders it probable that this rock should be placed in the overlying slates rather than in the basal member of the Upper Huronian which is predominantly a hard vitreous quartzite. On the other hand the rocks underlying the iron formation are in places mashed to micaceous schist as shown by the drill holes in section 4, T 41 N, R 1 E.

The *iron formation* is typical, lean, banded "hard ore jasper." In general the bands are white, dark gray or black and occasionally red. The iron is in the form of magnetite and hard blue and specular hematite. Amphibole and chlorite are sparingly developed. It is possible with considerable search to pick up small pieces of ore that contain 60 per cent metallic iron, but in general the formation is lean and cherty. In thin section, quartz, magnetite, hematite and siderite, with occasional needles of amphibole and flakes of chlorite, appear as the constituent minerals.

The thickness of the iron formation is probably in the neighborhood of 650 feet, about the same as at the Whiteside and the Ford-Lucas localities in the township adjacent on the south, although the exact thickness cannot be determined from the pits.

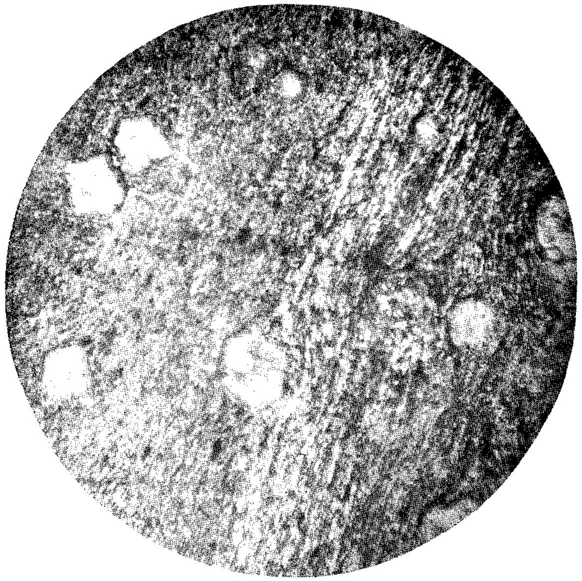
Ellipsoidal greenstone occurs a short distance south of the exploration in section 27. Its relation to the iron formation is unknown. It is probable that effusive greenstone is interbedded in the Middle Huronian series. The petrographic character of these rocks will be considered later.

Broomhandle exploration. In the NW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 29, T 42 N, R 1 E, there are five pits on the magnetic belt that marks the position of the iron formation at the Michigan mine in section 22. Highly metamorphic, lean, iron formation and a coarse grained, altered

Plate VII.

(A). (Without analizer, X 16). Black slate from test pits of Ford-Lucas exploration, SE¼ of SE¼ of section 5, T. 41 N, R. 1 E., Wisconsin. Secondary garnet imbedded in a schistose groundmass composed of quartz, feldspar (?), carbonaceous material and biotite. Note that the garnet during growth has pushed aside the groundmass.

(B). (Without analizer, X 16). Grünerite-magnetite-schist from drill hole 17, SE¼ of SW¼ of section 26, T. 43 N., R. 3 E., Wisconsin. The section shows only grünerite and quartz but magnetite is abundantly developed in this rock. The concentration of the amphibole in thin bands is well shown.



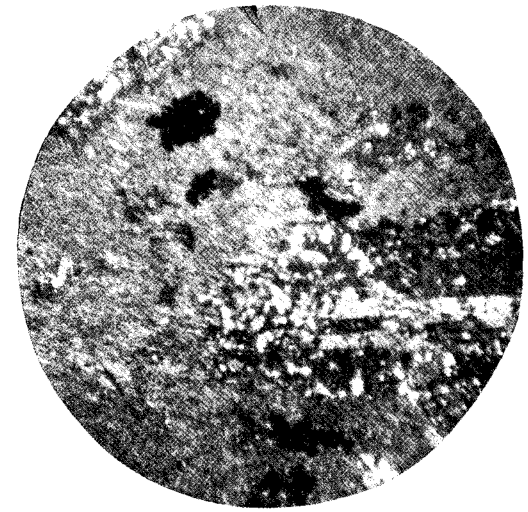
(A)

(B)

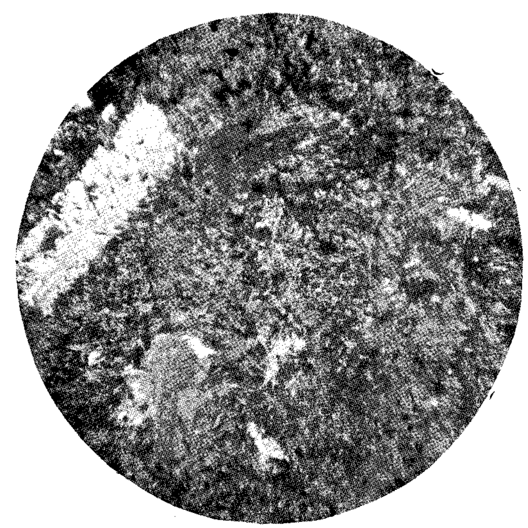
Plate VIII.

(A). (With analizer, X 16). Altered porphyrite from section 22, T. 42 N., R. 1 E., Wisconsin, near Michigan mine. The plate exhibits a large phenocryst of plagioclase showing granulation and fracturing. The groundmass is a schistose matte of green hornblende needles with scattered grains of epidote and a few irregular patches of magnetite.

(B). (With analizer, X 16). Altered porphyrite from east end of Turtle range near south quarter post, section 27, T. 46 N., R. 41 W., Michigan. The normal composition of this rock is essentially similar to that in (A). The groundmass is coarser grained but is predominantly green hornblende with a small amount of magnetite, epidote, limpid feldspar and quartz. The large phenocrysts are plagioclase.



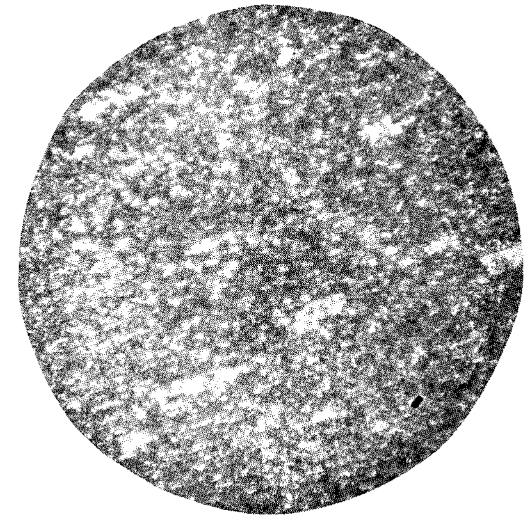
(A)



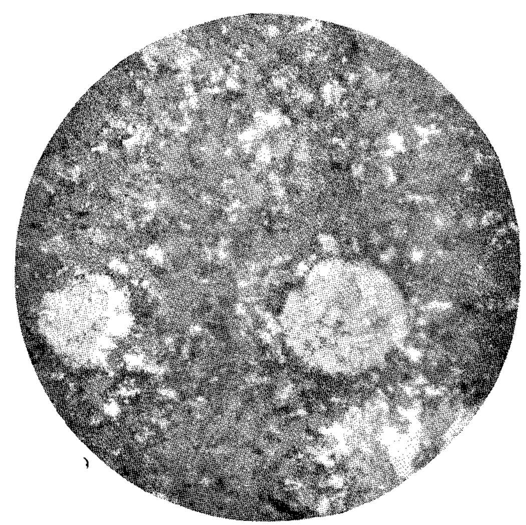
(B)

(A). (Without analizer, X 16). Fine grained hornblende schist from SE¼ of NE¼ of section 33, T. 46 N., R. 41 W., Michigan. This plate shows the appearance of the fine grained hornblende schist of the Turtle range which is regarded as metamorphic basic lava or tuff. Mineralogically, this rock is identical with the groundmass of the altered porphyrite.

(B). (Without analizer, X 16). Altered basic amygdaloidal lava from near the center of section 4, T. 42 N., R. 3 E., Wisconsin. This rock is one of the effusives from the Turtle range west of Mercer, Wisconsin. The amygdaloidal structure is well shown in the figure. The filling is epidote, zoisite and quartz. The groundmass is largely composed of compact needles of green hornblende.



(A)



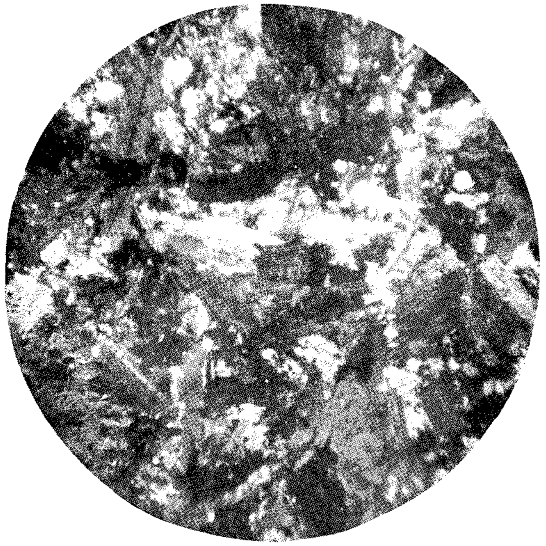
(B)

Plate X.

(A). (With analizer, X 16). Diabase from dike cutting basic lavas in the NW¼ of SW¼ of section 34, T. 43 N., R. 3 E., Wisconsin. This plate is introduced to show the extremely fresh appearance of the diabase dikes found on the Turtle and Marenisco ranges. Minerals present are plagioclase, augite, magnetite and olivine. The olivine is generally more or less altered to serpentine but the other minerals are fresh and show only incipient alteration.

(B). (With analizer, X 16). Altered diabase in the SW¼ of section 15, T. 42 N., R. 2 E., Wisconsin. This is one of the more readily recognizable massive greenstones abundant on the Turtle and Marenisco ranges. Contrast the appearance of this rock with the diabase of (A). Consideration of the mineral composition of the altered diabase shows that it was probably identical with that in (A), with the exception that the rock in (B) is apparently lacking in olivine. It is made up of altered feldspar, the original lath shapes of which are barely discernible, magnetite, leucoxine and green hornblende, the latter probably derived from augite although no trace of pyroxene now remains.

(A)



(B)

diorite appear on the dumps. The formation is mainly dark gray, recrystallized chert with occasional bands containing considerable magnetite and a few narrow bands of green amphibole. The major part of the dump material is dull gray chert. In thin section, banded rocks of the iron formation disclose the presence of quartz and magnetite, with many small needles of actinolite, a few flakes of chlorite, specks of hematite and small irregular areas of carbonate and pyrite. The quartz constitutes a very fine, crystalline mosaic and in places shows the irregular grains and suture lines characteristic of chert. Magnetite is roughly concentrated in streaks and bands and associated with this mineral are minute needles of actinolite usually visible only under high magnification.

Closely associated with the iron formation in this locality is a coarse grained, *massive greenstone.* One of the pits shows both iron formation and greenstone on the dump, while the two south pits are in greenstone alone. The greenstone is composed mainly of large individuals of allotriomorphic, ragged, green hornblende. The interstitial material is mainly secondary albite, quartz, epidote, zoisite, magnetite-leucoxine, and occasional flakes of biotite. Obscure traces of large striated plagioclase are still to be seen, but the original textures and minerals have been largely destroyed by alteration.

The highly metamorphic character of the iron formation in this locality together with the sudden termination of the magnetic belt just west of the pits is evidence that the greenstone is intrusive in the iron formation and perhaps representative of a large body of igneous material which cuts out the Huronian rocks west of this locality.

Mercer Section. Proceeding northeast along the Turtle range from townships 42 and 41 N, R 1 E, Wisconsin, nothing is known regarding the character of the Middle Huronian sediments except the data obtained from recent diamond drilling. A number of drill holes were put down by the F. I. Carpenter syndicate in the vicinity of Mercer, T 43 N, R 3 E, Wisconsin. At this locality the Turtle range is marked by two belts of magnetic attraction separated by narrow strips of normal territory.

Diamond drill hole No. 17 is located on the maximum magnetic line of the south belt a short distance north and west of the south quarter corner of section 26, T 43 N, R 3 E. After passing through 174 feet of overburden this hole was ledged in a steeply dipping banded rock showing wider bands of light gray quartz alternating with narrower bands of light brown amphibole and others nearly black in color containing magnetite. In thin section the rock appears to be composed of quartz, magnetite, grunerite and a small amount of carbonate. The minerals are arranged in bands, some consisting of quartz alone, some of quartz and magnetite, and others of grunerite and quartz with subordinate magnetite and a little carbonate. The grunerite fibers in the center of the grunerite bands are oriented parallel to the banding but on the borders the amphibole needles are at right angles to the banding and penetrate into the adjacent quartz grains. The larger crystals of grunerite are beautifully twinned and generally idiomorphic in cross section The rock is a *grunerite-magnetite-schist* typical of highly metamorphic iron formations. Analysis of drill core at a depth of 208 feet shows Fe., 29.1 per cent.

Drill hole No. 19 on the maximum line of the north belt in the NW¼ of the NE¼ of section 26, T 43 N, R 3 E, was discontinued after penetrating 22 feet of rock. After passing through about one and one-half feet of biotite-hornblende schist the drill entered a dark colored, cherty rock containing reddish garnet, green fibrous amphibole, and pyrite in crystals of sufficient size to be macroscopically visible. Toward the bottom of the hole the rock has a pronounced banding caused by alternating layers of pure black chert and cherty bands containing amphibole and garnet. Magnetite is present in sufficient quantity to affect the magnetic needle although not developed in crystals of sufficient size to be macroscopically visible

A thin section cut from one of the amphibole-garnet bands exhibits a fine grained, cherty mass of quartz in which the other minerals are embedded. Amphibole, biotite and large irregular crystals of garnet are scattered throughout the rock. Small grains of magnetite are included in the garnet and larger amphibole crystals. The amphibole is mainly dark green and strongly pleochroic but associated with it is a colorless amphibole. In thin section the latter commonly forms a light border around the edges of the former with which it is in perfect optical orientation, a feature which is also retained when, less commonly, the two varieties are in parallel intergrowth. Finally, both the colorless and green varieties occur in separate crystals, the latter in greater abundance. A very small optic angle giving an interference figure nearly uniaxial in character is a peculiarity of the green hornblende. The optical sign is negative. The colorless amphibole has a large optic angle and is apparently positive. Where it is not associated with the green hornblende it possesses twinning characteristic of grunerite.

That this rock is a metamorphic phase of the iron formation is apparent from its cherty character, abundance of magnetite and iron amphibole, and pronounced banding. The presence of garnet is interesting. A somewhat similar type of alteration, described by Leith, occurs in the Biwabic formation of the Mesaba range at the contact with the Embarrass granite* and Van Hise, Bailey and Smyth describe similar occurrences in the Negaunee iron formation of the Marquette range at the Republic and Magnetic mines**. At the latter locality grunerite and green hornblende occur in parallel intergrowth and biotite and garnet are abundantly developed in the iron formation adjacent to the greenstones and at low horizons in the formation.

*Leith, C. K. Monograph No. 43, U. S. Geological Survey, p. 162.

Four other drill holes in this vicinity penetrated altered basic intrusives belonging to the diorite and diabase family. The highly metamorphic iron formation found on both belts renders it very probable that the latter are intrusive in the Huronian series at this locality.

About three miles southwest of Mercer a drill hole (No. 14) located on the north border of the magnetic belt passing through section 11, T 42 N, R 3 E, penetrated a slate formation in the form of a garnetiferous, pyritic and graphitic schist. In hand specimen and in thin section this rock is very similar to the slate at the Ford-Lucas and Whiteside localities. In mineral composition the two rocks are identical.

Winegar Section. (*Fig. 7*). The Turtle range was recently cross-sectioned in the vicinity of Winegar, Wisconsin, T 44 N, R 6 E, by eight diamond drill holes. The section indicates a synclinal fold carrying Lower Huronian quartzite and dolomite on the opposite flanks with the Middle Huronian slate-iron formation series occupying the middle or trough. The quartzite and dolomite have been described above.

In general, the Middle Huronian has suffered extreme metamorphism and there is abundant evidence in the drill cores that igneous intrusion has played an important role in this connection. As near as it is possible to judge from the drilling the iron formation is underlain and perhaps in part interbedded with badly altered slate.

Hole 39 penetrated 34 feet of *dark gray, fine grained carbonaceous schist* cut by many stringers of intrusive granitic and pegmatitic material, especially in the upper 10 feet. The contact between the schist and the granite is marked by narrow veins and seams of pyrite. The cleavage approaches in perfection that of slate and in part of the core a well defined narrow banding is exhibited. Biotite is the most abundant mineral. The interstices between the biotite crystals are filled with a dull gray, weakly polarizing substance not separable even under the microscope. It is probably secondary quartz and feldspar. The only other noticeable features are long, lens shaped bodies of pyrite oriented parallel to the schistosity and the occasional development of large porphyritic chlorite individuals at variance with the schistosity. The latter are rich in inclusions of pyrite and carbonaceous material. As will be shown later, the Middle (Animikie) Huronian series at the Banner locality, about five miles northeast, is represented by iron formation, slightly anamorphosed, underlain by a considerable thickness of black

**Van Hise, C. R.; Bailey, W. L.; and Smyth, H. L. U. S. G. S. Monograph No. 28, pp. 390-91.

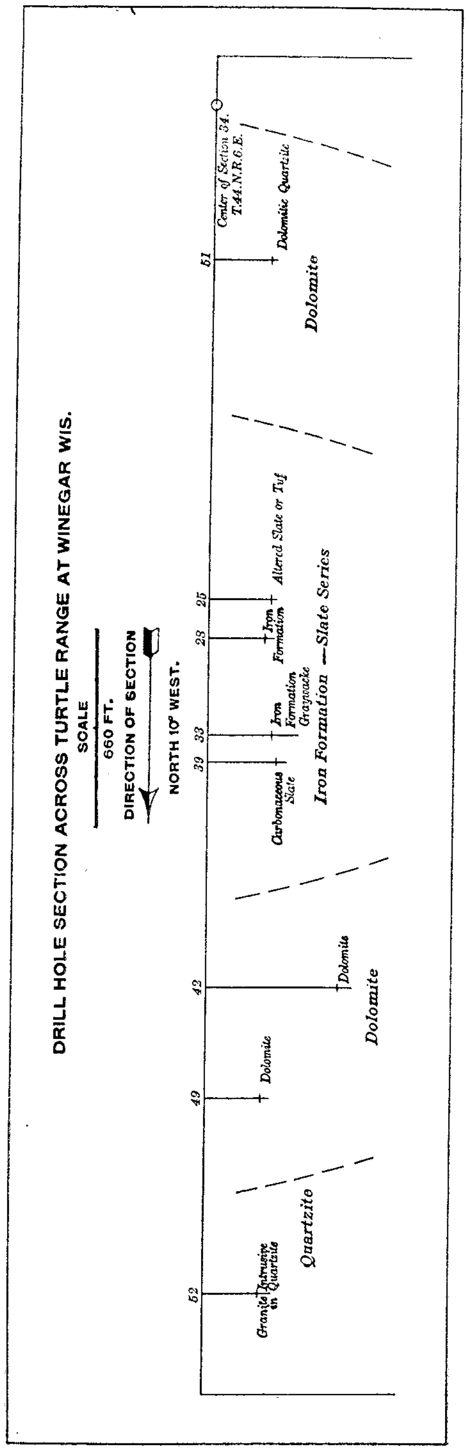


Figure 7

slate. There can be no doubt that the carbonaceous schist found in hole 39 is an altered sediment although original textures and structures are now largely destroyed. From a consideration of its mineral composition and its position with reference to the holes in dolomite and in iron formation it is probable that this rock is to be correlated with the slate below the iron formation at the Banner exploration.

Hole 33, located about 100 paces south of No. 39 encountered rock at 215 feet and drilling was continued to a depth of 307 feet. The core from 215 to 239 feet is fine grained, dark colored graywacke. Here and there the rock has a silky lustre due to local development of muscovite. Microscopic examination reveals small rounded and angular grains of quartz embedded in a schistose ground mass of micaceous minerals, mainly chlorite, biotite, and muscovite. Accessory minerals are epidote, black dust (carbonaceous?), a few small garnets and octahedrons of magnetite. The core from 239-244 feet is lean ferruginous chert made up of alternating bands of various shades of gray and to less extent red or green. The iron is in the form of magnetite with subordinate hematite and pyrite.

The lean iron formation described above grades downward into a dark, greenish black, garnetiferous schist containing quartz, pyrite, garnet, biotite, and considerable black dust, probably carbonaceous material. In thin section most of the garnets are altered around the edges to a fine grained, green colored matte. Under high magnification this green matte appears to be a chaotic assemblage of innumerable minute doubly refracting needles of a mineral resembling serpentine. The origin of this rock is indeterminate, but the presence of carbonaceous dust, the apparent absence of feldspar, either original or secondary, and the fact that the rock from 215-244 feet is plainly sedimentary are strong presumptive evidence that the schist from 244 feet downward is also a sediment.

Hole 28, about 250 paces south of hole No. 33, penetrates 26 feet of typical, banded, biotitic-sideritic-magnetitic-schist cut by a dike of fine grained diabase. The constituent minerals in the order of their relative abundance are quartz, biotite, magnetite, siderite, pyrite, chlorite, sericite, and amphibole. The carbonate in this rock was determined as siderite by microchemical tests. Although in some respects this rock is peculiar, when the abundance of iron is taken into consideration there can be no doubt that it belongs to the iron bearing series. The presence of considerable biotite and chlorite and the almost total lack of typical iron amphiboles such as grunerite or actinolite may perhaps be accounted for on the theory that the iron formation at this locality was originally deposited with considerable intermixed clastic material. No trace of clastic textures now remain, but in mineral composition this rock is very similar to the iron formation largely intermixed with fragmental grains of quartz and feldspar exposed south of the Marenisco station.

Hole 25, about 130 paces south of No. 28, cut 15 feet of dark, greenish colored, fine grained schist, full of narrow wavy bands or veins of white quartz. Locally there is an abundant development of orthoclase and pyrite in the quartz bands and this suggests the idea that the quartz bands are pegmatitic material injected parallel to the schistosity. The greenschist is, in general, very fine grained and near the bottom of the hole is characterized by abundant development of light red garnets. Near the top of the hole the schist contains many small oval shaped spots of lighter green color than the ground mass and oriented parallel to the schistosity. Under the microscope these green spots appear as large crystals of green hornblende embedded in a fine grained ground mass consisting of biotite, feldspar, and quartz, and a few specks of leucoxine; the large hornblende individuals are full of small inclusions of limpid feldspar and quartz. Small grains of limpid feldspar and quartz also fill the spaces between the flakes of biotite which is the most abundant mineral. The number, distribution and arrangement of the inclusions of quartz and feldspar in the large green hornblende crystals simulate exactly their distribution in the ground mass and under crossed nicols there is little difference in appearance between the large hornblende crystals and the micaceous ground mass. Close examination reveals, however, that whereas in the ground mass the biotite is made up of many small individual flakes with nearly simultaneous extinction due to crystallographic parallelism, each green spot represents a large individual of green hornblende. The alignment of the hornblende and biotite and the abundance of ferro-magnesian mineral makes the thin sections nearly dark when the direction of schistosity is parallel to one of the cross hairs of the microscope. The small limpid feldspar grains are more abundant than quartz and show incipient alteration to sericite. In general, both the quartz and feldspar grains are arranged with their longer dimensions parallel to the schistosity. A few rounded grains of both minerals are to be seen, but they are of small size and fit perfectly into the mosaic. In addition to the minerals described, magnetite, pyrite, epidote, and rutile are present in small amounts. This rock is now in the most complete sense a crystalline schist and no direct evidence of its original character may be obtained. The presence of abundant basic material and particularly the green hornblende are somewhat suggestive of an igneous rock, perhaps of the nature of a

tuff. In some respects it resembles the "spilosites" produced by contact metamorphism of the Mansfield slate by intrusion of dolerite*.

The interpretation placed upon the data obtained from drilling at Winegar may be seen by reference to *Fig. 7*. The highly metamorphic character of the Middle Huronian adds greatly to the difficulty of interpretation and no definite succession can be determined with cer-

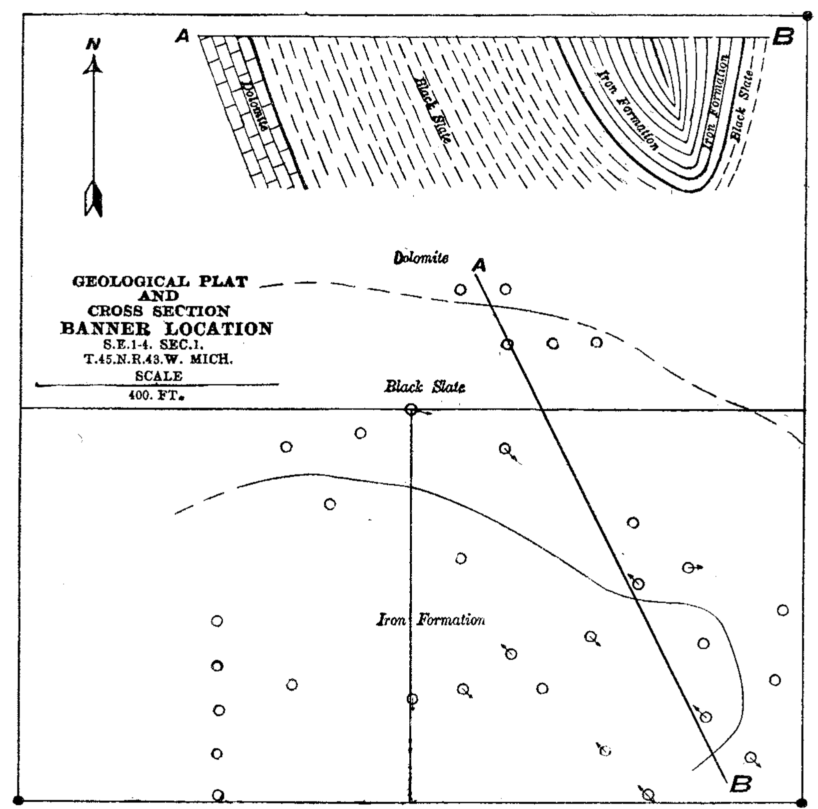


Figure 8.

tainty. It seems highly probable that the deposition of the iron bearing rocks was accompanied by a large intermixture of mud and probably volcanic tuff. Later the rocks were folded and intruded by both acid and basic igneous material with the production of a complex series of schists, the origin of parts of which are in many cases extremely difficult of determination.

Banner Location. (*Fig. 8*). Recent drilling by the E. J. Longyear Co. in the $SE\frac{1}{4}$ of section 1, T 45 N, R 43 W, in the neighborhood of

*J. M. Clements, H. L. Smyth, and W. S. Bailey, Mon. 36, U. S. Geological Survey, p. 206, plate 37, fig. A.

an old shaft and group of test pits known as the Banner mine, has given a very clear idea of the character and succession of the Huronian rocks of this portion of the Turtle range. At this locality the rocks are much less metamorphic than any heretofore described. As may be seen on the accompanying geological maps and sections the Huronian series occupies a southwestward pitching synclinal trough.

Dolomite, the lowermost known member, is overlain by *gray schist,* apparently not less than 150 feet thick. Between the schist and *iron formation* is a thickness of not less than 500 feet of *black pyritic slate.* The iron formation which occupies the center of the trough, is probably from 700 to 1000 feet thick. It is, for the most part, rich ferruginous chert or "soft ore jasper." Near its southern margin it contains some hard blue hematite and unaltered iron carbonate. In places the iron formation carries ore bodies, but, so far as known, these are too small to warrant mining.

The succession here may be compared with that at Winegar. Dolomite appears to underlie a slate-iron formation series in both localities. At Winegar there is apparently considerable mud and volcanic debris in the iron bearing rocks but at the Banner exploration they are comparatively free from intermixed detrital material. The two localities are connected by a continuous magnetic belt and it is probable that the two successions are representative of one and the same series.

IGNEOUS ROCKS.

With the exception of the single outcrop of iron formation at the Michigan mine the known natural exposures on the Turtle range are igneous, and comprise both intrusives and extrusives.

Intrusives. In general, the intrusives are basic in composition although granite occurs in drill holes at Winegar. At the Broomhandle exploration near the west end of the range, greenstone is closely associated with and probably intrusive in the iron formation. Northwest from this locality, on the rock ridges southwest of Mercer, dikes of diabase occur in association with effusive lavas. The intrusives are highly altered and are composed mainly of large individuals of sedgy green hornblende magnetite-leucoxine and alteration products of feldspar such as epidote, quartz, ziosite, and limpid albite. In most instances the microscope reveals some traces of original, lathshaped plagioclase. In addition to the altered types, dykes of fresh diabase are occasionally seen. The fresh diabase is characterized by its content of primary augite.

Two drill holes near Mercer penetrate fresh diabase, a third, massive greenstone conforming more closely to altered diorite.

Granite and greenstone apparently intrude both the Middle and Lower Huronian series at Winegar.

Extrusives. The most abundant rock outcrops on the Turtle range are effusive greenstone. Rocks of this type are plentifully exposed in Ts 46-45 N, R 41 W, Michigan; and in T 42 N, Rs 1, 2, 3 E, and T 43 N, R 3 E, Wisconsin.

At the former locality, the magnetic belt marking the position of the Turtle range is closely associated with porphyritic green schist and a number of exposures of ellipsoidal greenstone occur a short distance south of the belt in section 3, T 46 N, R 41 W. Associated with the porphyrites and ellipsoidal greenstones are fine grained green schists and aphanitic greenstone.

The greenstone porphyrites were found on several traverses just south of the maximum magnetic line. They are light green, fine grained and exhibit on weathered surfaces small white phenocrysts of feldspar, generally rounded but occasionally lathshaped or roughly rectangular in outline. The phenocrysts are in general from 1-32 to 1-4 of an inch in diameter, although larger ones are occasionally found. On fresh fractured surfaces the feldspar phenocrysts are not easily seen. Schistose structure with an average strike of N 60° E and southerly dips is conspicuous.

Microscopic examination shows that these rocks are very similar in many respects to the lavas in the north portion of this township described in connection with the Marenisco range. They are, however, more basic in composition. Phenocrysts of plagioclase are embedded in the ground mass consisting mainly of pale green weakly pleochroic needles of amphibole. Associated with this mineral are lesser amounts of magnetite, pyrite, limpid feldspar carbonate and probably quartz. Occasionally the main mineral in the ground mass is chlorite instead of amphibole. Epidote in small granules is rather common in the chlorite areas. In one observation the ground mass has the appearance of whorls suggestive of an original perlitic structure. In general, the needles of amphibole follow the periphery of the feldspar phenocrysts but occasionally penetrate them producing a micropoecilitic structure. The magnetite is scattered throughout the ground mass in irregular patches and is apparently unassociated with leucoxine although rutile is a common associate. The phenocrysts of plagioclase are in general saussuritized; less commonly they are altered to biotite and muscovite. The twinning lamellae are practically destroyed but the small angle of the feldspar phenocrysts in general indicates a rather acid plagioclase, so far as we can determine, approaching oligoclase in composition. The green porphyrite appears to have been, originally, an andesite.

Ellipsoidal greenstones occur just south of the north line in section 3, T 45 N, R 41 W. The outlines of the ellipsoids are in some cases plainly discernible, but in the majority of instances they are imperfect and only faintly suggested. Some parts of the rock are made up almost entirely of the ellipsoidal forms resting in material having the same apparent composition as the ellipsoids themselves. The ellipsoids vary in size from a few inches up to four feet in major axis. The longer ones lie in the general direction of regional schistosity. The outlines of the ellipsoids are marked by the deflection of the lines of schistosity around them, the matrix between the ellipsoids being plainly more schistose than the rock within the ellipsoidal boundaries. Amygdaloids occur in outcrops close to the ellipsoidal greenstones. No minerals are recognizable with the naked eye in either the ellipsoidal or amygdaloidal greenstone. The entire series has been intensely metamorphosed with a development of schistosity striking about N 70° E and dipping south.

Closely associated with the rocks described above are *fine grained, green schists* which under the microscope appear almost identical in mineral composition with the ground mass of the greenstone porphyrite which is composed of small green hornblende needles. Accessory minerals are feldspar, quartz, epidote, carbonate and magnetite-leucoxine.

Similar fine grained hornblende schists are found in connection with the effusives southwest of Mercer, Wisconsin. These will be described in greater detail in connection with that locality.

From the vicinity of Mercer, Wisconsin, to the southeastern part of T 43 N, R 3 E, to section 9, T 42 N, R 2 E, there are many exposures of greenstone and greenschist on a series of rather pronounced ridges having a general strike parallel to the magnetic belts. For the most part the rocks are effusive lavas of agglomeratic and occasionally amygdaloidal structures and porphyritic textures. Associated with the effusives there are lesser amounts of basic intrusives, mainly diabase.

The agglomeratic structures are not abundantly developed, but in places they are a conspicuous feature of the exposures. In section 34, T 43 N, R 3 E, and in section 4, T 42 N, R 3 E, this structure is beautifully developed in many exposures. At the former locality, near the center of the section the outcrops present the appearance of typical breccia. Angular and rounded fragments of fine grained greenstone, ranging from less than an inch to a foot or more in diameter, are embedded in a dark green, schistose matrix generally of the same apparent mineral composition of the ground mass but of coarser grain. However, the composition of the matrix is somewhat variable and at one locality it appears to be mainly calcite. In section 4 many of the fragments of the breccia are amygdaloidal but an exposure in section 32, T 43 N, R 3 E, is characterized by a porphyritic texture. At the latter locality the fragments are of large size and in some cases oval or ellipsoidal in outline. Some of the ellipsoidal boulders measure two or three feet in the longer dimensions. The material which cements them together is, for the most part, coarse grained, white, vein quartz with considerable feldspar. In some respects the structure of the greenstone at this locality resembles the ellipsoidal structure described by Clements* as characteristic of the Ely greenstones of the Vermilion district of Minnesota. However, in the Vermilion district the ellipsoids are set in a matrix described as not greatly different from the greenstone itself, whereas in the present case the matrix is radically dissimilar. Porphyritic texture is a very prominent feature of most of the outcrops of greenstone. The agglomeratic structures are only occasionally seen. Closely associated with the porphyritic types are fine grained aphanitic greenstones and green schists occasionally exhibiting amygdaloidal structures. They resemble in texture the ground mass of the porphyritic varieties and in many cases are almost identical in mineral composition. In a single exposure the rock may change from porphyritic to non-porphyritic and there is no doubt that these fine grained schists and aphanitic greenstones are basic lavas differing but little in composition from the porphyritic varieties. Both types of rock exhibit in places a well developed schistosity striking about N 60° E.

The *porphyritic greenstones* are in many respects similar to those already described but are, in general, more basic in composition. They are composed mainly of phenocrysts of highly altered plagioclase embedded in a ground mass of small, pale green, weakly pleochroic needles of green hornblende. The intensity of pleochroism is apparently governed by the size of the individual crystals. The smaller crystals are very weakly pleochroic, but this phenomenon is strongly developed in the larger ones. The ground mass also contains secondary unstriated plagioclase and probably quartz, many scattered grains of epidote, and considerable magnetite with associated leucoxine. Small patches of carbonate, pyrite, and occasional crystals of rutile and brookite are present in some specimens. The phenocrysts of feldspar most commonly show alteration to a coarse grained mosaic of quartz, albite and biotite. The alteration is rarely complete; as a rule much of the original mineral remains. Saussuritization and sericitization of the feldspar is less often observed. Granulation around the edges of the crystals is a common feature. In the schistose varieties the phenocrysts exhibit only partial parallel orientation, some of them lying with their major axes at right angles to the schistosity in which position many of them are completely fractured and broken in halves cemented

*Clements, J. Morgan. Vermilion Iron Bearing District. Monograph 45, U. S. Geological Survey.

by a coarse crystallization of secondary quartz and albite. The hornblende needles of the ground mass are oriented in all directions in the massive types while in the schistose varieties they exhibit a perfect parallelism.

The plagioclase phenocrysts are too highly altered for exact determination by optical methods, but the prevailing alteration products and a rather large extinction angle shown by the remnants of the original crystals are indicative of a basic composition, which, in consideration with the basic character of the ground mass, points to an original composition near that of andesite.

The microscope readily reveals the effusive nature of the *aphanitic non-schistose greenstones,* especially of the fresher types. Traces of small lathshaped feldspars and the presence of serpentine indicates that the rock is basalt, probably olivine-bearing in phases characterized by serpentine. Even the fresher basalts are now largely composed of secondary products of which green hornblende feldspar and quartz are the most important. Magnetite, epidote, zoisite, carbonate, chlorite, apatite, rutile, pyrite and sericite are present in considerable quantity. The occurrence of the first named three is practically universal, of the others sporadic. Magnetite, as usual, is generally coated with leucoxine.

The more altered aphanitic greenstones are characterized by a large amount of amphibole and absence of all traces of original structures and textures except where they are amygdaloidal. Their general character is almost identical with the ground mass of the altered andesites. In some instances the hornblende individuals are slightly larger and more pleochroic than ordinarily in the porphyrites.

Amygdules may be observed in rocks of this type in at least two localities. The outcrops near the center of section 4, T 42 N, R 3 E, exhibits the best development of this structure. The rock here is a dark green, aphanitic greenstone showing many small white amygdules from 1-20 to 1-10 of an inch in size. In thin section the vesicular filling appears to be coarse grained interlocking crystals of zoisite, epidote and quartz. The matrix of this rock is identical with that of the rocks just described.

By parallel orientation of the hornblende the rocks pass into green schists which in mineral composition do not differ from the more altered massive variety. As a rule they are coarser grained, but ordinarily the only difference consists in the parallel orientation of the amphibole fibres. In the schistose varieties no traces of original minerals, structures or textures are left, and were these rocks found apart from the less altered phases it would be impossible to prove their origin from basic lavas.

Ellipsoidal lavas are exposed in sections 27 and 23, T 42 N, R 1 E.

The outcrops in section 23 are also characterized by the parallel alignment of the ellipsoids. However, the rock itself possesses no parallel orientation of the constituent minerals and therefore cannot be correctly termed a schist. Microscopic examination indicates that the rock is an altered andesite.

The close association of the effusive greenstones with the magnetic belt is characteristic wherever they are exposed. In many cases the greenstone forms long low ridges parallel to and lying just in the outside limits or immediately north or south of the belts of attraction. In other cases, notably from Mercer northwestward, the greenstone occupies non-magnetic territory between the areas of magnetic attraction. At the Michigan mine the greenstone occurs just south of the iron formation and a mile east. Exposures of this rock are immediately north of the belt marking the position of the iron bearing formation.

No contacts between the greenstone and the sedimentaries are known anywhere on the range but the distribution of the greenstone and its close association with the magnetic belts marking the position of the Middle Huronian (Animikie) iron formation amply justify, in the absence of definite proof to the contrary, the conclusion that the effusives are flows interbedded in the Huronian series.

CHAPTER VI.

GEOLOGY OF THE MANITOWISH RANGE.

R. C. ALLEN AND L. P. BARRETT.

The Manitowish range extends from Watersmeet, Michigan, southwest into T 41 N, R 2 E, Wisconsin, a distance of approximately 55 miles. Its position is marked by a series of weak parallel magnetic belts although locally, as in the vicinity of Watersmeet, strong magnetism is characteristic. In general the magnetic belts are narrow but in some localities they exceed a mile in width. This is true of the belt of strong magnetism near Watersmeet.

The region is heavily drift covered and aside from a number of exposures of a peculiar kyanite-mica schist in the southwest portion of T 42 N, R 4 E, Wisconsin, only three outcrops are known. Diamond drilling in a number of localities by the F. I. Carpenter syndicate shows clearly the general characteristics of the rocks in Wisconsin. In Michigan the nature of the rocks underlying the Manitowish magnetic belts may only be surmised.

Both the outcrops and drill cores exhibit coarse grained schists and gneisses and granite. At no locality is it possible to work out a succession of sedimentary formations and in fact it is extremely difficult in many cases to determine even a close approximation to the character of the original rock from which the crystalline schists were derived. It seems perfectly clear that the Manitowish rocks have been metamorphosed to a degree more extreme than that of any other known range or considerable area in the Lake Superior country. There is ample evidence that this intense metamorphism is due to the intrusion of granite on a grand scale. The facts seem to be explainable only on the theory of sub-crustal fusion, i. e. the original sediments have been completely engulfed and assimilated by the intruding magmas, the resultant schists and gneisses deriving their constituents in part from the magma and in part from the fused sediments.

Owing to their limited number the outcrops and the drill records will be discussed in detail and such conclusions drawn as seem warranted from the meager facts.

Granite is exposed at two localities, viz., in sections 34 and 35, T 43 N, R 7 E, Wisconsin. In both localities the rock is light gray biotite granite cut by many pegmatite veins, the latter showing in places well developed graphic intergrowths of quartz and feldspar. The granite is composed of orthoclase, quartz, biotite, muscovite, sericite, apatite and ferrite. These rocks differ from the granites previously described in connection with the other ranges in the absence of microcline. Under the microscope the larger minerals show characteristic granulation and the feldspar has undergone considerable alteration around the edges, although the centers of the crystals are usually very fresh. The exposures lie a little south of the magnetic belts of the Manitowish range but they are probably to be correlated with the great mass of granite intrusive into the sediments of the Manitowish range and the Vieux Desert-Conover district.

The only other exposures on the Manitowish range are *coarse grained crystalline schists and gneisses* marked by an abundant development of biotite, garnet and kyanite. In sections 28, 29, 31 and 33, T 42 N R 4 E, Wisconsin, there are a number of outcrops of these rocks. In section 13, T 42 N, R 5 E, there is a doubtful exposure of the gneiss on the narrows between Spider and Island lakes. At this locality there are groups of large angular boulders and several large blocks of gneiss that possess a common strike of schistosity of about N 70° E. The blocks may be in place. It is certain that none of the material has been transported any great distance.

The rocks in these outcrops are coarse grained and vary from light gray to grayish black; a bluish tinge is noticeable wherever kyanite is abundant. The kyanite is more resistive to weathering than the other minerals and stands out in prominent relief. Gneissose structure, marked by alternate layers of slightly different texture or mineral composition, is nearly always present. In all of the larger outcrops contortion of the gneissose bands is a conspicuous feature. The gneiss is cut by innumerable pegmatite dykes and stringers and veins of quartz.

The chief minerals of the gneiss are quartz, biotite, garnet, kyanite and plagioclase. Muscovite, magnetite, zircon, rutile, apatite, chlorite and pyrite are of subordinate importance. Quartz, biotite, garnet and kyanite are easily recognized in hand specimen, but the other minerals are usually detected only under the microscope. The coarser grained bands are composed mainly of quartz, biotite, kyanite and garnet; the finer grained layers lack the kyanite and usually show a considerable development of feldspar. The texture is very coarse and thoroughly crystalline but the only minerals which exhibit idiomorphic forms are kyanite, apatite and in some instances garnet and pyrite. Quartz is the most abundant mineral and, in larger individuals, exhibits abundant strain shadows and inclusions of liquid and gas. Biotite is the second most important mineral and is deep brown and strongly pleochroic except

where bleaching accompanied by separation of magnetite has taken place. The garnets are light brown or red in hand specimen, colorless in thin section. Good crystal development is rare and they are commonly rounded or irregular in outline. The kyanite crystals show the characteristic long development and good crystal form in the prism zone. The individuals average one half inch in length parallel to the C axis and shows no tendency to orientation in the plane of schistosity or in any other plane. Both the garnet and kyanite are filled with inclusions of quartz, biotite and magnetite; this, together with lack of orientation, is evidence that these minerals formed under conditions of static metamorphism after the crystallization of the other minerals had taken place. Plagioclase is the common feldspar and occurs in considerable abundance in the finer grained kyanite-free bands. It is in all cases very fresh, showing only slight alteration. In composition it appears to be oligoclase and albite-oligoclase.

The main clue to the origin of the biotitic, garnetiferous, kyanitic gneiss lies in its mineral composition. The universal presence of the aluminum silicate, kyanite, is the most suggestive feature. In discussing the occurrence of the aluminum silicate group Van Hise* says: "The special homes of the aluminum-silicate minerals are the metamorphosed argillaceous sedimentary rocks. As is well known, kaolin is one of the chief constituents of such rocks, and doubtless it is from this mineral, in larger part under deep seated conditions, that the aluminum silicates are formed." The same author in discussing the criteria to be used in discriminating between the metamorphic igneous and sedimentary rocks, says,† "Staurolite and andalusite, sillimanite and cyanite are very characteristic minerals. Therefore, where certain single minerals are dominant in the schists and gneisses it seems to be a fairly safe conclusion that the rocks are sedimentary in origin." The mineral kyanite, because it has the highest specific gravity of the aluminum silicate group, is significant also of the most profound anamorphism and the universal presence of this mineral coupled with the entire absence of andalusite or sillimanite is a measure of the intensity and character of the metamorphism prevalent on the Manitowish range. The regional schistosity and contortion of the gneissose bands together with the occurrence of numerous pegmatitic dikes cutting the gneiss is proof that the original sediments have been metamorphosed not only by folding, but by igneous intrusion as well. The thoroughly recrystalline character of the gneiss furnishes the final proof of the intensity of the metamorphic changes to which these rocks have been subjected.

*Van Hise, C. R. A Treatise on Metamorphism, Mono. 47, U. S. G. S. p. 317.
†Van Hise (citd) p. 916.

RESULTS OF DIAMOND DRILLING.

Hole 16 is on the northeast extremity of the maximum magnetic line of the narrow magnetic belt which extends from section 14, T 41 N, R 2 E, to section 24, T 42 N, R 3 E. The rock was tested for a depth of 40 feet. The upper 25 feet of rock in this hole differs so remarkably from that of the lower 15 feet and the rock in both zones is so unique that separate detailed descriptions are demanded.

The rock in the upper 25 feet of the hole is of reddish color, contains abundant dark colored crystals of garnet, is cut by many bands of quartz and is finely banded. The main mass of the rock is composed of dark colored irregular shaped crystals of garnet which are imbedded in a crystalline ground mass of quartz, carbonate, limonite and magnetite. Layers of nearly pure white quartz and of red and white banded chert alternate with the garnet bearing zones. In thin section the rock is observed to be composed of the minerals garnet, quartz, carbonate, limonite and magnetite with a mall amount of biotite and chlorite. The garnets are colorless, irregular in outline, and full of inclusions of other minerals. The carbonate is closely associated with hematite and is probably siderite. This rock is probably an intensely metamorphosed iron formation. This conclusion is warranted from a consideration of its iron content, the occurrence of thin seams or bands of ferruginous chert and its relation to the maximum magnetic line of a linear magnetic belt which has been traced continuously for a distance of 8 miles. Garnetized iron formations are elsewhere found near contacts with intrusive igneous rocks.

The lower 15 feet of core is a feldspathic biotite schist microscopically somewhat similar to that of the upper 25 feet. It differs mainly in the absence of siderite, iron oxide, and the presence of feldspar. It contains abundant small red garnets imbedded in a finely grained, dark, massive ground mass. In thin section the garnets exhibit irregular outlines and lie in an interlocking crystalline mosaic of quartz, biotite and feldspar. The biotite shows a slight tendency toward parallel alignment. With the exception of an incipient sericitic alteration of the feldspar the minerals in the rock show no alteration. The rock is completely recrystalline and no trace of original texture remains. This rock could be derived from a sediment of graywacke type but its essential similarity to the rock in the upper part of this hole, which seems to be without a doubt a metamorphic iron formation, suggests a similar derivation through extreme metamorphism by granitic intrusion, the feldspathic material being a direct contribution from the granite magma. This conclusion is further supported by evidence, in other parts of this range, of the assimilation by granite of the sedimentary rocks, the original positions of which are now occupied by schist and gneisses and are preserved only by linear faint magnetic belts which have been traced continuously in some cases for as much as 20 miles.

Beginning in section 10, T 41 N, R 3 E, a continuous belt of magnetic attraction has been traced in a northeasterly direction a distance of 20 miles to an apparent connection with a magnetic belt of the Turtle range in sections 14 and 15, T 43 N, R 6 E. Three drill holes were put down at widely separated localities on this belt.

Hole 22 was located in section 26, T 42 N, R 4 E, a short distance north of Powell on the C. & N. W. R. R. This hole was sunk on the line of maximum magnetic attraction and, after passing through 122 feet of drift, drilling was continued for a depth of 12 feet in a coarse grained garnetiferous mica schist showing injected veins of granitic material. The rock is composed of quartz, biotite and garnet with considerable chlorite and pyrite, small scattered grains of magnetite, a few needles of rutile and fine flakes of carbonaceous (?) material. This rock is very similar in mineral composition to the kyanite free bands in the kyanitic garnetiferous biotite gneiss that outcrops just north of the magnetic belt two miles west of section 26. It is thoroughly crystalline schist and the only clue to its origin is its present mineral composition. The predominant minerals are biotite and quartz while garnet is occasionally found in considerable abundance. Schists which are composed mainly of quartz and mica are regarded by Van Hise* as probably metamorphic sediments. The general resemblance of this rock to certain layers in the associated kyanite-bearing gneisses is strong presumptive evidence of a sedimentary origin. The intimate injection of granitic material is one, if not the most important, cause of the extreme metamorphism of this rock.

Hole No. 35 in section 2, T 42 N, R 5 E, about 7 miles northeast of hole 22 along the strike of the magnetic belt was put down on the south edge of the magnetic field. The core exhibits dark gray to black, coarsely grained rock heavily impregnated with pyrite and carrying an abundance of small light reddish garnets, for the most part about 1-16 of an inch in diameter. Near the top of the hole are many grains of quartz and pyrite. In thin section the rock is almost identical in texture and composition with the core in the bottom of Hole 33, of the Winegar section of the Turtle range, which is of particular interest in view of the fact that there is an apparent connection between the Turtle and Manitowish ranges along the line of this magnetic belt. The rock is composed of colorless garnets rich in inclusions of fine black particles of carbonaceous material imbedded in a groundmass of interlocking quartz and biotite. Pyrite and small patches of minute

*Van Hise, C. R. Treatise on Metamorphism, Mono. 47, U. S. G. S. p. 916.

green fibres similar to those in the core from hole 33 are also present. There can be little doubt of the sedimentary origin of this rock, the best proof of which is the abundant carbonaceous material.

In section 28, T 43 N, R 6 E, about four miles northeast of hole 35, the underlying rocks were tested again by drill hole No. 41. The overburden at this locality extends to a depth of 129 feet and drilling was continued in the ledge for 19 feet. The rock is coarsely grained, garnetiferous biotite-quartz-schist similar to that found in hole 22.

The magnetic belt lying south of the one tested by holes 22, 35 and 41 was tested by three holes. In the vicinity of Powell this belt exhibits two lines of maximum attraction, the southernmost of which is separated from the main belt in section 36, T 42 N, R 4 E, by a short interval of normal territory. Hole 20 (section 26) was sunk on the north line of maximum magnetic variation; hole 24 (section 36, T 42 N, R 4 E) is a short distance north of the maximum line but within the limits of the magnetic field. Seven miles northeast along the strike of the magnetic belt a third drill hole (No. 38) was put down just south of the maximum magnetic variation in section 7, T 42 N, R 6 E.

The rock in hole 20 is coarse grained biotite-muscovite-quartz schist thoroughly impregnated with granitic material. The granite cuts the schist in a series of veins of pegmatite and aplite. In general, the schist is composed of quartz and biotite, with considerable feldspar, pyrite and magnetite. Near the pegmatite veins muscovite is abundantly developed.

Hole 24 penetrated 15 feet of fine grained feldspathic biotite schist cut by veins of pegmatite. The bottom three feet is coarsely grained massive white biotite muscovite granite.

Hole 38 is in feldspathic biotitic quartzose gneiss. A definite banding is produced by alteration of zones of the same apparent mineral composition but of slightly different texture. Occasional narrow pegmatite veins running parallel to the schistosity are to be seen. Like all the other rocks found on this range the gneiss is thoroughly recrystalline and in its present condition contains no direct evidence of its original character.

In the south part of T 42 N, R 5 E, and the north portion of T 41 N, R 5 E, there are four small disconnected areas of magnetic attraction. The two easterly belts have a strike almost at right angles to the strike of the Manitowish ranges.

Hole 32 was put down at the north end of the most easterly belt, which trends a little west of north through section 35, T 42 N, R 5 E. It is just a mile in length and a little less than one-half mile wide. The hole is in the projection of this belt about 300 paces from its northeastern extremity and penetrates coarse grained white muscovite-biotite granite.

GENERAL SUMMARY.

We can briefly sum up the known facts regarding the Manitowish range in three statements, i. e. (1) its position is marked by a series of parallel narrow linear magnetic belts broken here and there by gaps of normal territory; (2) the underlying associated rocks are mainly crystalline schists and gneisses; (3) the schists and gneisses are almost universally associated with large amounts of injected granitic material and pegmatite dikes.

The narrow and linear characters of the magnetic belts admit of but two inferences in regard to the original character of the underlying rocks, viz., they were (1) either folded sedimentaries or (2) basic lavas. At the present time the rocks underlying the magnetic belts are thoroughly crystalline acid schists and gneisses, which fact effectually eliminates the second inference. It is not easy to grasp the significance of such profound metamorphism on such a grand scale. This extreme metamorphism is not confined to the Manitowish range but also occurs throughout the Vieux Desert area, on the western extremity of the Conover slate belt, and doubtless over a large unexplored territory the limits of which can only be conjectured. The original sediments seem to have been permeated, injected, and probably over large territories, absorbed by the intruding granite magma. The rocks now occupying the space originally filled by sediments are crystalline schists which have derived their constituents from both the sediments and the granitic magmas.

CHAPTER VII.

GEOLOGY OF THE VIEUX DESERT DISTRICT.

R. C. ALLEN AND L. P. BARRETT.

The Vieux Desert district includes a belt of country about four to five miles wide and about twenty miles long extending E-W through Lake Vieux Desert across the boundary between Michigan and Wisconsin. (See *Fig. 1*). West of the lake there are two parallel faint magnetic double belts trending E-W across flat sand plains. In Michigan there is a single magnetic belt traversing wooded hilly country from the lake to the middle of T 47 N, R 37 W.

The rocks in the Vieux Desert district in Wisconsin are buried beneath 125 to 200 feet of glacial drift. The thickness of the drift in Michigan is unknown but, as in Wisconsin, there are no rock exposures. Eleven diamond drill holes were sunk in 1912 by the F. I. Carpenter syndicate in the magnetic territory in the vicinity of Lake Vieux Desert and westward. These holes are so located as to give a general idea of the geology of the Vieux Desert district which is essentially similar to that of the Manitowish range. The rocks are mainly coarse grained schists and gneisses, granite and highly metamorphic but recognizable slate and graywacke. A description of the drill cores from each of the eleven holes follows:

Hole 1 is on the north line of maximum magnetic attraction of the northern double belt in the SW$\frac{1}{4}$ SW$\frac{1}{4}$ section 35, T 43 N, R 10 E. The drill penetrated four feet of pink biotite granite.

Hole 2 (SW$\frac{1}{4}$ SW$\frac{1}{4}$ of section 35, T 43 N, R 10 E, Wisconsin) is a short distance north of No. 1. It cut 50 feet of granite and, below it, about 50 feet of dark gray schist cut in many places by pegmatite and granite dikes. The granite is gray and pink, medium grained, and is composed of orthoclase, quartz, microcline, plagioclase, chlorite, biotite, ferrite, muscovite, zircon, apatite, and a few little grains of magnetite-leucoxine. In thin section only a slight tendency toward granulation and the development of mortar structure is to be noted. The orthoclase is full of inclusions of hematite and exhibits considerable alteration to rather large flakes of muscovite. The microcline is fresh and does not appear to be an alteration product of the orthoclase as in the granites of the Wolf Lake area. Plagioclase feldspar is very subordinate and like the microcline is fresh. Biotite is badly altered to chlorite, in many cases the alteration is practically complete. This feature is especially noticeable in the upper 15 feet of core.

The schist from the lower 50 feet of core is fine, even grained and made up principally of quartz, biotite, feldspar, pyrite, graphite and magnetite with occasional grains of epidote and small crystals of apatite. In thin section the feldspar is limpid, unstriated and probably near albite in composition. The content of graphite is a marked feature and gives the rock its dull gray color. Pyrite is very abundant in seams and streaks running parallel to the schistosity. The abundant graphite and pyrite in this rock is strong evidence of its sedimentary origin.

Hole 3 (NW$\frac{1}{4}$ NW$\frac{1}{4}$, section 2, T 42 N, R 10 E, Wisconsin) is about 300 paces north of hole No. 1. The drill penetrated 34 feet of biotitic garnetiferous kyanitic gneiss similar to that on the Manitowish range.

Hole 6 (NE$\frac{1}{4}$ NE$\frac{1}{4}$, section 2, T 42 N, R 10 E, Wisconsin) is about three fourths of a mile east of hole No. 1 and on the same maximum line of magnetic attraction. It is bottomed in light gray banded gneiss composed of quartz, feldspar, pyrite muscovite, biotite and graphite. The banded structure is produced by alternating layers of coarser and finer texture. The coarser and finer textured bands are apparently identical in mineral composition with the exception that the coarser layers are lacking in graphite.

Hole 4 (SW$\frac{1}{4}$ NW$\frac{1}{4}$ section 2, T 42 N, R 10 E, Wisconsin) is a short distance south of the south maximum line of the north belt. It was bottomed at a depth of 206 feet in granite and dark gray, rather fine grained rock made up principally of quartz, garnet and biotite. The granite is coarse grained and pink and appears, in hand specimen, to be composed almost entirely of quartz and feldspar. The gray rock is exceedingly hard and has a well defined schistose structure although in thin section the biotite exhibits a rough parallel alignment. In addition to the minerals mentioned, microscopic examination reveals considerable pyrite and magnetite and a small amount of chlorite, sericite and apatite. The quartz, garnet and biotite are arranged in an allotriomorphic crystalline aggregate. The garnet is filled with inclusions of quartz, pyrite and innumerable particles of magnetite and graphite (?). Some small flakes of sericite are developed along the fractures in the garnet. The larger magnetite crystals are coated with leucoxine. Both pyrite and magnetite are in close association with biotite and as said above are also included in garnet.

Hole 9 (NE$\frac{1}{4}$ NE$\frac{1}{4}$, section 3, T 42 N, R 9 E, Wisconsin) is at the extreme west limit of the north magnetic belt. It is bottomed in granite.

The south magnetic belt was tested by four holes, numbers 5, 7, 10 and 12. These holes were put down at widely spaced localities. In each hole the rock is crystalline coarse grained micaceous schist and gneiss cut by dikes of pegmatite and granite. For the most part the schists are composed of quartz, biotite and muscovite. Garnet and feldspar are locally important. The core from hole 5 is characterized by abundant greenish white talc. Pyrite, magnetite, chlorite, rutile, zircon, and apatite are everywhere present in small quantities.

CONCLUSION.

The rocks of the Vieux Desert district are granite, gneiss, and schist, the gneiss and schist predominating. The gneiss and schist are characterized by the minerals *graphite, kyanite, garnet, magnetite,* and pyrite, and are related to parallel linear symmetrical magnetic belts. It is believed that the schist and gneiss have formed through injection and assimilation of sedimentary rocks by granite magma. The metamorphic effect of granitic intrusion in the Vieux Desert district is apparently similar to that prevalent on the Manitowish range.

CHAPTER VIII.

GEOLOGY OF THE CONOVER DISTRICT.

R. C. ALLEN AND L. P. BARRETT.

The boundaries of the Conover district are ill defined. A series of magnetic belts with a general east-west trend extend through T 41 N, R's 9, 10, 11 and 12 E, Wisconsin, almost exactly parallel to similar magnetic belts in the Vieux Desert district about eight miles north. The geology of the Conover district is known only from exploration by diamond drilling made by the F. I. Carpenter syndicate in 1913. Fifteen holes were drilled with particular reference to the magnetic belts. As a general statement it may be said that the magnetic belts mark the position of a slate series covered by from 150 to 200 feet of glacial drift striking east-west parallel to the magnetic lines. The bedding in the slates is everywhere steeply inclined. As in the Vieux Desert district these slates are intruded by granite by which they are apparently entirely replaced west of the center of T 41 N, R 9 E. From thispoint eastward granite was not encountered under or near the maxmum magnetic lines and the slate shows little or no effect of metamorphism by igneous intrusion. Granite occurs to the south in section 33 and vicinity, T 41 N, R 10 E. A drill hole near the north $\frac{1}{4}$ corner of section 8 of the same township penetrated slate. This slate is much harder and more highly recrystalline than that which underlies the magnetic belt of the Conover district and probably indicates approach to a contact with the intrusive granite which is known to occur throughout the Vieux Desert district and very probably occupies the greater part of the intervening area.

It is very probable that the slate series of the Conover district is continuous eastward with the slate-iron formation series of the Iron River district. This connection is indicated by the general structural features of the two districts, the similarity of the slates, and the penetration of slate in numerous drill holes in section 4, T 42 N, R 36 W, Michigan, and in a single drill hole in section 9, T 41 N, R 13 E, Wisconsin, thus practically bridging the interval between the eastern extremity of the magnetic belts of the Conover district and slate exposures in the Iron River district. About one and one-quarter miles southwest of the latter locality in the NE$\frac{1}{4}$ of section 17 of the same township another drill hole is in granite.

From the meager information available the Conover slates may be considered as a tongue of the slate-iron formation series of the Iron River district projected westward into the area which has been invaded by the great granite batholith and its outliers of Northern Wisconsin. This granite, as we have seen, terminates the Conover slate belt near the center of T 41 N, R 9 E, Wisconsin, but the main magnetic belt which is underlain by slate throughout the Conover district continues on without break into the granite area for several miles where it is proved by drilling to mark the position of quartz-mica schist and gneiss cut by dykes and stringers of white biotite granite exactly similar to the rocks which underlie the magnetic belt of the Vieux Desert district. There can be no question that this mica schist and gneiss is a metamorphic equivalent of the comparatively unaltered slate underlying the same magnetic belt east of that locality. This relationship is a further evidence of the origin of the mica schists and gneisses of the Vieux Desert district wherein the relationship to the original unaltered sediments is less clear.

The rocks underlying the eastern three-fourths of the Conover district are soft, red, gray, and black slates containing seams of ferruginous chert and carrying abundant iron carbonate. Oxidation has extended to varying depths up to 75 feet and in a couple of drill holes material running as high as 40% metallic iron was encountered on and extending a few feet below the rock surface. It is entirely possible that the Conover slate is associated with productive iron formation which has, however, not been penetrated in drilling.

The Conover slates are exactly similar to those associated with the Vulcan iron formation in the Crystal Falls and Iron River districts.

PETROGRAPHIC DESCRIPTION OF THE CONOVER SLATES.

For the sake of convenience the petrographic description of the rocks penetrated by the various drill holes in the Conover district will be referred to the different magnetic belts wherein these holes are located (see *Fig. 1*).

The most easterly magnetic belt is short, narrow and ill defined. It extends through sections 13, 14 and 15, T 41 N, R 12 E. The rocks underlying this belt have not been explored by drilling.

Belt A extends from section 9, T 41 N, R 12 E, westward three miles into sections 11 and 14, T 41 N, R 11 E. This belt was tested near the south border by hole 48 located near the west ¼ post of section 13, T 41 N, R 11 E. Rock was encountered at 168 feet and drilling was continued to a depth of 65 feet in soft banded ferruginous slate, for the most part red, or grayish red in color but with some gray and greenish gray phases. Banding and cleavage are parallel and steeply inclined to the vertical. No other holes were put down on this belt.

Belt B extends from section 24, T 41 N, R 11 E, 18 miles westward into section 7, T 41 N, R 9 E. It has an average width of about three-quarters of a mile and with the exception of the westernmost five or six miles is characterized by a single continuous maximum magnetic line.

Belt B was tested at several different localities. In the central and eastern part the underlying rock is slate. On the west end where the magnetic field is variable and uneven the slates have suffered extreme metamorphism by the intrusion of granite and are now represented by mica schist. A description of the holes put down on this belt follows:

At the eastern extremity, hole 46, NE¼ of the NE¼, section 23, T 41 N, R 11 E, penetrated ferruginous slate, grading downward into unoxidized greenish gray carbonate slates.

Hole 27, NE¼ of NW¼ section 22, T 41 N, R 10 E, near the south border of the belt, penetrated gray slate. The rock has a good cleavage and a well defined banding. Both structures are parallel and indicate a nearly vertical dip.

In the eastern part of sections 17 and 20, T 41 N, R 10 E, Belt B has two lines of maximum attraction and is also characterized by strong disturbance of the needle. The belt was cross-sectioned at this locality by three drill holes. Hole 8, NE¼ of NE¼, section 20, is located on the south line of maximum magnetic attraction. The rock in this hole, which was tested for a depth of 25 feet, is not duplicated elsewhere in the Conover area and presents some features of exceptional petrographic interest.

The lower ten feet is a soft light grayish green rock composed essentially of carbonate, talc and magnetite. Carbonate forms the body of the rock. Magnetite occurs in disseminated grains although there is a tendency for this mineral to be concentrated in irregular and also roughly rectangular areas. Talc occurs abundantly in irregular masses, thin veins and scattered flakes. This rock has probably resulted from the metamorphism of a dolomite containing a large amount of iron carbonate. Heat and pressure has converted the iron carbonate to magnetite and the dolomite to talc. It is probable that the metamorphism is due to igneous intrusion rather than to deep burial because the rock is not schistose. The igneous intrusives furnished the silica necessary for the formation of talc.

The core from the upper part of the hole exhibits a massive grayish green rock very similar microscopically to that in the lower ten feet. It differs mineralogically in being composed mainly of serpentine with subordinate magnetite and carbonate. The appearance of this rock under the microscope is illustrated in Plate XII. In ordinary light a well defined granular texture is apparent in the arrangement of the magnetite and carbonate but under crossed nicols this texture is obscured by the doubly refracting lattice work of interlocking fibres of serpentine. The serpentine is colorless and has a low birefringence and index of refraction. It is probably the variety antigorite. The carbonate and magnetite are closely associated and their peculiar distribution is their chief feature of interest. The serpentine fibres are arranged without regard to the granular texture outlined by the magnetite and carbonate areas.

The origin of the serpentine rock is not entirely clear. Three possibilities are suggested. (1) It may be an altered olivine rock or dunite in the form of a dike cutting the ferruginous dolomite. (2) It may be derived through serpentinization of forsterite developed in the ferruginous dolomite by contact metamorphic action. (3) The serpentine may have been derived directly from the dolomite through the agency of hot solutions coming from adjacent intrusives without the previous formation of olivine minerals.

If the rock was once a dunite no trace of olivine now remains although the arrangement of the magnetite and carbonate is suggestive that they outline the position of original olivine grains. Objections to this theory are the entire absence of minerals or alteration products of minerals common in olivine rocks such as pyroxine, chromite, plagioclase and spinel and the absence of a sharp boundary between the serpentine rock and the altered ferruginous dolomite.

The metamorphism of dolomite accompanied by the formation of the variety of olivine known as forsterite and the subsequent alteration of the forsterite to serpentine is always brought about by igneous intrusion. The changes that take place involve the reduction of dolomite to calcite, the magnesia combining with silica to form forsterite. The silica is doubtless derived from hot solutions emanating from the igneous intrusives. It is possible that the rock was formed in this way. No igneous rocks were encountered in hole 8, but this fact is of little importance in view of the general evidence of igneous intrusives in the vicinity. If forsterite was once present, subsequent alteration to serpentine has been complete and no trace of the mineral now remains.

The third possibility, viz., the direct production of serpentine from the magnesian carbonate without the previous formation of an olivine mineral is, so far as known to the authors, a type of alteration not previously described. On the basis of the limited data obtainable from

one drill hole this type of metamorphism can only be suggested as an interesting possibility. The magnesia could be derived from the dolomite and the silica from outside hot solutions coming from igneous sources. The entire absence of any trace of olivine and the lattice work arrangement of the fibres of serpentine rather than their occurrence in a mesh or sieve structure typical of olivine alteration makes this theory worthy of consideration.

Hole 18, SE¼ of SE¼, section 17, is about a quarter of a mile north of No. 8 and a short distance north of the north maximum line of attraction. This hole was inclined 60° to the south and the underlying rock was tested for a depth of 188 feet. The rock is a banded ferruginous slate containing thin seams of chert and lean iron formation, cut in one place by a narrow dike of greenstone. The dominant phase consists of alternate narrow layers of greenish gray and red slate, although in places the rock is entirely red, in others light gray or green, the red bands being absent. A thin section cut from one of the grayish green phases shows carbonate, quartz, green hornblende, and magnetite with subordinate sericite, chlorite, and epidote. The rock is very fine grained and decidedly schistose. Its clastic origin is plainly apparent from the rounded outlines of the larger quartz grains.

Hole 21, NE¼ of SE¼, section 17, is located about 300 paces north of No. 18 and penetrates banded ferruginous slates essentially similar to the rock found in hole 18.

Hole 23, center of section 17, T 41 N, R 10 E, is outside of the magnetic belt and about one-half mile west and 350 paces north of No. 21. Drilling was continued for 100 feet in red and gray banded ferruginous slate interbedded with a black pyritic phase toward the bottom of the hole.

Three quarters of a mile west of the cross section just described the magnetic belt was tested again by two holes, in the NW¼ of NW¼, section 20, T 41 N, R 10 E. No. 15 is on the point of maximum magnetic attraction, while No. 11 is located 175 paces farther south. The rock from *hole 15* is rich ferruginous slate with some ferruginous chert in the upper 47 feet and gray talcose slate in the lower 60 feet. Analysis of the ferruginous slate near the top of the ledge gives Fe.=32% and P.=.028%. *Hole 11* is in gray banded carbonate slate with occasional red or green layers. This slate is very similar to that found in Nos. 18 and 21.

The rocks underlying the belt were again tested in the NW¼ of SE¼, section 24, T 41 N, R 9 E, by *hole 37*, about 100 paces south of the maximum line of magnetic attraction. The slate at this locality is gray with purple bands and mottling near the surface. Small magnetite octahedra and occasional minute garnets are disseminated throughout the core. In the lower part of the hole there is a slight coarsening of the grain coupled with considerable contortion in the bedding planes. While this rock is still slate, it seems, however, to be considerably metamorphosed. It is probably a gradation phase between the unaltered slate to the east and the highly metamorphic crystalline schist west of this locality.

Hole 43, SW$\frac{1}{4}$ of NW$\frac{1}{4}$, section 17, T 41 N, R 9 E, four miles west of No. 37, penetrated mica schist cut by dikes of white biotite granite. This rock is similar to that found on the Manitowish range and in the Vieux Desert area and is undoubtedly the metamorphic equivalent of the slates found in this same magnetic belt a short distance east, the alteration being caused by granitic intrusion. This belt is continuous, but at its western end where the underlying slates have been metamorphosed by the intrusion of granite the magnetic attractions are variable and no single maximum line can be traced.

Hole 40, NW$\frac{1}{4}$ of SW$\frac{1}{4}$, section 9, T 41 N, R 9 E, was put down in non-magnetic territory about one-half mile north of belt B. The test shows biotite schist and granite similar to that found in hole 37.

Belt C extends from section 7, T 41 N, R 11 E, westward five miles through section 9, T 41 N, R 10 E. It is characterized by two and in places three maximum magnetic lines. This belt was tested by hole 34, SW$\frac{1}{4}$ of SE$\frac{1}{4}$, section 11, T 41 N, R 10 E, just south of the maximum line of variation. The drill core is quartzose slate in the upper 15 feet followed by 10 feet of soft green chlorite schist. The chlorite schist contains seams and layers of hematite in the upper portion. In thin section this rock is found to be composed of a schistose aggregate of chlorite and green hornblende, with many clusters of titanium minerals, considerable sericite or talc, a few scattered flakes of hematite, and an occasional grain of epidote and magnetite. It is not possible to determine the exact relationship of the schist to the quartz slate owing to the broken character of the core near the contact. In some ways this contact is suggestive of a fault breccia cemented by iron oxide, but no positive statement is justified.

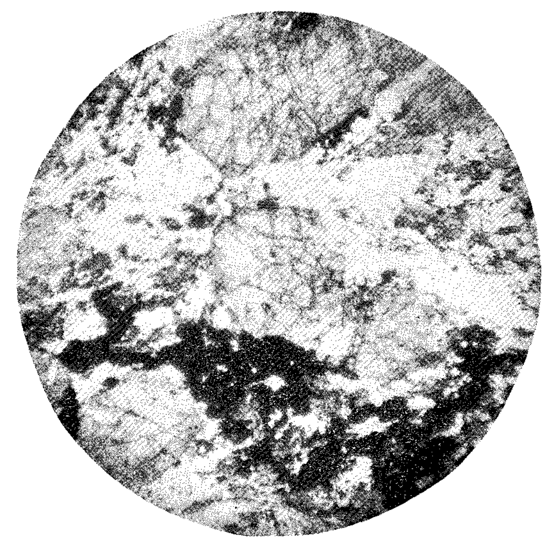
Hole 36, SW$\frac{1}{4}$ of NE$\frac{1}{4}$, section 8, T 41 N, R 10 E, is west of the limits of belt C, and a short distance north of the projected strike. The rock is medium grained garnetiferous biotite schist with stringers and veins of granitic material.

Three holes were put down at other localities in the Conover area not directly connected with belts A, B or C. Hole 31, NE$\frac{1}{4}$ of NE$\frac{1}{4}$, section 33, T 41 N, R 10 E, just north of a small oval shaped magnetic area in the south part of T 41 N, R 10 E, encountered granite. Holes

(A). (Without analizer, X 16). Kyanitic-garnetiferous-gneiss from section 30, T. 42 N., R. 4 E., Wisconsin. This plate is introduced to show the coarse granitoid texture of the kyanite bearing gneiss of the Manitowish range. Kyanite, garnet, quartz, biotite and magnetite are easily recognized.

(B). (Without analizer, X 16). Garnetiferous-pyritic-graphitic rock from drill hole 5 near southeast corner of section 2, T. 42 N., R. 5 E., Wisconsin. This rock is identical with that found in hole 33 of the Winegar section on the Turtle range and is introduced here to show the appearance in thin section of these peculiar garnet rocks which are believed to be altered sediments. The mineral with the high index of refraction is garnet, the large black mass, pyrite, the small black specks, graphite, the light gray flaky mineral, biotite. The white areas are occupied by a coarsely crystalline mosaic of quartz. The garnets are filled with minute black dust not apparent in the reproduction.

(A)

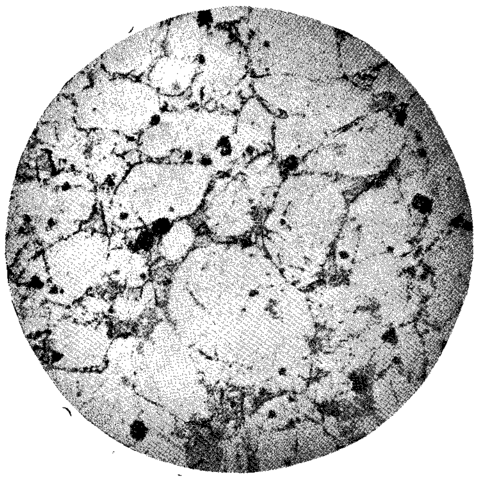


(B)

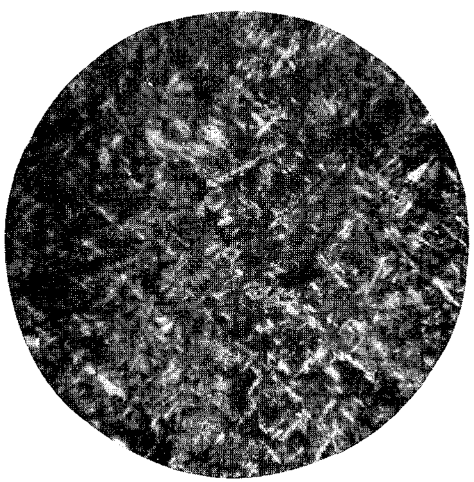
Plate XII.

(A). (Without analizer, X 16). Serpentine-magnetite-carbonate rock from hole 8, NE¼ of NE¼ of section 20, T. 41 N., R. 10 E. The granular texture of the rock as outlined by the arrangement of magnetite and carbonate is well shown. The black areas are magnetite, the gray areas are carbonate, the light areas are colorless serpentine.

(B). (With analizer, X 16). Same as (A) showing obliteration of the granular structure under crossed nicols by the doubly refracting lattice work of serpentine.



(A)



(B)

Nos. 47 and 44, were put down in T 41 N, R 13 E, in non-magnetic territory east of the Conover belts, but in line with their projected trend. Hole 47, SE$\frac{1}{4}$ of NE$\frac{1}{4}$, section 17, is in granite, while hole 44, SW$\frac{1}{4}$ of NW$\frac{1}{4}$, section 9, penetrates about 50 feet of ferruginous slate with occasional chert bands developed toward the botton of the hole. When the hole was abandoned about 2 feet of black slate had been entered.

CHAPTER IX.

THE PAINT SLATE AND THE WOLF LAKE GRANITE, GNEISS AND SCHIST.

R. C. ALLEN AND L. P. BARRETT.

The Paint slate and the Wolf Lake granite are described together in order to bring out more clearly the evidence pointing to a correlation of the mica schist series of the Turtle range with the great Paint slate formation of the Animikie of the Crystal Falls-Iron River district. The Wolf Lake granite and associated mica schist occupies the territory of about 75 square miles which is enclosed on the north, west, and south sides by the Turtle range and the Watersmeet branch of the Manitowish range. This area opens out eastward into the territory occupied by the Paint slate. There is clear evidence that the Wolf Lake granite is intrusive in the Paint slate. This relation will be discussed following a description of these formations.

THE PAINT SLATE FORMATION.

The Paint slate formation comprises an unknown but undoubtedly great thickness of graywacke, graywacke-slate and gray slate associated with basic intrusive and extrusive igneous rocks occupying a large but ill defined area north and west of the Iron River and Crystal Falls districts, and south of the west end of the Marquette iron range. It constitutes a large part of what has been described as the Michigamme slate series.

The Paint formation is mainly graywacke and graywacke slate and contrasts strongly with the black and gray slate which are associated with the iron formation of the Iron River and Crystal Falls districts and consequently was described by Allen in 1909* under a distinct formation name. Since 1909 these rocks have been further studied by Allen and assistants in T's 44 and 45 N, R's 34, 35, 36 and 37 W, Michigan. In this area exposures are plentiful only in the vicinity of Paint River and its tributaries. A general scarcity of exposures, renders impossible the identification of horizons over any considerable area and makes structural mapping, which is difficult in formations of this type under the most favorable conditions, also impossible. In the

*Publication 3, Michigan Geol. & Biol. Survey.

eastern part of the area of the Paint slate the rocks are, comparatively speaking, not highly metamorphosed, and are on the whole coarser grained. In many of the exposures bedding structure is preserved but westward and southwestward the rocks become progressively more highly metamorphic until, through recrystallization and the development of schistosity, the bedding structure is wholly obliterated.

The composition of the Paint slate is almost uniform although there are variations ranging from typical graywacke to what may be termed feldspathic quartzite and here and there fine conglomerate. The rocks are everywhere composed dominantly of quartz, orthoclase and plagioclase, evidently derived from older terranes which have broken down by mechanical disintegration. Most of the exposures exhibit a secondary schistose structure which is in some places parallel to the bedding but in most localities intersects the bedding planes at low angles.

Perhaps the most striking characteristic of the series as a whole is the uniform gray or grayish green color of the weathered exposures. The exposures in any one locality are almost exactly similar to those in nearly all other localities with allowance for difference in degree of metamorphism. Another interesting feature is the occurrence of ellipsoidal cavities on the surface of many of the exposures. These cavities are ordinarily 5 or 6 inches long, one or two inches wide and an inch or more deep. The long dimension invariably concides with the strike of the secondary structure. Similar cavities occur in the upper slate formation of the Marenisco range. Another peculiar feature of weathering, particularly well developed in the exposures near the center of the NW¼ of section 15, T 45 N, R 36 W, is the occurrence of small mamillary protuberances from one-half to one inch in diameter projecting a half inch or more above the general surface of the rock. Nearly all of these protuberances have a small hole in the center about a half inch deep. The appearance of the rock reminds one of the surface of boiling mush. The cause of this extraordinary phenomenon is obscure. The rock is typical graywacke. Thin sections cut from the mamillary protuberances exhibit under the microscope no dissimilarity in composition or texture when compared with those cut indiscriminately from the body of the rock.

PETROGRAPHIC DESCRIPTION OF PAINT SLATE.

Microscopic study of the Paint slate affords a basis for division of the series into three main types of rock, viz., (1) graywacke and graywacke schist, (2) fine grained gray slate and (3) mica schist and mica-hornblende schist, the metamorphic equivalents of (1) and (2). Arkose, quartzite and graywacke conglomerate occur here and there but are unimportant in comparison with the enormous mass of the graywacke types.

Graywacke and graywacke schist. The important minerals in these rocks are quartz, orthoclase, plagioclase, chlorite, and sericite. In some specimens biotite and carbonate are abundant. Pyrite, epidote, zoisite, zircon, apatite, tourmaline and magnetite-leucoxine and rarely augite are the accessory minerals.

In general the texture is medium to fine grained and clearly of clastic origin which is manifest in the rounded outlines of the larger grains of quartz and feldspar, while many of the quartz individuals exhibit secondary enlargement. In the schistose graywackes the flakes of chlorite and sericite are in parallel alignment but the grains of quartz and feldspar are not commonly affected by this structure although in some specimens they exhibit a tendency toward orientation of their longer axes in the plane of schistosity. With decrease in the content of feldspar the graywackes grade into arkose and quartzite, and with increase in size of the detrital fragments into conglomerate.

Although quartz is the most abundant mineral, plagioclase, orthoclase, chlorite and sericite are almost equally important. In exceptional cases biotite takes the place of chlorite. The larger grains of plagioclase are fresh and exhibit the characteristic twinning lamellae. The orthoclase commonly shows cloudy alteration and inclusions of hematite particles. The presence of tourmaline in small crystals showing good development in the prism zone but without terminations is practically universal. In some instances the grains are rounded and waterworn and it is probable that the tourmaline is all of detrital origin although this question cannot be determined with certainty. This mineral is never abundant but from one to a half dozen minute crystals are present in every thin section examined. Tourmaline was not reported by Allen in 1909 but a re-examination of the thin sections of the Paint slate described by him resulted in the identification of this mineral in minute quantity. In some of the slides calcite occurs in isolated areas and less often in irregular individuals arranged in lines parallel to the schistosity. Pyrite and epidote occur in considerable abundance in some of the specimens.

Slate. The slates are gray, grayish green and black. They are essentially similar in mineral composition to the graywackes. The important minerals are quartz, feldspar, chlorite, sericite, biotite and in some instances, carbonaceous material. The minor minerals are pyrite, carbonate, magnetite (usually coated with leucoxine), rutile, apatite, epidote, zircon, and tourmaline. The first two are frequently of considerable importance. The rock is so fine grained and schistose that the mineral composition is only observable under high powers although most of the slides exhibit scattered rounded grains of quartz and feldspar of considerable size and these bear witness to its clastic origin.

Mica schist, hornblende schist and altered graywacke. For the most part these rocks are fine grained feldspathic mica schists which are here and there hornblendic. They are characteristic of the Paint slate in the western part of the area. They are composed of quartz, feldspar, biotite or hornblende, chlorite, sericite, epidote, pyrite, tourma line, zircon, magnetite-leucoxine and apatite.

There are all possible gradations between the mica schists in which the clastic structures and textures have been obliterated by recrystallization and the graywacke and slate. In some of the outcrops the schist alternates with massive or coarser grained layers in which sedimentary textures are still preserved. In other instances microscopic study shows that the recrystallization is only complete for the finer grained material in the rock, the larger fragments retaining their rounded outlines. Some of the schists are also marked by a banding which cuts the plane of schistosity at a small angle. In certain of the less altered varieties the biotite is oriented haphazardly but the schistose structure is retained through the parallel arrangement of chlorite and sericite. The biotite individuals enclose fragments of quartz and feldspar and are plainly secondary.

SUMMARY STATEMENT.

The Paint slate, so far as it is possible to judge from the field observations and microscopic study, comprises a vast thickness of fragmental rocks laid down under subaqueous conditions. The material is apparently derived from the mechanical disintegration of crystalline rocks of acid or intermediate composition. In some localities, particularly along the south border, there are associated greenstones both intrusive and extrusive, but throughout the greater part of the area underlain by the Paint formation greenstone or other igneous rocks are notably absent. Here and there dykes of diabase cut the slate but they are not of great size or of frequent occurrence.

The rocks are characterized by a regional schistosity striking nearly east and west. Both northern and southern dips occur, the latter being characteristic of the more westerly exposures. Where bedding is recognizable it is generally in approximate parallelism to the secondary structures of cleavage or schistosity. It is clear that the rocks have been highly folded by forces acting mainly in a north-south direction.

The relationship of the Paint slate with adjacent formations is not known. It is believed to be conformably above the Middle Huronian (Animikie) slate-iron formation series of the Crystal Falls and Iron River districts. It is intruded by the Wolf Lake granite which is correlated with the Presque Isle granite of the Gogebic range. The age of the Paint slate is believed to be largely Middle Huronian (Animikie) and is discussed in connection with the general correlations in chapter 2. Part of it may be of Upper Huronian age.

GRANITES, GNEISSES AND SCHISTS OF THE WOLF LAKE AREA.

The exposures in this area comprise a complex of mica schist, green schist, granite and gneiss. The prevailing strike of schistosity is about east and west with dip vertical or steeply inclined to the south, although northerly dips are not uncommon.

The mica schists are best developed in T 46 N, R's 39-40 W, and granites and green schists in T 45 N, R 39 W. However, mica schists are locally found in the latter township and granite and green schist are not entirely lacking in the two northern ones. The schists are everywhere intruded by the granite and are therefore regarded as the oldest rocks of the complex.

The Wolf Lake Granite.

The Wolf Lake granite comprises massive and gneissose varieties of acid composition and subordinate more basic phases including quartz-diorite and syenite. The rocks are mainly white, gray, and pink, with typical granitic, pegmatitic and porphyritic textures.

The primary minerals of the common normal granite are orthoclase, quartz, plagioclase, biotite, fine particles of red hematite, magnetite (often associated with leucoxine) and occasional crystals of zircon and apatite. Secondary minerals are microcline and other feldspars, sericite, chlorite and quartz. Most of the specimens exhibit in thin section a characteristic mortar structure. In the gneissose varieties the biotite and chlorite show parallel orientation. The feldspar, with the exception of microcline, shows considerable alteration. The microcline appears in many cases to be an alteration product of orthoclase. It occurs in small scattered patches in orthoclase crystals, less commonly it forms a border around orthoclase individuals. In some specimens chlorite is the only ferro-magnesian mineral but in others it is closely associated with biotite from which it is probably derived. Hornblende does not occur in the typical normal granite.

The syenite differs from the normal granite only in the almost total absence of quartz and merits no special description.

The more basic varieties of the granite are composed of plagioclase, orthoclase, quartz, biotite, hornblende, magnetite, and titanite. Secondary minerals are feldspar, carbonate, zoisite, epidote and biotite. In thin section the mortar structure is typically developed, the feldspar is commonly granulated, and the mica shows parallel orientation. The feldspar is predominantly plagioclase, generally highly altered to calcite, zoisite, quartz and biotite. Orthoclase is subordinate, shows alteration to sericite and, to some extent, intergrowth with quartz. The rocks have a composition probably very near that of the quartz-diorite.

In certain places small masses of basic material, characterized by the development of considerable hornblende, have separated from the granitic magma.

The Wolf Lake Schists.

The mica schist series includes biotite-quartz schist, biotite-muscovite-garnet schist, hornblende-biotite schist, feldspathic biotite schist and chlorite schist. The greenschist may be more correctly termed amphibolite or hornblendite. Green hornblende is the most abundant and important mineral, especially in the coarse grained varieties and occurs largely to the practical exclusion of other minerals. Part of the green schist appears to be merely a differentiation product of the granitic magma. On the other hand, granite is found plainly intrusive in hornblende schist, and this is probably their prevailing relationship.

Green schist. The green schist or amphibolite is most abundant in the northwest portion of T 45 N, R 39 W. It is uniformly dark green to black and comprises both coarse grained types and fine grained rocks approaching slate in appearance. Under the microscope the coarser grained varieties appear to be made almost entirely of large individuals of green hornblende with a small amount of epidote, quartz and magnetite, the latter closely associated with leucoxine or other titanium minerals. The hornblende is of the strong pleochroic greenish blue variety and commonly shows yellowish limonitic colored bands around the edges and filling the cleavage cracks. The other minerals occur both as inclusions within and in the interstices between the hornblende individuals. Magnetite occurs in irregular grains and clusters of grains closely associated with leucoxine or small crystals of rutile and brookite. In one observation the latter mineral is present in fairly large sized grains some of which show in convergent light beautiful biaxial interference figures.

The finer grained green schists are characterized by a greater abundance of quartz, epidote, carbonate, and secondary feldspar (limpid albite). There is no direct clue to the original character of the green schists but it is probable that they are mashed igneous rocks of basic composition.

Mica schist. Throughout the Wolf Lake area there are exposures of *acid mica schists* similar in many respects to those found in the southern Archean (?) area described in connection with the Marenisco range. The mica schist series is particularly well developed in sections 29, 30, 21 and 32, T 46 N, R 39 W; in section 6, T 45 N, R 39 W; and in the southeastern part of T 46 N, R 40 W. The mica schists are characterized by an abundance of quartz veins, blebs, and stringers parallel to the schistosity. Banded structures at variance with the schistosity were not observed in the Wolf Lake area. In general appearance, however, the mica schists are very similar to those of the Marenisco range and, with the exception of their greater abundance of garnet, mineralogical differences are revealed only under the microscope. Both rocks are generally gray, fine grained and markedly schistose although in both areas there are exceptional non-schistose and massive types which have the appearance of fine grained graywacke.

Under the microscope the Wolf Lake schists reveal the presence of quartz, biotite, muscovite, chlorite, secondary limpid albite, garnet, sericite, magnetite (usually coated with leucoxine), pyrite and hematite. Green hornblende, epidote and calcite are sparingly present. In general the minerals are arranged in a rather fine grained interlocking crystalline mosaic. By extreme mashing the grains of quartz and secondary feldspar are elongated parallel to the orientation of the micas, but as a rule the latter only, show marked alignment. The garnets in all cases were evidently developed under conditions of static metamorphism. They are full of inclusions of other minerals and as a rule have made space for themselves largely by pushing the mica aside, thus developing a more or less perfect augen structure.

The predominant type of mica schist is composed mainly of quartz, pale brown biotite with pale green chlorite, and a lesser amount of colorless muscovite, limpid feldspar and small colorless garnets. Accessory minerals are magnetite and an occasional irregular patch of pyrite generally associated with hematite. In thin section the minerals are arranged in a typical crystalline interlocking mosaic, and while many of the quartz grains show roundish outlines they fit perfectly into the mosaic and in no case have undoubted detrital grains been observed. The very subordinate amount of secondary feldspar is in rather sharp contrast to its abundance in the feldspathic biotite schists of the Southern Archean (?) area of the Marenisco range.

In addition to the rocks described above, certain restricted types are composed of biotite, chlorite, quartz and garnet with pyrite and magnetite-leucoxine as accessories. Other types contain muscovite, biotite, and garnet in large individuals, the mica showing perfect parallel orientation, and in one observation the schist is composed almost entirely of chlorite and quartz with subordinate carbonaceous (?) material.

Through the assistance of Dr. C. K. Leith a composite sample of the mica schist of the Marenisco and Turtle ranges was analyzed both chemically and physically in the hope of making definite determination of its origin. Unfortunately neither analysis offers conclusive evidence. Prof. W. J. Mead of the University of Wisconsin made a solution separation of the crushed sample and examined the heavy residual minerals under the microscope. He found no evidence of rounded grains and to this extent the evidence, though inconclusive, is against sedimentary origin. The chemical analysis was made by Dr. W. G. Wilcox, and is given below:

Analysis of Mica Schist.

SiO_2	59.50%	
Al_2O_3	16.47	(does not include TiO_2)
Fe_2O_3	4.08	
FeO	6.61	
TiO_2	.88	
MnO	Present but not determined.	
CaO	1.04	
MgO	1.59	
Na_2O	2.65	
K_2O	2.40	
CO_2	trace	
Carbon (organic matter)	.35	
Water below 100 deg. C	.12	
Water above 100 deg. C	2.43	
Total	98.02%	

RELATIONS OF WOLF LAKE GRANITE AND MICA SCHIST TO THE PAINT SLATE FORMATION.

We have shown that there is considerable evidence of sedimentary origin of the mica schist of the Southern Archean (?) area of the Marenisco range. (Chapter 4). That the Wolf Lake schists are of sedimentary origin is strongly supported, if not indeed conclusively proven, through what seems to be a direct connection with the Paint Slate in section 13, T 46 N, R 39 W. In the NE¼ of the SW¼ of this section, adjacent to the railroad, mica schist, identical in every respect to those described above, is inseparable from schistose graywacke. Both rocks occur in the same exposures and grade one into the other. There is no question whatever that the mica schist here is an extremely schistose graywacke. The same relations are exhibited about three quarters of a mile southeast of this locality, at and near the rapids on the Middle branch of the Ontonagon river in the SE¼ of section 18, T 46 N, R 38 W. In a distance of about 250 paces the river falls northward in a series of cascades from 50 to 60 feet directly across the E-W strike of the schistosity of the graywacke. The dip of the plane of schistosity is south about 70°, opposed to the direction of the flow of the stream. The rocks exhibit every gradation from dark massive graywacke to crystalline mica schists carrying blebs and stringers of quartz which are exactly similar to the Wolf Lake schists. The graywacke is identical with the most common phases of the Paint slate which apparently underlies the area from this locality eastward to the northern part of the Iron River district. The conclusion that the Paint slate and the mica schist of the Wolf Lake area are one and the same formation is almost inescapable. If this conclusion be embraced it follows that the Paint slate is intruded by the Wolf Lake granite. In chapter 2 on general correlations it is shown that the Paint slate is probably of Middle Huronian age. The age of the Wolf Lake granite is probably not older than Middle Huronian (Animikie). It has been shown in chapters 3, 4, 5, 6 and 7 that the intrusive granite of the east end of the Gogebic range and the Marenisco, Turtle, Manitowish and Vieux Desert-Conover districts is doubtless Middle Huronian (Animikie) and in chapter 2 these granites are correlated with those of the Florence and Menominee ranges which also intrude Animikie sediments. Therefore, it is the most reasonable assumption that the Wolf Lake granite is merely an outlier of the great Animikie granite batholith of Northern Wisconsin, and is of late Middle Huronian age. For a further discussion of the correlation of the Paint slate and the granites which intrude the Animikie sediments see chapter 2.

CHAPTER X.

CORRELATION AND STRUCTURE OF THE PRE-CAMBRIAN FORMATIONS OF THE GWINN IRON-BEARING DISTRICT OF MICHIGAN*

R. C. ALLEN.

Published information regarding the geology of the Gwinn district is very meager. In 1873, Major J. B. Brooks published† a brief description of the locality now occupied by the Princeton and Stegmiller mines, then known as the S. C. Smith mine, in sections 17, 18, and 20, T. 45, R. 25. In speaking of the occurrence of iron ore there he says: "The geographical position is less remarkable than what might be called its geological isolation, for it appears to be in a small patch of Huronian rocks, in the midst of a great area of barren territory, underlain by the Laurentian and Silurian systems." Brooks observed the black slate adjacent to the ore on the northeast in sections 17 and 18 and in "section 20, west of the river, a talcky schist, holding grains of quartz," but was unable to determine the stratigraphic relation of these rocks to the iron formation.

About ten years later this locality was again examined by Dr. Carl Rominger, ‡who writes as follows: "The Cheshire mine, formerly known as the S. C. Smith mine . . . . is working a strip of slaty and quartzose rock beds, known to extend along the valley of the Escanaba River for a distance of nine miles from the northwest corner of section 19, T. 46, R. 26, to the center of T. 45, R. 25." Rominger describes the rocks shown in the mining pits in sections 18 and 20, T. 45, R. 25, in considerable detail. He recognizes an iron formation underlain and overlain by slate. Owing to his misunderstanding of the structure his succession is reversed.

In 1911 the United States Geological Survey published a brief account of the geology of the Gwinn (Swanzy) district by C. R. Van Hise and C. K. Leith.§ These authors had made no detailed survey of this district and attempted merely a summary of the information from other sources available to them at the time their monograph was written. They describe the Gwinn district as a southeastward-pitching syncli-

*Published in the Journal of Geology, Vol. XXII, No. 6, September-October, 1914.
†Michigan Geological Survey, I, 150-51.
‡Ibid, V, (1894), Part I, pp. 70-73.
§C. R. Van Hise and C. K. Leith, Monograph 52, U. S. Geological Survey, pp. 283-86.

norium about two miles long and from one-half to two miles wide, the structure being unknown toward the southeast because of the deep overburden. They correlate the pre-Cambrian sedimentary rocks with the Upper Huronian series and describe them as (1) a basal "quartz slate and quartzite grading down into arkose or decomposed granite" which is overlain by (2) the Michigamme slate carrying the Bijiki iron-bearing formation in "lenses and layers" near its base.

Recent studies by the writer, based on field mapping and an examination of the records of several hundred diamond drill holes, show clearly that the Gwinn district contains *at least two* unconformable series of sedimentary rocks. It seems probable that the upper series, which will be described as the Princeton series, is equivalent to the Upper Huronian of the Marquette district, that the lower series, which will be described as the Gwinn series, is equivalent to the Middle Huronian of the Marquette district, and that the Lower Huronian series, while not present in the Gwinn synclinorium, is represented by certain fragments of quartzite and cherty slate in the conglomerate at the base of the lower or Gwinn series.

Without the information afforded by records of drill holes and other exploratory operations, any statement of the geology of the Gwinn district would probably be misleading and in any event necessarily fragmentary and incomplete. Outcrops are not plentiful except in certain restricted localities and are limited to the north two-fifths of the district. The records of drill holes, carefully compiled by geologists of the Cleveland Cliffs Iron Co. and the Oliver Iron Mining Co., are the main reliance for mapping the formations. Only a few of the drill samples were seen by the writer, but each of the formations is somewhere exposed either in outcrops or in excavations and was studied on the ground. It will be seen on the accompanying map that information is entirely wanting in some parts of the synclinorium and in other parts is insufficient for accurate mapping. Only a few of the many faults, which certainly occur, particularly in the north end of the district, have been mapped and the exact location and character of even those is not apparent.

The lithology of the various formations will be considered only so far as essential to an understanding of the succession and the correlations, but the discussion necessarily will be more in detail than the account published in *Monograph 52*, to which reference has been made.

Preliminary to the statement of the geology, there is given in parallel columns for comparison the succession and correlation of the United States Geological Survey and of the writer.

TABLE I.

TABLE OF CORRELATIONS. MARQUETTE AND GWINN DISTRICTS

	Marquette District—United States Geological Survey.	Gwinn District—U.S. Geol. Survey, 1911	Gwinn District—Mich. Geol. Survey, 1913
Quarternary system	Pleistocene series—glacial drift	Pleistocene series—glacial deposits	Pleistocene series—glacial deposits
Ordovician system Cambrian system	Unconformity. Upper Cambrian (Potsdam sandstone)	Unconformity Limestone Sandstone	Unconformity Limestone and sandstone
Algonkian system—Keweenawan series	Unconformity Not identified but probably represented by part of intrusives in Upper Huronian	Unconformity	Unconformity Not identified but probably represented by basic dikes which intrude all of the pre-Cambrian formations
Huronian series Upper Huronian	Unconformity Greenstone intrusives and extrusives Michigamme slate (slate and mica schist) locally represented by Clarksburg (volcanic) formation Bijiki schist (iron-bearing) Goodrich quartzite	Unconformity Michigamme slate Bijiki iron-bearing member in lenses and layers near base of Michigamme slate Goodrich quartzite. Quartz slate and quartzite grading down into arkose or recomposed granite	Unconformity Michigamme slate, carrying beds of ferruginous slate and chert, quartzite, and graywacke Conglomerate and graywacke (Goodrich)
Middle Huronian	Unconformity Negaunee formation (iron-bearing) Siamo slate Ajibik quartzite		Unconformity Iron-bearing formation and associated overlying and underlying slate (Negaunee-Siamo) Arkose conglomerate, arkose and quartz-slate conglomerate (Ajibik)

TABLE I.—Continued.

	Marquette District—United States Geological Survey.	Gwinn District—U. S. Geol. Survey, 1911.	Gwinn District—Mich. Geol. Survey, 1913.
Lower Huronian	Unconformity Wewe slate Kona dolomite Mesnard quartzite		
Archean system Laurentian series Keewatin series	Unconformity Granite, syenite, peridotite Palmer gneiss Kitchi schist and Mona schist	Unconformity Granite	Unconformity Granite and greenstone, mainly granite

LOCATION AND TOPOGRAPHY, ETC.

The Gwinn synclinorium occupies an area about six miles long and from one to two miles wide, mainly in T 45 N, R 25 W, but extending a short distance into T 44 N, R 25 W. The trend of the major structure is about N 45° W, or almost exactly parallel to the Republic trough, the southern end of which is 22 miles west and 6 miles north of the north end of the Gwinn fold. Gwinn, the principal village, is 16 miles south of the city of Marquette.

The southeast three-fifths of the Gwinn fold is buried beneath a featureless and almost flat sand plain which extends north and east to the hills of the Marquette range. In the opposite direction the surface is broken and hilly with occasional rock exposures. Granite hills encircle the northwest and north sides of the synclinorium. The district is drained by the Escanaba River, which follows the northeast side of the trough to Gwinn and then turns south across the sand plains. On the plains the water table is within a few feet of the surface and the ore bodies are deeply buried under water-saturated sand and gravel, a condition which is a serious menace to mining operations.

The first shipment of ore was made in 1872 from the Cheshire mine, now known as the Princeton No. 1 pit. About 1902 the Cleveland Cliffs Iron Co. purchased the Princeton (Swanzy, Cheshire) mine and during the time which has since elapsed has extended its holdings by purchase and lease until it now controls all of the known workable ore bodies with the exception of the Stegmiller, which is mined by the American (Oliver) Mining Co. Since the building of the beautiful and principal village of Gwinn by the Cleveland Cliffs Iron Co. the name of the district has been changed by common usage from Swanzy to Gwinn. There are five producing mines in the district. Concrete shafts have been sunk to a number of additional ore bodies but it is not known when these will be equipped for mining operations.

NOTES ON THE STRUCTURE OF THE GWINN SYNCLINORIUM.

The Gwinn synclinorium contains two unconformable series of sedimentary rocks, having a combined thickness of from 800 to 1,000 feet. Outliers of flat-lying Paleozoic (Cambrian or Ordovician) sandstone and limestone occur throughout this area. The pre-Cambrian beds are remnants of formations, originally much more extensive, which have escaped erosion by downfolding or depression in the Archean basement.

The synclinorium is constricted to not more than three-fourths of a mile in width in the vicinity of the NW$\frac{1}{4}$ of section 29, T 45, R 25. North of the constricted portion, the rocks are folded and faulted in

19

a complex manner but south of it the structure is apparently somewhat less complicated.

The southern three-fifths of the synclinorium is a spoon-shaped basin four miles long with a maximum width of about two miles. The deepest part of the fold is adjacent to the northeast limb where the Archean granite is reached in many drill holes at depths of from 1,000 to 1,200 feet (see cross-section III-IV., *Fig. 9*). Drilling along the southwest limb indicates a number of sharp drag folds pitching northwest. The folds on the opposite limb are not so sharp and are apparently simple cross-folds. The most prominent one appears in the SE$\frac{1}{4}$ of section 35. The synclinorium practically terminates against a faulted zone on the southeast. It is not possible to determine from present information the full extent of this zone nor the character of the faulting. The rocks in the faulted area are largely slate, chert, conglomerate, and breccia resembling lithologically the succession in the upper or Princeton series, but the regular succession of formations shown on both limbs of the fold terminates abruptly at the line indicated as a fault on the map. Another cross-fault trends diagonally northesat through section 28, producing a horizontal displacement of not less than 700 or 800 ft. in the NE$\frac{1}{4}$ of section 32 and from 150 to 200 ft. in the N$\frac{1}{2}$ of the NW$\frac{1}{4}$ of section 28. The offset in the latter locality may be explained by folding, but the sharpness of the break in the former locality strongly suggests faulting. In any case, the extension and direction of the fault as indicated on the map is to a considerable degree hypothetical.

Knowledge of the structure of the northeast two-fifths of the Gwinn synclinorium pertains chiefly to the northeast limb. The most conspicuous structural feature of this limb is the broad cross-anticline responsible for the extraordinary surface exposure of the iron formation in the vicinity of the Austin and Stephenson mines, giving rise to two prominent synclines, the northern one carrying the Princeton No. 2 ore body and the southern one the Austin-Stephenson deposit (see cross-section I-II *Fig. 9*). Northward from Princeton No. 2 mine the east limb is overturned and dips at an angle of about 80° to the northeast, about parallel to a faulted contact with black slate extending from somewhere north of the Old Swanzy pit in the SW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 18 southeast for a distance of probably more than a mile. Where observed in the Swanzy pit and in the Princeton No. 1 pit in the SE$\frac{1}{4}$ of section 18, the dip of the fault plane is northeast about 75° or 80°. Both the iron formation and the adjacent slate are intensely sheared along the zone of faulting. The belt of slates adjacent to the fault on the northeast may be stratigraphically either above or below the iron formation so far as the writer has proof. The upper and the lower slate

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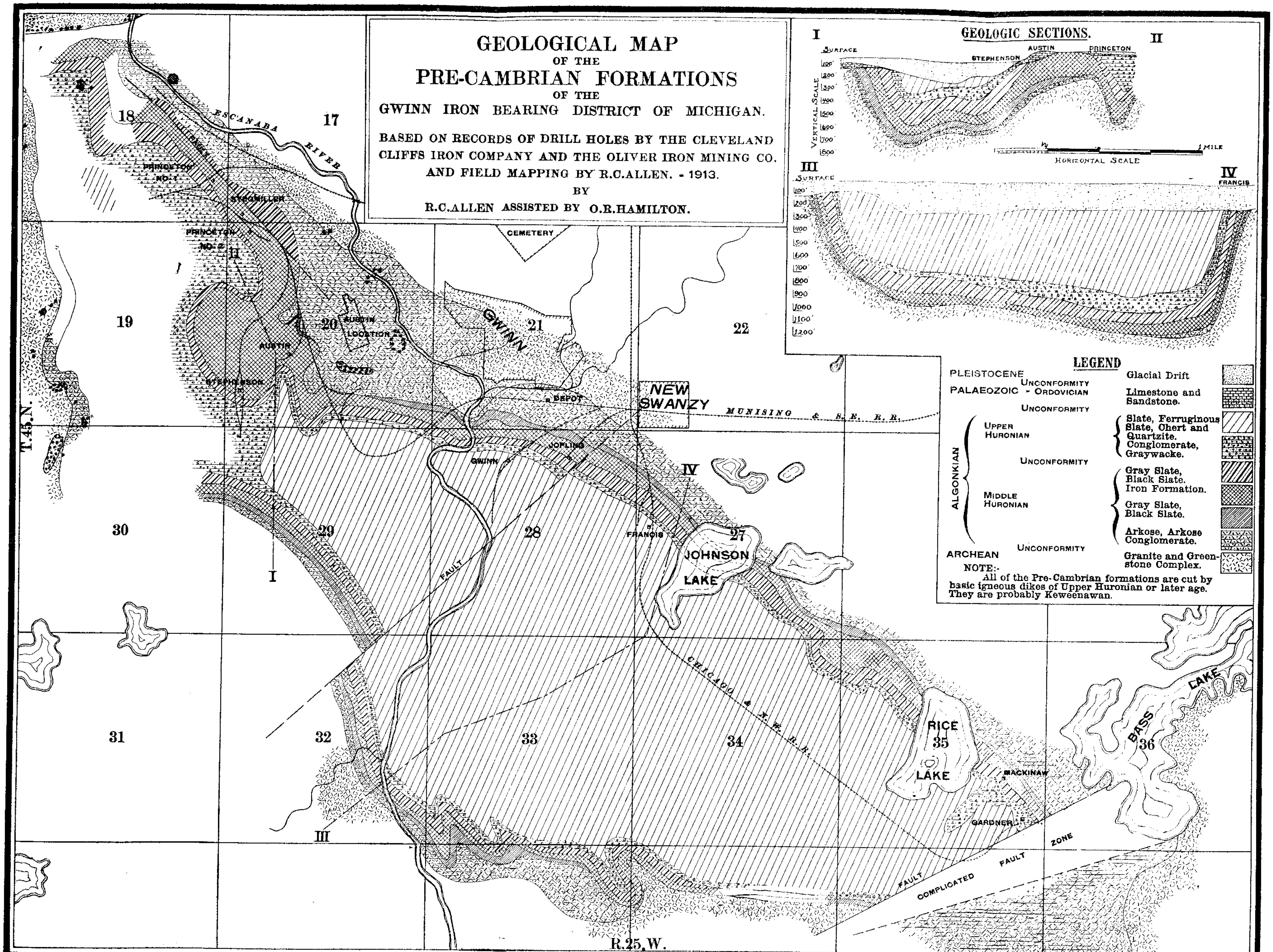

GEOLOGICAL MAP
OF THE
PRE-CAMBRIAN FORMATIONS
OF THE
GWINN IRON BEARING DISTRICT OF MICHIGAN.
BASED ON RECORDS OF DRILL HOLES BY THE CLEVELAND CLIFFS IRON COMPANY AND THE OLIVER IRON MINING CO. AND FIELD MAPPING BY R.C.ALLEN. - 1913.
BY
R.C.ALLEN ASSISTED BY O.R.HAMILTON.
GEOLOGIC SECTIONS.
I
II
III
IV
SURFACE
STEPHENSON
AUSTIN
PRINCETON
FRANCIS
VERTICAL SCALE
HORIZONTAL SCALE
1 MILE
LEGEND
PLEISTOCENE
Glacial Drift
UNCONFORMITY
PALAEOZOIC - ORDOVICIAN
Limestone and Sandstone.
UNCONFORMITY
ALGONKIAN
UPPER HURONIAN
Slate, Ferruginous Slate, Chert and Quartzite.
Conglomerate, Graywacke.
UNCONFORMITY
MIDDLE HURONIAN
Gray Slate, Black Slate. Iron Formation.
Gray Slate, Black Slate.
Arkose, Arkose Conglomerate.
UNCONFORMITY
ARCHEAN
Granite and Greenstone Complex.
NOTE:- All of the Pre-Cambrian formations are cut by basic igneous dikes of Upper Huronian or later age. They are probably Keweenawan.
ESCANABA RIVER
PRINCETON NO. 1
STEGMILLER
PRINCETON NO. 2
CEMETERY
AUSTIN LOCATION
AUSTIN
STEPHENSON
GWINN
DEPOT
NEW SWANZY
MUNISING & S.E. R.R.
JOPLING
FRANCIS
JOHNSON LAKE
FAULT
CHICAGO & N.W. R.R.
RICE LAKE
BASS LAKE
MACKINAW
GARDNER
COMPLICATED FAULT ZONE
T.45.N.
R.25.W.
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18
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Figure 9.

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members of the Gwinn series are lithologically very similar. Drill holes and the mine workings show that the iron formation in this vicinity lies directly on the basal arkose member of the Gwinn series with here and there a few feet of black slate lying between them. This makes it very probable that the slate belt northeast of the fault belongs to the upper slate member of the Gwinn series. North of the middle of section 18, details of the structure are unknown but the distribution of formations indicated by the few exposures and drill holes suggests deformation by both folding and faulting of a complex character.

ARCHEAN SYSTEM.

The Archean system comprises both acid and basic plutonic rocks, granite greatly predominating. These rocks inclose the synclinorium on the west, north and east sides, encircling the north and northwest sides in bold hills and protruding through the drift in low knobs on the east side from New Swanzy northward. Numerous drill holes reach the system after penetrating the overlying sedimentaries within the borders of the synclinorium.

ALGONKIAN SYSTEM.

The Algonkian system is represented by two unconformable series of Huronian sedimentary rocks, the Princeton (upper) and the Gwinn (lower) series. Both series are intruded by basic dikes, probably of Keweenawan age. The basal conglomerate of the Gwinn series contains pebbles and boulders of quartzite, quartz slate, and siliceous, cherty, slightly dolomitic slate derived from a third sedimentary series unconformably below the Gwinn series but not present so far as known in the Gwinn synclinorium.

MIDDLE HURONIAN.

Gwinn Series.

There are four members of the Gwinn series, viz., from the base upward, (1) conglomerate and arkose, (2) black slate and gray slate, (3) iron formation, and (4) black slate, gray slate, and graywacke.

1. *Conglomerate-arkose*—The basal member of the Gwinn series is mainly arkose and arkose conglomerate. It lies on an uneven surface of Archean granite and is reported to occur in isolated patches over a considerable area outside of the Gwinn synclinorium. Within the fold its thickness varies from practically nothing to above 60 ft. The dominant phase of the member is arkose or decomposed granite. It is evident that the arkose has its origin in the disintegration and subsequent sedimentation of the disintegrated particles of the underlying

granite which in many places it resembles so closely that distinction is difficult. There are phases of the arkose in which the feldspar crystals show little perceptible wear, much less the quartz grains. It is particularly difficult to separate from granite in places near the contact where secondary mica has developed and veins of quartz and pegmatite occur like those in the granite. Phases in which there has been perceptible or conspicuous rounding of the quartz and feldspar particles are commonest and these may be either massive or schistose. The schistosity in the arkose is the result of mashing of the feldspars, by which process the quartz grains are generally not greatly affected. Where the arkose is overlain by the iron formation and particularly by iron ore, as in the mines north and west of Gwinn, it is in many places highly decomposed, soft, and iron stained, the feldspars being largely kaolinized.

The conglomerate is much less abundant than the arkose and according to drill records is not present in most localities. Its occurrence seems to be erratic and, curiously enough, where exposed in the SE¼ of the SW¼ of section 19, T. 45, R. 25, it lies some distance above the base of the formation. Drift bowlders of the conglomerate are rather plentiful but the only exposures known to the writer are in the SW¼ of section 19. Here there are 12-15 ft. of it exposed in layers from 1 to 2 ft. thick dipping about 16° E. and striking N. 15° W. At this locality the contact with the granite is about 150 paces west. The matrix of the conglomerate is chiefly arkose but in one exposure it is siliceous, gray slate interbedded with the arkose. The pebbles are up to several inches in diameter and are mainly vein quartz which is abundant in the underlying granite. There are also many fragments of greenschist, dense, vitreous, gray quartzite and siliceous, cherty, slightly dolomitic slate of grayish-green color. The composition of the conglomerate may also be studied to advantage on the waste dump of the Gwinn mine in the NE¼ of the NW¼ of section 28 where a bowlder bed was encountered in cutting the pumping station in the shaft. All of the bowlders are well rounded and vary up to 6 to 7 inches in diameter. The matrix is arkose so decomposed that many of the bowlders are lying free on the dump. In addition to the rocks represented in the exposures in section 19 there are many bowlders of granite and greenstone.

The origin of the quartzite and slate pebbles is of great interest in its bearing on the correlation of the Gwinn series. Near Little Lake, about five miles east, in a range of hills on the north side of section 19, T. 45, R. 24, ther are numerous outcrops of quartzite, quartz slate and arkose. Van Hise and Leith considered these rocks to be the base (Goodrich quartzite) of the Gwinn series which we have described. In fact, their description seems to apply mainly to these exposures and

not to the basal member of the Gwinn series as it actually exists in the Gwinn synclinorium. There is an arkose and arkose conglomerate in these exposures exactly similar, even to the pebbles in its associated conglomerate, to the basal member of the Gwinn series. This formation, however, is plainly unconformably below the quartzites and quartz slates, as proven by the occurrence of a coarse conglomerate at the base of the quartzite carrying numerous bowlders of the arkose some of which are as much as 2 ft. in diameter. The exposures at Little Lake are not in the Gwinn synclinorium but will be described in a later chapter. The point is emphasized, however, that the presence of quartzite and cherty, quartz-slate pebbles in the basal member of the Gwinn series proves that there is at least one unconformable series of sediments between the Archean and the Gwinn series. The writer believes that this series is the Lower Huronian as represented in the Marquette district a short distance north.

2. *The Lower Slate.*—In the southeastern three-fifths of the district a black, graphitic, and a gray slate formation intervenes between the basal arkose member and the iron formation. It is less generally present from the Stephenson mine northward, in this area never exceeding a few feet in thickness, but south of the Stephenson mine it varies up to above 60 ft. thick. Were it not for lithologic dissimilarity this slate would be included in the basal member, but inasmuch as it represents a distinct change in conditions of sedimentation and moreover seems to maintain a definite stratigraphic relation to the overlying and underlying formations, it should perhaps be described as a distinct member of the series.

3. *The Iron-Bearing Member.*—Like the other formations in the Gwinn series the iron-bearing member varies markedly in thickness but is nevertheless persistent, occupying a constant and definite stratigraphic position in the series. The description of the occurrence of this member in "lenses and layers" in slate by Van Hise and Leith is misleading in so far as this implies that the member is discontinuous within the synclinorium. The thickness of the iron formation is ordinarily 50-100 ft. with a maximum of probably less than 125 ft. and a minimum of only a few feet as shown in some drill holes toward the center of the basin west of the Princeton and Stegmiller mines. Some sections show a greater thickness than 125 ft., which is accounted for by folding. The formation is thinner and at the same time leaner toward the west side of the synclinorium. All of the known ore bodies are on the east limb of the fold.

The iron formation is mainly banded, ferruginous chert similar to the "soft ore jasper" of the other Michigan ranges. The original or unaltered phase is cherty iron carbonate. North of the Swanzy pit in section 18, the base of the formation, as shown by drilling, seems to be mainly grunerite schist. This part of the district shows evidence of greater deformation by folding and faulting than areas farther south.

The upper part of the iron bearing member is slaty in many places and the base of the overlying slate is here and there so ferruginous that it is a matter of choice as to whether it should be mapped as slate or iron formation. On the map these phases are included in the overlying slates.

The iron ores are both Bessemer and non-Bessemer grades, the latter greatly predominating, very soft and fine textured in the main and generally high in moisture. A purplish satin luster is a peculiar characteristic of the Gwinn ores. There are some pits in the upper part of the formation west of the Austin mine that show hard jasper and hard, blue hematite. Localization of the ores is largely coincident with synclinal troughs and faulted zones but is not limited to these structures. An inclined position of the iron formation between the overlying slate and underlying slate or arkose satisfies the structural requirements for ore concentration.

4. *The Upyer Slate.*—The upper slate member is from 30 to 100 ft. thick. It is unconformably overlain by the basal conglomerate of the Princeton series. Its relation to the underlying iron-bearing member is largely gradational. It comprises an interbedded series of black slate, gray slate, and dark graywacke-quartzite. The black graphitic phase is more commonly directly above the iron formation than the gray slate, and the graywacke-quartzite phase seems to be in upper and middle horizons.

UPPER HURONIAN.

Princeton Series.

The Princeton series consists of an interbedded series of slates, ferruginous slates, and cherts, quartzites, ferruginous quartzites, and graywacke with a basal conglomerate. The series is 400-500 ft. thick. Probably the entire thickness is not represented in the Gwinn fold. It is rarely seen in outcrops but it has been penetrated by numerous drill holes and some open pits. For the purpose of this article the interesting member is the basal conglomerate.

The basal conglomerate varies from 30 to 50 ft. to more than 100 ft. in thickness. Nearly all of the many drill holes which cross its horizon show its presence but here and there it is represented by a coarse graywacke. So far as known, the only exposures are in the SE$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 18, T. 45, R. 25, where a number of exposures occur on a low brush-covered ridge. Adjacent to them on the east the upper slate member of the Gwinn series is exposed in pits. The strike of the conglomerate is N. 70° W. and the dip 80° N.

The matrix of the conglomerate is coarse, dark graywacke-quartzite, the pebbles are chert and siliceous black slate, quartz, and arkose, derived from the underlying Gwinn series, and quartzite. The matrix carries a good deal of disseminated ferruginous material and some very small fragments of iron ore. There are also a good many small irregular cavities in the rock which are lined with hematite and limonite produced by weathering-out of iron-bearing fragments of some kind. The largest chert fragments are two to three inches long and one-half to an inch wide. All of them show wear by attrition, the smaller ones being generally lens shaped.

So far as can be ascertained, the Princeton and Gwinn series are structurally almost accordant. The strike of the conglomerate where exposed in section 18 indicates discordance in trend with the Gwinn series, but too little is known of the structure in that vicinity to place any importance on this observation.

KEWEENAWAN SERIES (?)

Basic dikes have been cut in a few drill holes and may be observed in section 20, T. 45, R. 25, cutting the basal arkose member of the Gwinn series. These dikes intrude both the Princeton and the Gwinn series. They are older than Paleozoic and younger than the Princeton series. Their age is therefore probably Keweenawan.

PALEOZOIC.

Isolated remnants of limestone and sandstone of Cambrian or Ordovician age, or possibly both, occur throughout the district. Some of these are in excess of 50 ft. thick. No fossils or other means of determining the exact age of these outliers is available at the present time.

CORRELATION OF THE GWINN AND THE PRINCETON SERIES.

It has been shown that the pre-Cambrian sedimentary rocks of the Gwinn synclinorium consist of two unconformable series. The unconformity between them is marked by a basal conglomerate the position, extent, and thickness of which imply an important erosion interval which intervened between the periods of deposition of the two series.

Concerning the respective ages of these two series, it may be said that probably no geologist familiar with the pre-Cambrian formations of the Lake Superior region would correlate the Gwinn (lower) series with the Lower Huronian. It contains an important iron formation associated with graphitic slates, an assemblage of rocks not known in the Lower Huronian. Moreover, the basal conglomerate carries fragments of quartzite and quartz slate dissimilar to any known Archean sediments in Michigan but exactly similar to certain Lower Huronian rocks in the adjacent Marquette district. This evidence considered in connection with the unconformity separating the Princeton and the Gwinn series is a sufficient basis for the correlation suggested, but an additional consideration tending to show that the Gwinn series is Middle Huronian appears in the absence from its basal conglomerate of jasper fragments from the Negaunee formation so strongly developed in the adjacent Marquette district.

Escape from the correlations suggested in this paper involves a disregard or subordination of the importance of the unconformity separating the Gwinn and the Princeton series. There is no certain evidence in this synclinorium of great structural discordance between these two series but it may be and probably is as great as that separating the Upper Huronian and the Middle Huronian series of the Marquette district. Great structural discordance could hardly be expected inasmuch as the main deformation took place after the deposition of the Princeton series. Some structural discordance is implied in the consideration that although the upper slate member of the Gwinn series was probably not cut through in this district, there was sufficient erosion in adjacent territory to uncover the different members of the entire Gwinn series prior to the deposition of the basal conglomerate of the Princeton series.

CHAPTER XI.

EVIDENCE OF THE MIDDLE-UPPER HURONIAN UNCONFORMITY IN THE QUARTZITE HILLS AT LITTLE LAKE, MICHIGAN*

R. C. ALLEN AND L. P. BARRETT.

A critical examination of the exposures of quartzite, quartz slate, and arkose in the hills near Little Lake in T 45 N, R 24 W, Marquette County, Michigan, was inspired by the results of studies by the senior writer in the Gwinn synclinorium, which lies between five and seven miles west.

The Gwinn synclinorium contains two series of Huronian sedimentary rocks, separated by an unconformity which is characterized by a conglomerate at the base of the upper (Princeton) series containing fragments derived from the various formations (including a productive iron-bearing member) of the lower (Gwinn) series and also from a third sedimentary series not represented in the synclinorium. The work at Little Lake resulted in the identification of an unconformity which, in connection with other data to be described, establishes a basis for correlation of the formations at Little Lake with certain of those in the Gwinn synclinorium.

So far as the writers are aware, no previous mapping and careful study of the rocks at Little Lake has been made. Rominger barely mentions the locality in 1894 in the statement that "iron-bearing rock beds occur in the vicinity of Little Lake."† Reference was again made to this locality in 1911 by Van Hise and Leith‡ who correlated the quartzite, quartz slate, and arkose in the hills at Little Lake with the Goodrich quartzite or basal member of the Upper Huronian as developed in the Marquette district and the arkose and arkose conglomerate at the base of the Gwinn series in the adjacent Gwinn (Swanzy) synclinorium.

The succession and correlation of the formations in the Gwinn synclinorium and those at Little Lake are given below:

*Published in the Journal of Geology Vol. XXII, No. 6, September-October, 1914.
†Michigan Geological Survey, 1894, Vol. V, Part I, p. 71.
‡C. R. Van Hise and C. K. Leith, Monograph 52, U. S. G. S., pp. 283-86.

CORRELATION TABLES.

Gwinn Synclinorium and Little Lake Hills.

	Gwinn-Little Lake Dist., U.S. Geol. Survey, 1911.	Gwinn District, Mich. Geol. Survey, 1913.	Little Lake Hills, Michigan Geol. Survey, 1913.
Quarternary System	Pleistocene Series—Glacial Deposits	Pleistocene Series—Glacial Deposits	Pleistocene Series—Glacial Deposits
	Unconformity	Unconformity	Unconformity
Ordovician System? or Cambrian System?	Limestone Sandstone	Limestone and sandstone	Limestone
Algonkian System—Keweenawan Series	Unconformity	Unconformity Not identified by probably represented by basic dikes which intrude all of the pre-Cambrian formations	
Huronian Series	Michigamme slate Bjiliki iron-bearing member in lenses and layers near base of Michigamme slate	Michigamme slate, carrying beds of ferruginous slate and chert, quartzite and graywacke	Quartz slate and quartzite
Upper Huronian	Goodrich quartzite. Quartz slate and quartzite grading down into arkose or recomposed granite	Conglomerate and graywacke (Goodrich)	Conglomerate
Middle Huronian		Unconformity Iron-bearing formation and associated overlying and underlying slate (Negaunee-Siamo) Arkose conglomerate, arkose and quartz slate conglomerate (Ajibik)	Unconformity Conglomerate, arkose and quartzite.
Lower Huronian			
Archean System Laurentian Series Keewatin Series	Unconformity Granite	Unconformity Granite and greenstone, mainly granite	Not exposed near Little Lake Hills. Probably granite

STRUCTURE OF THE LITTLE LAKE HILLS.

Rising to a height of possibly 100 feet above a featureless flat sand plain near the station of Little Lake are two hills on which there are many exposures of pre-Cambrian arkose, quartzite, and quartz slate with associated conglomerates. These hills present today, in reference to the fluvio-glacial sand plains in which their bases are buried, somewhat the same appearance that they seem to have had near the close of pre-Cambrian time, when they were monadnocks on a pre-Cambrian peneplain, for remnants of flat lying Paleozoic (Cambrian or Ordovician) limestone still cling to their sides and summits.

The eastern and larger hill is nearly a half-mile in diameter; the western and smaller one is about three-eighths of a mile long in an E-W direction with a basal width of about one-eighth of a mile. The exposures are most abundant on the north half of the east hill, but on both hills there are a large number of pits and trenches which were dug many years ago by prospectors whose diligence deserved a better reward than this locality seems to have offered. Aside from the red color of some of the quartz slate beds in the upper series, iron-stained shear zones in the quartzite and arkose, and an exposure at locality *F* (see *Fig. 10*) of about eighteen inches of hematite occupying a lens-shaped cavity along a zone of thrust faulting in massive quartzite, there appears no present evidence of the attractiveness which these hills seem to have presented to the early prospector for iron ore.

The structure of the north side of the east hill is apparently an anticline, the crest of which has been cut away by erosion, thus exposing the arkose and associated conglomerate of the lower (Gwinn) series flanked on the north, east, and west sides by conglomerate, quartzite, and quartz slate of the upper (Princeton) series. This is the only complete structural feature which can be determined from the available data. There is evidence in the development of cleavage and schistose structures, shear zones and faults of both normal and thrust type, that general deformation has been severe. Further evidence of the intensity of deformation is afforded in the overturning of the formations, with consequent apparent reversal in succession, in exposures at locality *A* at the southeast extremity of the east hill. While evidence of minor faulting is abundant in outcrops and pits, it is found impossible with information available to trace the course or measure the throw of any of these faults. The fault at locality *C-H* is a partial exception but the only thing known about this fault is its direction and the fact that its vertical displacement is inconsiderable. In reference to the structure of the west hill perhaps no inferences are warranted. So far as known, the arkose of the lower series is not exposed but the distribution of the lower and higher members of the

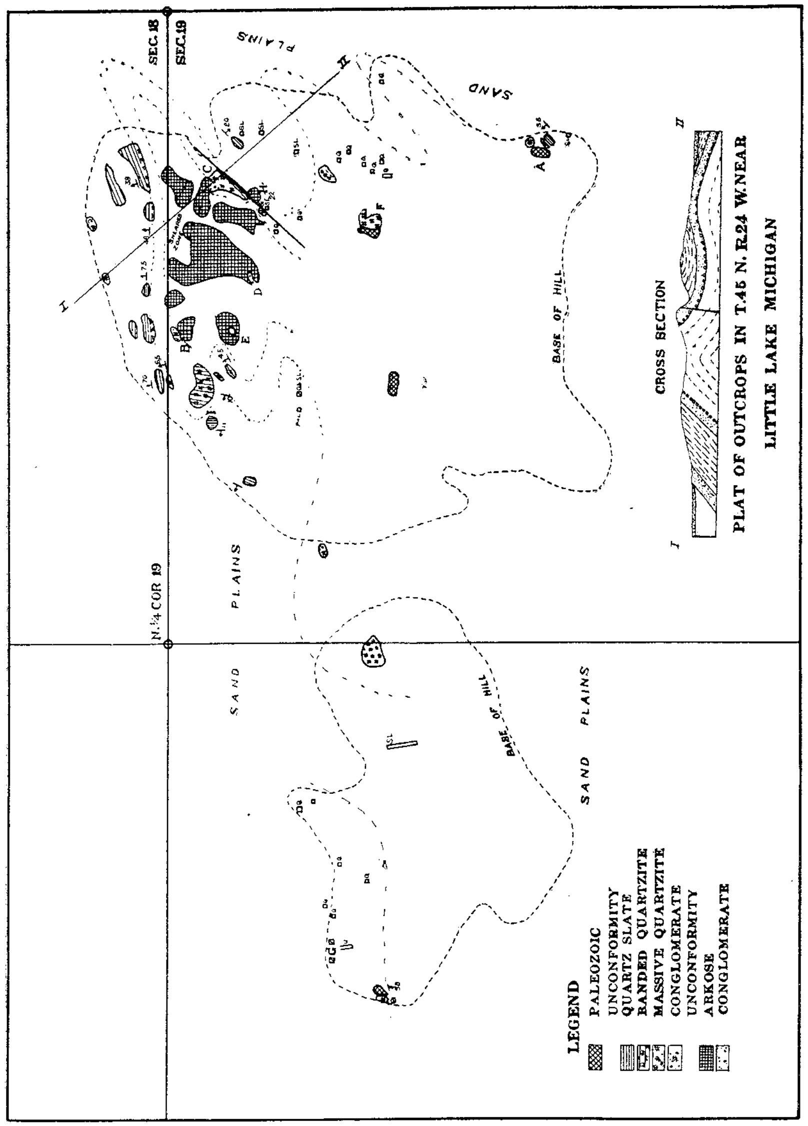

Figure 10.

upper series together with the topographic expression faintly suggests a shallow syncline trending across the hill in a NE-SW direction carrying the quartz slate member in the trough and exposing the underlying quartzite on its opposite flanks. But the structure is probably not so simple as this for there is evidence of faulting in some of the pits.

THE LOWER (GWINN) SERIES.

Arkose and conglomerate.—The major portion of the arkose formation is in reality now an abundantly sericitic quartzite, the sericite being a metamorphic derivative of the original feldspar. The abundance of sericite affords on cleavage surfaces, a characteristic pearly luster. From the dominant phase there are gradations through intermediate phases to typical arkose with feldspar practically unaltered. Of subordinate importance are interstratified lenses of conglomerate varying from a foot or two up to eight feet in thickness. The pebbles are mainly vein quartz well rounded and of various sizes under four inches in diameter. Other pebbles of dense, vitreous, gray quartzite, black chert, and siliceous dolomitic slate are much less abundant. The matrix of the conglomerate beds has the composition of quartzite rather than arkose and is usually dark, dense, vitreous, and slightly sericitic.

Bedding structure is not observable in any of the various phases of the formation, except as it may be represented by an occasional thin layer of gray chert. The deposition of these cherty layers probably heralded the approach of a change in conditions of sedimentation represented by an iron-bearing member in the adjacent Gwinn synclinorium which lies in part directly on a similar arkose-conglomerate formation. At Little Lake the iron-bearing member appears to have been removed by erosion prior to the deposition of the overlying conglomerate and quartzites. The similarity of the arkose-conglomerate of Little Lake to that at the base of the Gwinn series extends to the pebble content. Rounded fragments of dolomitic siliceous slate, and gray quartzite are common to both localities, but the bowlders of granite and green schist which occur in the conglomerate of the Gwinn district were not observed in the exposures at Little Lake.

THE UPPER (PRINCETON) SERIES.

The upper series, so far as represented at Little Lake, comprises a higher horizon of red-and-gray-banded quartz slate and slaty quartzite grading down through banded quartzite and massive non-bedded quartzite into a basal conglomerate.

Conglomerate.—The contact of the upper and the lower series is exposed at localities *B* and *C* (see *Fig. 10*). At locality *B* this contact is distinguishable only on careful examination. The base of the upper series on weathered exposures is not conspicuously dissimilar to the underlying arkose except on freshly fractured surfaces which reveal, in contradistinction to the underlying sericitic, quartz-feldspar rock, a dense, hard matrix of quartzite holding pebbles of vein quartz of sizes less than an inch in diameter. At locality *C*, however, all doubt of the unconformable relations of the arkose-conglomerate and the overlying series is dispelled. The change from arkose to dense, black, vitreous quartzite is abrupt at a wavy contact of knife-like sharpness. In addition to the quartz pebbles observed at locality *C* there are pebbles of chert and large bowlders of the underlying arkose above one foot in diameter. The arkose bowlders are much softer than the embedding matrix of quartzite and weather out to form characteristic pit-like depressions. The full thickness of the basal conglomerate is not exposed at locality *C*, but at locality *B* it is apparently only six feet. At *C* only about four feet are observable.

Quartzite and quartz slate.—There are three distinct main phases of this series, viz., (1) a massive phase associated with the basal conglomerate, grading upward into (2) a banded phase which in turn is over-lain rather sharply by (3) beds of gray- and red-banded quartz slate. Although these three phases correspond to definite stratigraphic horizons, considerable difficulty is experienced in correlating the various exposures of the different members of this series. The chief difficulties refer to the relation of the quartzite on the west hill to that exposed on the east hill and to the determination of the stratigraphic position of the two outcrops of quartzite north of the slate at the base of the east hill. The outcrops of gray quartz slate and red-banded quartz slate on the north slope of the west hill are apparently stratigraphically above the exposures of quartzite in outcrops and pits on its northwest and northeast sides. Whether the quartzite at the base of the north slope of the east hill is stratigraphically above the quartz slate or represents the underlying massive quartzite brought up by faulting cannot be determined.

Extended description of the different phases of the quartz rocks in the upper series has little interest for present purposes. The dissimilarities of the different members refer mainly to texture and bedding structures rather than to composition. The red color of certain layers in the quartz slates is caused by the presence of small particles of finely disseminated hematite.

NOTES ON THE CORRELATION.

In chapter 10 the senior writer discussed the importance of the unconformity separating the Princeton (upper) and Gwinn (lower) series in the Gwinn synclinorium and adduced evidence in support of the correlation of these two series with the Upper and the Middle Huronian. The lithologic similarity of the arkose-conglomerate formation at Little Lake to the basal member of the Gwinn series, only a few miles distant, considered in connection with the unconformity separating it from the overlying quartzites and quartz slates is a sufficient basis for extending the arguments for the correlations in the Gwinn district to cover the two unconformable series at Little Lake. The geology of each area accounts for three unconformable series of sedimentary rocks corresponding to the Lower, Middle, and Upper Huronian of the adjacent Marquette district. The upper two series are present while the lower one is represented in both areas by fragments of some of its formations in the base of the middle series.

The absence in the lower series at Little Lake of the slate and iron formation members developed in the Gwinn synclinorium strengthens the evidence of the importance of the erosion interval which intervened between the deposition of the Princeton and Gwinn series. Incidentally it has a practical bearing on the possibilities for success attendant on drilling for iron ore in the immediate vicinity of the Little Lake hills. Some drilling of which the writers have no records, has already been done and we understand that additional drilling has been contemplated by parties who are likewise ignorant of the results of the former explorations.

CHAPTER XII.

RELATIVE TO AN EXTENSION OF THE MENOMINEE IRON RANGE EASTWARD FROM WAUCEDAH TO ESCANABA, MICHIGAN.*

R. C. ALLEN.

The Menominee Iron Range of Michigan, so far as known, includes a folded series of Huronian rocks trending a little south of east from the Menominee River in T. 40, R. 31 to the longitude of the village of Waucedah, Dickinson county, a distance of about 19 miles. The Lower Huronian is represented by a series of thick formations of quartzite (Sturgeon) and dolomite (Randville), the Middle Huronian (?) by cherty quartzite not exceeding 70 feet in thickness, and the Upper Huronian by a vast thickness of slate (Hanbury) overlain by volcanic green schists (Quinnesec) and carrying two productive iron bearing formations in basal horizons. The Huronian series lies unconformably on the Archean Complex.†

The areal distribution of the iron formation is shown on the accompanying figure 11.

It is reported that drilling a short distance west of the Menominee river in Florence county, Wisconsin, failed to locate the iron formation of the southernmost belt in the territory where it may have been expected to occur judging from its structure and strike between the city of Iron Mountain and the river. In the opposite direction the iron formations are overlapped by Cambrain sandstone in the vicinity of Waucedah. East of Waucedah the thickness of the Paleozoic rocks increases, presumably rather regularly, to about 800 feet in the vicinity of Escanaba.

It has been obvious for many years that the Menominee range Huronian series, including the iron formations, extends an unknown distance east of Waucedah beneath the flat lying Paleozoic formations. The magnetism of certain of the Huronian rocks, particularly (but not exclusively) the iron formation, furnishes the only means short of actual drilling or underground exploration by which they may be traced into the Paleozoic territory. Magnetic surveys of a part of the area east of Waucedah have been made by certain mining companies, and

*Published in Economic Geology, Vol. IX, No. 3, April, 1914.

†For description of geology of the Menominee iron range see Monograph 52, U. S. G. S. page 328-46.

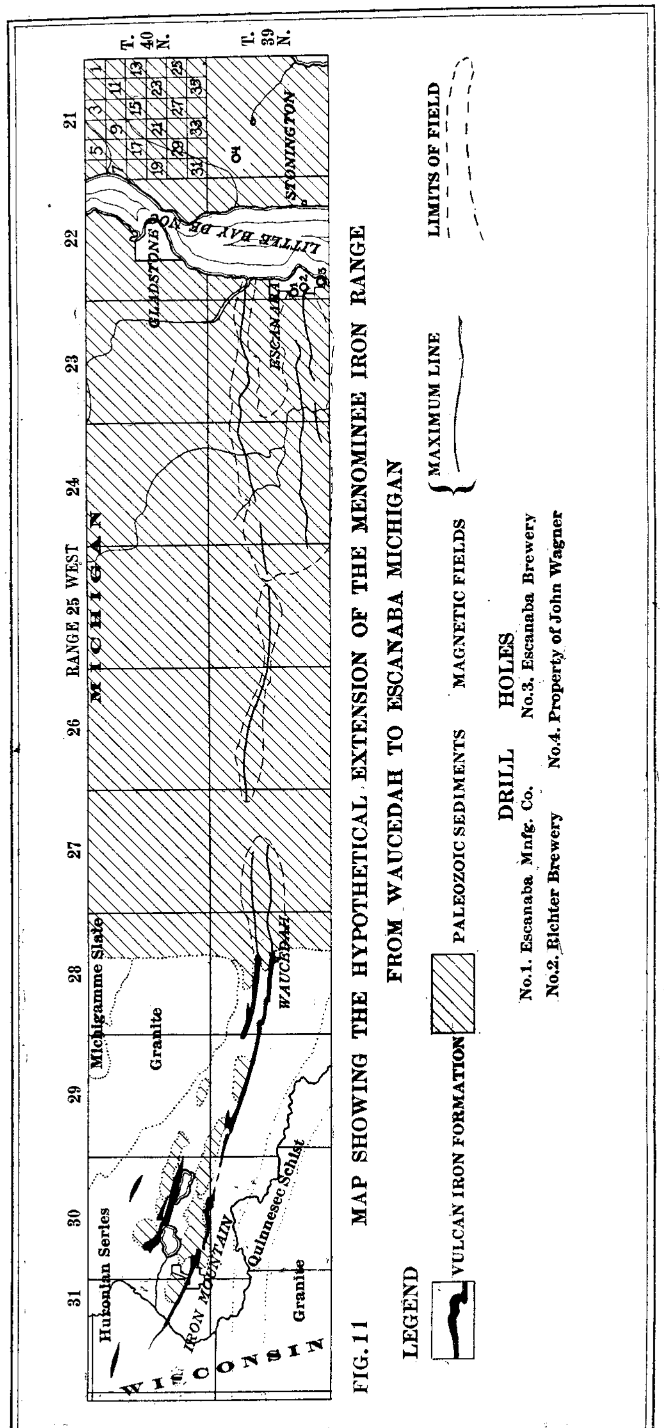

FIG. 11 MAP SHOWING THE HYPOTHETICAL EXTENSION OF THE MENOMINEE IRON RANGE FROM WAUCEDAH TO ESCANABA MICHIGAN

Figure 11.

the results of some of their work were placed at the disposal of the writer. The economic importance and scientific interest of the problem furnished the incentive to complete the magnetic survey of the range eastward to Lake Michigan.

The survey was executed in the field by L. P. Barrett, assisted for a portion of the time by H. J. Allen. Where information was available efforts were extended only to checking the accuracy of former surveys. The results are shown in a general way on the accompanying plate.*

CONCLUSION.

It will be seen that the magnetic belts which are coincident with the two separate belts of iron formation near Waucedah extend eastward without break for about six miles. The assumption that these belts have the same relation to iron formation beneath the Paleozoic rocks that they have to known occurrences at Waucedah and westward seems warranted. It is, however, unsafe to conclude that the magnetic belts further east to Little Bay de Noc are all or even partially underlain by iron formations of the ore bearing type of the Menominee range. From their general and linear-symmetrical characters it may be inferred that the magnetic rocks are folded sedimentaries and that they contain iron, at least partly, in the form of magnetite. But the magnetic beds may or may not be the stratigraphic equivalents of the iron formations of the Menominee range. In this connection the reported extension without break of a magnetic belt from the known iron formation at the opposite end of the range westward into magnetic slates, as shown by drilling, is instructive.

A recent drill hole in the general projection of the northernmost magnetic belt on Stonington Peninsula in the SW$\frac{1}{4}$ of the NW$\frac{1}{4}$ of section 8, T 39 N, R 21 W encountered dense, gray, vitreous quartzite similar to the Sturgeon (Lower Huronian) quartzite of the Menominee range after penetrating 780 feet of Paleozoic beds. It is reported that iron formation was penetrated at a depth of 732 feet at the Escanaba brewery, granite at 810 feet at the Richter brewery, and granite at 931 feet at the plant of the Escanaba Manufacturing Company, all in the city of Escanaba. There is little doubt that the above figures represent in each instance the approximate thickness of the Paleozoic rocks, but inasmuch as no records of the drillings were kept and no samples of the cuttings or cores preserved of the holes in Escanaba little credence should attach to the hearsay reports of the character of the underlying pre-Cambrian rocks.

From the evidence available it may be fairly assumed (1) that the

*Large scale plats showing the magnetic observations may be obtained on application to the state geologist, Lansng, Michigan.

magnetic belts mark the course of pre-Cambrian sedimentary rocks from Waucedah to Escanaba, (2) that these rocks contain magnetite, (3) that the magnetic beds are probably associated with other sedimentary formations which have little or no magnetism, (4) that it is not improbable that the succession and in a general way the structure of the pre-Cambrian beds may be closely related to those of the Menominee range west of Waucedah, and finally (5) that the occurrence of productive iron formation may be related in some degree and in some place or places between Waucedah and Escanaba to the magnetic belts. In advance of actual drilling operations no further assumptions are warranted.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

THE GEOLOGY OF LIMESTONE MOUNTAIN AND SHERMAN HILL IN HOUGHTON COUNTY, MICHIGAN.

E. C. CASE AND W. I. ROBINSON.

In southeastern Houghton county, there are three outliers of Paleozoic dolomite called respectively, Big Limestone Mountain, Little Limestone Mountain, and Sherman Hill. Big and Little Limestone Mountains lie half a mile east of the little station of Hazel on the Mass City branch of the Mineral Range Railroad, and directly north of the track. Big Limestone is a ridge a mile long and a half a mile wide running nearly north and south, and terminating in steep walls at its southern end. The western face rises abruptly 300 feet from the surface of the swampy land which surrounds the outliers but the eastern face slopes gently to the swamp level and is covered by a heavy growth of hardwood timber. Little Limestone lies south of Big Limestone and is separated from it by a deep irregular gully partly occupied by swamps and partly filled by glacial debris and talus. This hill is much smaller than Big Limestone, and runs NE-SW in contrast to the north and south trend of Big Limestone. It is also lower, rising but 150 feet from the swamp. The surface has been robbed of its timber by forest fires and the top is now under cultivation. The third and smallest outlier, Sherman Hill, is one and a half miles northeast of Big Limestone. It rises 150 feet above the swamp and is covered by a thick second growth of young hardwood. The dolomite appears as high bare cliffs on the northern and eastern part. All three masses of dolomite lie upon the Jacobsville Sandstone which forms the surface rock of the immediately surrounding country, and can be detected through the masses of talus at intervals along the bases of the hills.

The drift is locally thin around the hills, being mostly sand and gravel with a few scattered boulders. Long tapering slopes of drift extend from the southwestern, lee, sides of Little Limestone and Sherman Hill. The tops of the hills show little drift and no glacial markings were found in the few places where the dolomite appears through the soil and thick vegetation. Northwest of the hills a very heavy drift occurs in the valley of the Little Otter which has cut down through several hundred feet of red clay to the Jacobsville sandstone. The Jacobsville is here darker in color and composed of finer grains than at the outcrops beneath the dolomite of the hills, and as it is considerably lower topographically it is very possibly a lower member.

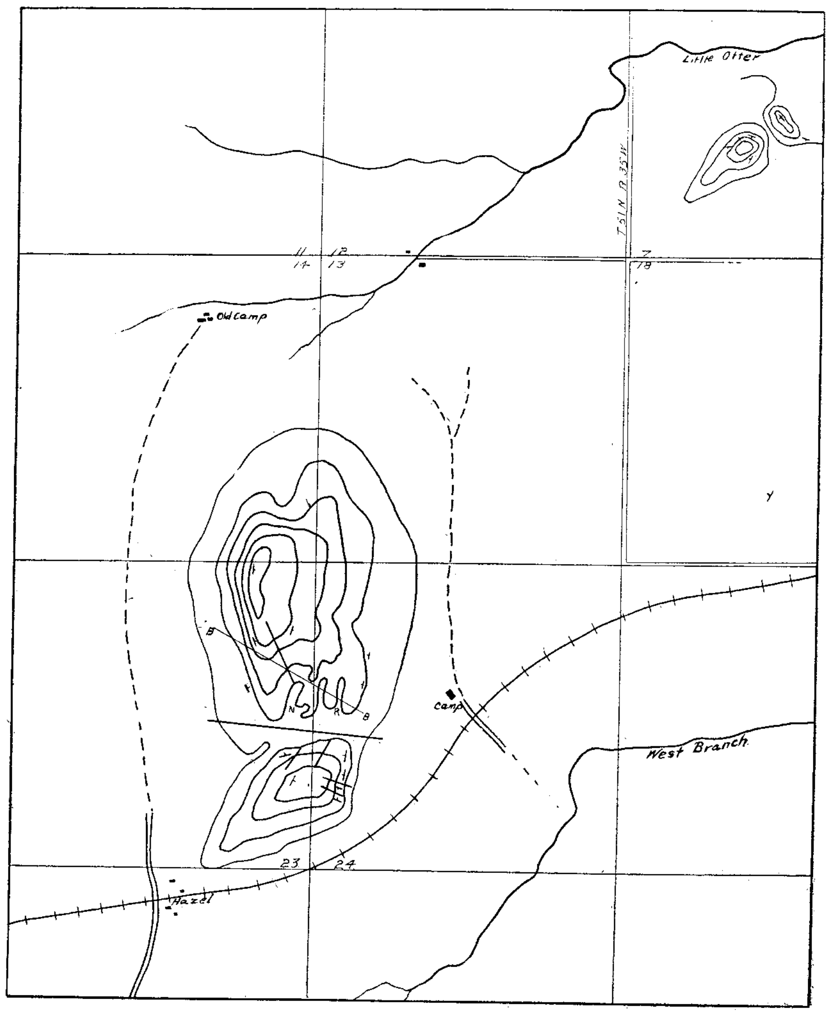

Figure 1. Limestone Mountain and vicinity modified from a map by W. L. Honnold and A. C. Lane. Contour interval 50 feet.

These outliers have been visited by several geologists who have reported variously upon their age and structure. C. T. Jackson*, in 1849, published a report upon the region in which he assigned the sandstone to the Triassic and considered it equivalent to the "New Red" of the Connecticut valley. He regarded it as overlapping the dolomite. He collected *Pentamerus oblongus* and so gave the age of the dolomite as Niagaran. His analysis of the dolomite is as follows:

Calcium Carbonate	44.49
Magnesium carbonate	44.65
Peroxide of Iron	1.98
Silica	8.91
	100.03

Foster and Whitney† in their "Report on the Geology and Topography of the Lake Superior Land District," established the correct position of the dolomite above the sandstone by observing the calcareous nature of the upper layers of the sandstone and the abundant sand grains and silica in the lower layers of the dolomite. They made a considerable collection of fossils which were submitted to James Hall for identification. His conclusion was that "The evidence from the whole together goes to prove that the rocks from which they were obtained belonged to the older Silurian period." The rocks were assigned to the Potsdam and Calciferous sandstones, the Chazy, Birdseye, and Black River limestones, and perhaps Trenton and even Hudson River groups. Hall lists the following fossils,

Maclurea.
Murchisonia or *Loxonema.*
Ambonychia (near *orbiculata* and *amygdalina*).
Modiolopsis (near *truncatus*).
Edmondia (near *subtruncata* and *subangulata*).
Edmondia (near *ventricosa*).
Leptaena sericea.
Orthis sp.
Glyptocrinus (stems).
Orthoceratites.

Dr. Carl Rominger‡ visited the locality and included a description of it in his report on the Upper Peninsula. He noted the very great disturbance, the complex faulting, and the varying dip of the layers

*31st Cong. Ex. Doc., No. 1, pp. 399 and 452, 1849.
†31st. Cong. Ex. Doc., No. 69, pp. 117-119, 1850.
‡Mich. Geological Survey, vol. 1, part 3, pp. 69-71, 1873.

of which he said, " . . . . . it appears to me more probable that there was an underwashing and sinking of the strata during the drift period rather than an actual upheaval of later date." He was essential in agreement with Hall as to the age of the beds and gave the following report on the fossils.

"In the lower ledges, casts of Bivalves and of Gasteropods are numerous, but not well enough preserved for determination; the same is the case with fragments of Orthoceras and Cyrtoceras. I have identified,

Orthis occidentalis.
Orthis testudinaria.
Orthis similar to *pectinella.*
Orthis lynx.
Rhynchonella increbescens.
Leptaena alternata.
Lingula quadrata.
Leptaena sericea.
Pleurotomaria lenticularis.
Subulites similar to *elongatus.*
Murchisonis major.
Bucania.
Ambonychia orbicularis.
Cyrtodonta subtruncata.
Nucula levata? larger than Hall's specimens.
Streptelasma corniculum.

The valve of a Brachiopod similar to the dorsal valve of *Orthis occidentalis*, but with the hinge line extended ear like, and exhibiting an internal septum like the ventral valve of a *Pentamerus*. A specimen of this kind may possibly have induced Jackson to mistake it for *Pentamerus oblongus.*"

In 1891 W. L. Honnold, then serving as geologist on the Michigan Geological Survey, spent some time in the vicinity and in connection with his studies made excavations at the base of the hills to determine the nature of the contact of the dolomite with the sandstone. He reported that the dolomite lay in apparently conformable contact with the sandstone which in his opinion forms a gentle syncline. He, also, noted that the upper layers of the sandstone are calcareous and the lower layers of the dolomite siliceous with no transition beds between the two. Unfortunately, Honnold's work has never been published but short abstracts have appeared.*

*Am. Jour. Sci., vol. 42, 3rd. Series, pp. 170-71, 417-19, 1891. Trans. Am. Inst. Min. Eng. vol. 27, pp. 684-85, 1897. Mich. Geol. Surv., Ann. Rep., p. 178, 1903.

In 1909 Lane† gave a further account of Honnold's work and an account of a visit by Hubbard, Seaman and Lane. This report included a map prepared by Honnold and the following list of fossils, which were identified by W. F. Cooper:

Orthoceras vertebrale.
Orthoceras undulostriatum.
Trochonema beloitensis.
Pleurotomaria subconica.
Orthoceras.
Orthoceras (vertebrale) darus.
Cypricardites ventricosus?
Cypricardites ventricosus.
Cypricardites obtusus.
Buthiatrephis.
Cypricardites megambonus.
Cypricardites niota.
Modiolopsis lata.
Cypricardites latus?
Cypricardites glabella.
Cyrtodonta billingsi.
Cypricardites amygdalinus.
Cuneamya subtruncata.
Pentamerus.
Rafinesquina alternata.
Orthis testudinaria.

In the summer of 1913, the authors spent six weeks working upon these outliers in an attempt to finally determine the age and structural relations of the beds. The work has not resulted in as definite conclusions as were hoped for, because the outcrops are largely obscured by heavy talus and a thick growth of vegetation which covers the hills, but it is believed that the information gained is as full as can be obtained in the present condition of the country. The dolomite layers have been much disturbed as is shown by the widely varying dips determined at various points of the outcrops. How this disturbance was caused is still problematical and certain tentative explanations are offered at the close of this paper.

STRATIGRAPHY AND CORRELATION OF THE BEDS.

From our sections and the fossils obtained, the following general section has been made out: (*Fig. 2*). The fossils were determined by

†Mich. Geol. Surv., pub. 6, Geol. Series 4, vol. 2, pp. 523-24, 1909.

GENERALIZED SECTION		
DEVONIAN	Middle	Thickness undetermined
SILURIAN	Niagaran Lockport	Thickness undetermined
ORDOVICIAN	Middle to Upper Richmond	Thickness undetermined
	Upper Part of Lower Richmond Arnheim	Thickness undetermined
	Lower Richmond	10 feet +.
	Upper Galena Stewartville	60 feet. Upper layers fossilliferous
	Decorah Upper Blue	20 feet.
	Upper Black River Upper Bluff	5 feet. at the top fossilliferous 75 feet below barren
CAMBRIAN	Jacobsville	100 feet exposed

Figure 2. The succession of the beds.

the junior author and finally submitted to Dr. E. O. Ulrich of the U. S. Geological Survey for revision and the determination of the exact horizons. For this, and for many helpful suggestions, we desire at this point to express our thanks to Dr. Ulrich.

IX. *Mid-Devonian.*—All that is known of this horizon is a single angular mass of chert, found in the talus on the southeastern slope of Big Limestone. It yielded four fossils:

Chonetes coronatus var.
Productella cf. navicella and spinulicosta.
Spirifer aff. Pennatus.
Cystodictya cf. hamiltonensis.

VIII. *Niagaran.* (Lockport).—A bed of very siliceous material was found on the south slope of Big Limestone (marked N on the map, see *Fig. 1*). It could not be traced a great distance up the slope and it was so badly broken that no satisfactory dip reading could be taken. No trace of such a layer was observed on the tops of any of the hills. The fossils collected are:

Streptelasma spongaxis.
Zaphrentis stokesi.
Duncanella? sp?
Clorinda cf. ventricosa.
Pentamerus sp.
Conchidium decussatum?
Dalmanella cf. elegantula.
Leperditia aff. cylindrica.
Loxonema sp.

VII. *Middle to Upper Richmond.*—Three fossils were found with the Niagaran material, the beds not being distinguishable:

Favosites asper.
Columnaria alveolata.
Plectorthis whitfieldi.

VI. *Upper part of the Lower Richmond.* (Arnheim).—At the locality marked R on the map, a single thin layer of dolomite was found. The rock was almost perpendicular but as it was in the zone of broken talus we cannot be certain that it was in place. The following fossils were found:

Crinoid columnals.
Coeloclema oweni.
Mitoclema minutum.

Mesotrypa patella.
Bythopora striata.
Rhynchotrema perlamellosa.
Rhynchotrema capax.
Conularia formosa.
Primitia cincinnatiensis.
Tedradella persulcata var.
Ceratopsis robusta.
Calymene a new species allied to C. *fayettensis* and C. *mamillatus,* Hall.
Conodont.

V. *Lower Richmond.*—A bed about ten feet thick, containing fossils of this age occurs at the top of Little Limestone and on the southeastern talus slope of Big Limestone. The matrix is a siliceous dolomite and the fossils are as a rule, silicified. The following fossils were collected:

Streptelasma rusticum?
Halysites gracilis.
Inocrinus aff. I. crassus.
Orbiculoidea? (Schizotreta) new species.
Rafinesquina new species.
Leptaena unicostata, two new varieties.
Plectambonites sp.
Plectorthis whitfieldi
Plectorthis kankakensis.
Dalmanella aff. rogota.
Dinorthis subquadrata.
Hebertella new species aff. H. insculpta, H. fausta.
Platystrophia sp.
Rhynchotrema capax.

IV. *Galena.* (Stewartville or Upper Galena). There is a heavy bedded cream colored dolomite which underlies bed V on Little Limestone, and occurs at the top of Sherman Hill. The fossils were found near the top of the layer which has a thickness of sixty feet. A list of the fossils collected follows:

Cyrtolites cf. retrorsus.
Liospira cf. angustata.
Hormotoma? major.
Lophospira minnesotensis.
Maclurea crassa.
Maclurina manitobensis.
Maclurina cuneata.

Trochonema umbilicatum.
Fusispira subbrevis.
Spiroceras sp.
Salpingostoma cf. expansa Hall, and buelli Whitfield.

III. *Decorah.* (Upper Blue). Below bed IV on the eastern face of Little Limestone there is an old quarry in a thin bedded dolomite. The top layers are gray, the lower layers cream colored with irregular spots of dark red iron stain. The fossils show that the two layers belong at the same horizon. A similar mottled layer carrying Decorah fossils, occurs at Sherman Hill, but here it shades up into the heavy dolomite without the thin bedded layer intervening. The following fossils were found:

Crinoid columnals.
Ceramophylla frondosa.
Trematopora? primigenia.
Halloporina crenulata.
Arthrostylus sp.
Arthoclema sp.
Rhinidictya mutabilis.
Rhinidictya fidelis?
Arthropora simplex.
Escharopora subrecta.
Escharopora confluens.
Streptelasma profundum.
Orthis tricenaria.
Strophomena incurvata.
Strophomena septata.
Dalmanella rogota?
Hormotoma salteri canadensis.
Aparchites sp.

II. *Upper Black River.* (Upper Bluff). At the extreme southwestern part of Big Limestone and eighty feet above the sandstone, there occurs a heavy bedded cream colored fossiliferous dolomite. The beds above and below are completely barren. The following fossils are found.

Ctenodonta nasuta.
Ctenodonta gibberula.
Endodesma? new species.
Cyrtodonta billingsi.
Cyrtodonta cf. billingsi new species.
Cyrtodonta cf. huronensis and subcarinata.

Cyrtodonta tenella.
Cyrtodonta new species.
Vanuxemia aff. niota Hall and subrotunda Ulrich.
Vanuxemia sp.

I. *Potsdam.* (Jacobsville). The lowest members of all the outliers and the only stratum which was observed at all three localities is a dull brown, coarse, poorly cemented sandstone with occasional streaks of a very fine conglomerate or very coarse sandstone. On Big Limestone and Little Limestone the pebbles of the conglomerate layer are of quartz, well rounded, and no larger than a pea. South of Sherman Hill, the conglomerate carries larger pebbles of greenstone and chert. This sandstone has been referred by Lane* to the Jacobsville Sandstone of probably Potsdam age.

STRUCTURE.

The dips in the uppermost of all the exposures show a remarkable diversity although there seems to be quite generally a dip toward the center of the outlier in each case. There is no suggestion of folding. Figure 2 shows the aspect of the southern slope of Big Limestone as seen from Little Limestone. The rocks forming the western face of Big Limestone dip quite regularly eastward. At the south end of the west face a dip of 30° E. 4° N. was obtained. Where the line between sections 14 and 23 crosses the cliff, a dip of 32°, E. 10° N. was found and between these two locations dips easterly were obtained varying from 14° to 20°. From figure 2 it will be seen there is great variation in the dip along the southern face of Big Limestone. The western block dips 20°, N. 60° E., east of this a block dips 14°, N. 51° E., and east of this still another block dips 50°, E. 5° S. Talus covers much

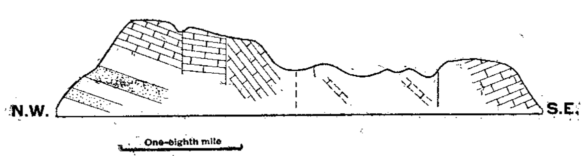

Figure 3. Cross section of southern slope of Big Limestone along B. B. (See map). The white areas indicate talus covered slopes. Vertical scale X 2.

of the remainder of the south cliff but readings were obtained which show that steeply inclined strata occupy the remainder of the section except at the eastern end where a block occurs which dips westerly at various angles. Readings of 21°, 22°, 28°, and 41° were obtained here.

*Jour. Geol., vol. 15, p. 680, 1907.

On Little Limestone a similar irregularity is noticeable. On the northwest cliff a large section of layer IV probably carrying layer V, has slumped away from the main cliff and lies with a dip of 31°, N. 64° E. South of this block on the west face there is a dip of 30°, E. 14° S. Other dips which were noticeable follow:

East face 35°, W. 18° N.
Northeast face 32°, W. 23° N.
Southeast face (Decorah beds) 34°, N. 30° E.

The beds overlying the Decorah and about 20 paces northeast of them 52°, S. 30° W.

These dips, and the dip of the layers of Sherman Hill, are plotted on the map (*Fig. 1*). That the faults which separate these blocks of varying dip are very minor, is proved by the slight displacement of layer IV which can be traced from the east side to the north side of Little Limestone in which distance there are two abrupt changes of dip.

There is evidence however, of a fault of larger importance between Big and Little Limestone. This evidence is mainly in a displacement of the Jacobsville sandstone and is presented in figure 3. From the

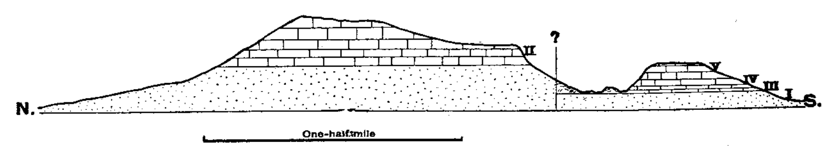

Figure 4. A generalized section of Big and Little Limestone. The vertical scale X 4.

swamp to the crest of Little Limestone is 150 feet. The dolomite has a combined thickness of 90 feet. If these layers are uniform and present under the whole mountain, there is 60 feet of sandstone above the swamp. In a similar way, Big Limestone rises 300 feet above the swamp. The dolomite is 140 feet thick leaving 160 feet of sandstone above the swamp. Allowing 20 feet for change in swamp level there is at least 80 feet difference in level between the sandstone of the two hills. Since these sandstones are lithologically identical, and there is a decided topographic break between them a fault is assumed to be present in the valley.

The succession of beds in Big and Little Limestone mountains, in the few cases in which the beds may be said to be approximately in place, is very different. In Big Limestone layer I, the Jacobsville, is followed by II, the Black River, while at Little Limestone I is followed by III, the Decorah, with not a trace of Black River between. The fossils of the Black River (layer II) were found near the top of Big Limestone, the highest point from which fossils were collected; below them topographically layers V, IV, and III were found apparently in place on Little Limestone (see *Fig. 4*).

From the foregoing account of the stratigraphy it is evident that several new points have been added to the geological history of Northern Michigan. Not only was the region covered by an Ordovician sea but by seas of Silurian and Devonian time as well. Ordovician fossils were discovered by Allen* near Iron River, Michigan and Silurian has been noted by earlier observers at Limestone Mountain, but this is the first time that Devonian fossils have been found in place or near their original position, so far north in the state. Our paleogeographic maps must so far be revised as to extend the Silurian and Devonian seas well into, if not over, the Northern Peninsula. The similarity of the Ordovician fossils with those of Minnesota and Wisconsin shows that the same sea reached from Michigan into these areas. Dr. Ulrich in a letter to the authors cites the peculiarity of the pentameroid forms and their similarity with forms found throughout the extreme western part of North America, indicating a wide connection of the Silurian sea in that direction.

The Devonian material is small in amount but so characteristic that there can be no doubt of the presence of marine waters in Mid-Devonian time. How far the Devonian sea and deposits extended over the Northern Peninsula is impossible to state. Our fossils were obtained from a large fragment on the southeast slope of Big Limestone, involved in the great talus from the lee of the hill, but its size, position, and angular condition, lead us to doubt that it has been transported any great distance, though it may easily have come from some region to the northeast of the dolomite hill. The heavy drift northwest of the mountains also may easily conceal remnants of Paleozoic deposits beyond any hope of detection. We consider it very doubtful that the Devonian deposits were originally connected with the nearest rocks of that age in Canada, in the vicinity of Lake Winnepeg and Hudson Bay.

HISTORY.

We are unable to propose any hypothesis for the preservation of these outliers, so far removed from the deposits with which they were originally connected. That the seas did not endure for any great length of time, is apparent from the relatively thin deposits and it may be that the northern peninsula was a region of limited sedimentation, toward the limits of the invading waters. The upper layers show no peculiar hardness nor consistency which would have enabled them to resist the degrading forces, and, as is shown below, the faulting does not account for the preservation.

*Mich. Geol. and Biol. Surv., Pub. 3, Geol. series 2, pp. 113-16, 1910.

While the hills discussed in this paper are the most remote outcrops of Paleozoic sediments later than the Cambrian known in Michigan, we cannot but believe that more of the same material is buried by the heavy drift to the northwest.

All obtainable evidence shows that the erosional history began, at the earliest, later than Mid-Devonian; how much later cannot be made out but considering the amount of material removed, and the completeness of the removal, we are inclined to the opinion that the region was exposed from sometime late in the Paleozoic.

As the preceding discussion shows, the layers are disturbed by numerous faults in an intricate manner. The fault between Big and Little Limestone is the largest that was detected, with a throw of at least 80 feet, with Big Limestone upthrown. Whether the steep cliff faces of Big and Little Limestone are fault scarps is less certain but this may be possible. The remaining faults are of minor character and importance, and may be accounted for by processes involving only very local conditions.

The fault between Big and Little Limestone.—This is the largest fault observed and throws more light than the others on the history of the hills. As has been shown before, layer II occurs near the top of Big Limestone. It is the lowest stratigraphically and the highest topographically of any fossiliferous bed. On the opposite side of the fault layer III occurs directly upon the sandstone. It is evident that the whole thickness, or nearly so, between the sandstones and layer III is missing on Little Limestone. This may be explained in various ways but because of the lack of evidence, the explanations which are offered are very tentative.

There is no doubt in our minds that the sandstone in the two hills is the same; texture, color, material, peculiarities of cross bedding and included layers of coarser sand grains leave no doubt on this subject This being true, we must suppose a lack of deposition of layer II on Little Limestone or account for its disappearance by erosion or solution. Under the first hypothesis, that of a lack of deposition on the site of Little Limestone, we would postulate an erosional irregularity of surface which permitted the deposition of a considerable thickness of Ordovician in the position of Big Limestone while the site of Little Limestone was occupied by an elevation not covered until much later by the invading sea. This idea is strengthened by the occurrence of a layer of dolomite, mottled by irregular spots of red, just above the sandstone wherever the sandstone and dolomite were together, irrespective of locality or stratigraphic position. This is seen on Big and Little Limestone, and Sherman Hill. The faulting took place along the edge of the elevation (see *Fig. 5*).

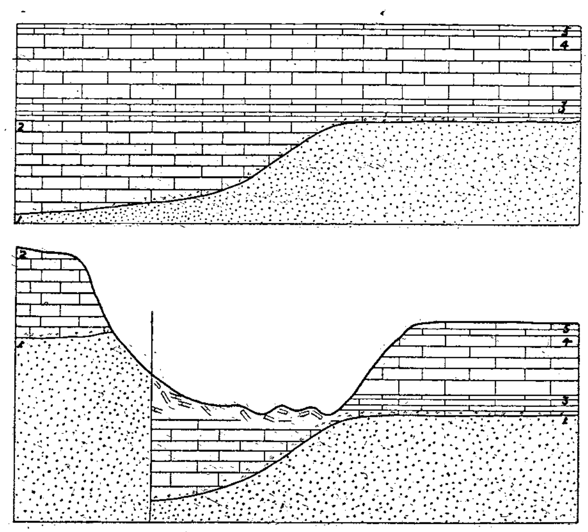

Figure 5. The upper figure shows a hypothetical progressive overlap. The lower figure shows the present condition due to faulting and erosion.

As alternative hypotheses, we may suggest the following: (1) the sandstone may be different in the two hills, that below layer II on Little Limestone being higher stratigraphically than that at the base of Big Limestone. This we regard as an impossibility for reasons given above. (2) The outcrops of layer III on Little Limestone may be large blocks fallen from a higher position because of undercutting and slumping of the layers. That such undercutting and slumping has occured at places on both hills in pre-glacial and glacial times is certain, but to assume it for layer II, ivolves the further assumption that the core of Little Limestone is formed by layer I, at least 80 feet thick, and since the whole hill does not rise over 90 feet from the sandstone, there is not room for such a core. It is very peculiar that no fossils of layer I were found on Little Limestone if any remnant of such a core exists. There is some possibility that Little Limestone has been split by a fault equal in throw, to the fault between Big and Little Limestone and parallel to it, and that the full series is represented on the east end of Little Limestone. One or two points support this suggestion. The east face of the north end of Little Limestone is very steep, descending abruptly to the swamp level. On the south end of the same face the slopes are less steep and there is a slight but well marked terrace indicating the position of the sandstone which outcrops here some distance above swamp level. This assumption of structure while possible is not less complicated than the one of an irregular surface of sandstone upon which the dolomite was deposited, and on the whole seems less satisfactory to us.

Layers VI, VII, VIII and IX are so irregular in position, and so evidently involved in the debris, that we are inclined to believe that they are not in position but attained their present attitude as landslides or slumps due to undercutting by surface or underground waters in comparatively recent times.

In our opinion these outliers have been broken both by major faults, which involve the sandstone below, and by minor faults or breaks, the result of erosional forces. Unfortunately our work does not throw much light upon the age of the great Keweenawan fault, the outliers do not approach near enough to the fault line to afford definite evidence. All that we can say safely is that there were considerable movements later than Mid-Devonian time, involving the Cambrian rocks.

In the preparation of this report the authors have had the advantage of a study of a manuscript "Report on the fossils of Limestone Mountain" prepared by Professor A. C. Lane while he was State Geologist of Michigan.

In conclusion the senior author wishes to state that most of the field work was done by the junior author and that to him is largely due the credit for the discovery of the wide extension of the Paleozoic seas over the Northern Peninsula of Michigan.

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