The author also notes the existence of a range of limestone hills north of Lake Fumee and an outcropping of quartzite south of it. The quartzite is considered to be identical with the upper quartzose beds of the limestone formation, and not to be equivalent to the lower quartzite at the Falls of the Sturgeon River.

This limestone ridge, surrounded on both sides by low, swampy lands, is directly north of the limestone belt which underlies the ore formation at the Norway and Stephenson mines, a little over a mile apart from it, with a swamp valley between them. Both belts dip to the south. We must therefore either suggest a rupture of the rock belt in the intervening space, or an intervening synclinal trough connecting the two. The same correspondence in dip exists between the limestone bluffs on the roadside near Quinnesec and the equivalent quartzose belts on the north side of Lake Fumee; but in that case we can prove by natural exposures the occurrence of a repeated plication of the rock belt in the intervening space. Besides the locality already mentioned in which this plication of the beds is seen, there is another one handy for observation in the southeast quarter of the northeast quarter of sec. 34, on the roadside to Lake Antoine, where the limestones dip northward in anticlinal position with the more southern outcrops. An anticlinal position exists also between the limestones exposed in the south slope of the Quinnesec ore range and those on the north slope of the range dipping under the bed of Lake Antoine, and great probability exists for the occurence of a synclinal trough of limestone in the place where the basins of Lake Antoine and Lake Fumee are now [p. 181].

Recapitulating the so far ascertained facts, we have become acquainted with three distinct groups of rock, one succeeding the other conformably, or at least in direct superposition on the other. The most southern, seemingly uppermost, is a series of dark, gray-colored slaty or schistose beds, with interlaminated quartzose belts, amounting to a thickness of perhaps over 2,000 feet, which I will call the *Lake Hanbury slate group*. A second group next succeeding it consists in the upper part of light-red, or whitish, or gray-colored, hydromicaceous and argillitic strata; in the lower, of siliceous beds richly impregnated with iron oxide in the amorphous hematitic condition, or in the crystalline form of martite, with metallic luster, which lower series incloses seams almost exclusively composed of martite granules, constituting the economically valuable ore deposits. This group I will name the *Quinnesec ore formation;* it amounts to a thickness of not less than 1,000 feet, but locally, perhaps, it is much thicker. The third group is formed of a series of light-colored quartzite and limestone beds of a siliceous character, usually in part of a brecciated structure, and also amounting to at least 1,000 feet in thickness, which I will call the *Norway limestone belt*. All these strata are upheaved in a certain axial direction, which is about west-northwest, and dip southward, if we consider them as a body, and overlook folds of the strata and other local irregularities [p. 182].

The author is not certain that the succession here given and the succession as marked out to the north and to the south of this known belt is correct, because of the difficulty of deciding properly as to the relative positions of the rock beds, on account of folding, faults, and the covering of critical areas by drift.

North of the limestone, in the southwest quarter of sec. 7, T. 39 N., R. 28 W., the author finds an occurrence of siliceous specular flag ores dipping southward under the limestone, which also has a southern dip. Again, north of the Norway mine is a belt of micaceous slaty argillites over 200 steps in width, and in the southeast quarter of the southeast quarter sec. 32, T. 40 N., R. 29 W., is a series of siliceous flags, argillites, and quartzose beds, consisting of alternating narrow bands of a jaspery quartz and of a compact siliceous iron ore. North of this bed again is a bed of graphitic slate 8 feet wide, beds of banded micaceous quartz-schists, and again graphitic slates. This recurrence of beds to the north of the principal iron-bearing formation is explained as due to a synclinal trough, supposed to exist in the limestone. This supposition requires the turning over of the series as usually seen. To quote the author:

The hitherto described rock series of the Menominee iron range allows a much more simple and harmonious explanation of its structure if we suggest a synclinal trough of limestone in this place and revert the generally observed order in the superposition of the rock beds, considering the most southern, apparently highest rock beds of the Lake Hanbury series as the lowest, directly succeeding above the diorites south of the Menominee; next higher would be the iron formation, and highest or youngest the limestone formation and strata north of it. This order is actually exhibited on the east side of Sturgeon River * * * and in the Chapin mine and Quinnesec mine. In all other described localities, according to this theory, which I believe to be the fact, the strata have been placed in an overtilted position by the upheaval acting most powerfully from south to north, whereby the limestones came to lie beneath the others, and were by me at first mistaken for the oldest in the succession [p. 186].

Immediately north of Pine Creek, in T. 40 N., R. 29 W., are ridges of quarzite, and north of them, and apparently in discordant contact with the quartzites, are bluffs of granite. This great quartzite, over 1,000 feet thick, begins in sec. 10, T. 39 N., R. 28 W., and runs westward in an almost continuous ridge to the Falls of the Sturgeon River and beyond for the distance of a mile or so. Of the limestone belt shown in Major Brooks's map south of the falls Dr. Rominger did not see the slightest evidence.

The relations between the quartzite and granite at the falls are thus described:

The bed rock of the falls is granite, which evidently forms here an arched, bubble-like protrusion, dipping, in all directions; the sedimentary strata above this bubble have likewise been pushed aside with the same irregularity. They have in places become entangled between the granite, and seem to dip under it, but the same ledges are seen in another place dipping in a different direction and to lie above the granite. * * * Interstratified with the granite are belts of dark diorite-like rock, consisting of quartz, white, probably anorthic feldspar, and of a large proportion of black mica. * * * In intimate, seemingly conformable contact with the granite occurs a series of schistose beds, which are exposed at the foot of the falls in an almost vertical position, but they seem to be in an anticlinal position on the two sides of the river. On the west side are stratified red-colored feldspathic rocks, crowded with granules of magnetite and with iron pyrites in small cubes; with them occur narrow seams of a rich granular magnetic ore contaminated with iron pyrites. This belt amounts to about 8 or 10 feet, and the strata dip under the granite. Next and below it is a rock belt, 10 feet wide, of schistose, feldspathic, and sericitic beds; then comes a seam of compact, finely granular,

red feldspar 20 feet wide. * * * Under it succeed silky, shining gray sericite-schists, with a feldspathic groundmass; then a break in the formation occurs, and the same feldspathic sericite-schists dip in an opposite direction, away from the granite, and farther on in this direction we soon come to quartzite ledges, apparently incumbent on them. On the east side of the river we find similar hard sericite-schists, with interlaminated granular feldspar seams, and with several belts [of] a coarse conglomerate rock formed of red granite pebbles and of white quartz pebbles, some of them opalescent. The cement is the schistose sericite. Some of the granular feldspathic beds of the schists are distinctly ripple marked. Going across this schistose belt, which amounts to about 100 feet, we come again into granite, which seems to be in conformable contiguity with the schists. We have here evidently a series of sedimentary beds deposited on a granitic substratum, which during the upheaval became wedged in between the plastic granite mass, tilting and overlapping them locally, so as to appear as the lower beds [pp. 190-192].

North of the falls for miles nothing but granite was seen, except where this rock is replaced by gneiss and is cut by “doleritic” and other basic dikes.

Passing to the green schists exposed so abundantly on the Menominee River, the author recounts their occurrence in order, beginning with the outcrops at Twin Falls. The greenstone-schist or diorite formation is rarely in contact with the iron formation, and even when in contact the relations between the two rock series are not clearly ascertainable.

* * * The dioritic rocks generally play the part of an intrusive rock with regard to the strictly sedimentary rock beds of the Huronian series. A superposition of the diorite formation on the Lake Hanbury rock series, which adjoins it the whole length of the Menominee Valley from the Upper [Big] Quinnesec Falls to the Sturgeon Falls, asserted by Major Brooks, is not observable; the nearly vertical strata of both formations are even never seen in contact. There is always quite a large covered interval between them. The nearest exposures of the two groups are observable in sec. 26, T. 39, R. 29, where, in the center of the section, a hill is formed of the vertical ledges of ferrugino-siliceous flagstones and slaty beds representing the Lake Hanbury series, and about two or three hundred steps from these exposures we find, on the south side of the road to Menominee, small hillocks of diorite. * * *

My reasons for holding the dioritic rocks south of the iron formation as older than the latter are based on the lithological similarity of this formation with the dioritic group of the Marquette district, and on the degree of metamorphism exhibited by the two groups, the dioritic and the iron-bearing. In the great succession of strata commencing with the Hanbury slate group and upward, we rarely find a bed so much altered that its sedimentary structure is altogether obsolesced, and the majority of the strata shows it very plain, while in the dioritic rocks, considered to be the younger, a stratified structure is also recognizable, but not one of these thousands of feet of ledges exhibits its original sedimentary lamination with any degree of distinctness like the others; they have evidently been transformed under cooperation of heat and partially brought into a plastic condition. * * * One might object: If the diorites are the older beds, why don’t we find them just as well developed on the north side of the upheaved beds, between the quartzite and the granite? The sandy and conglomeratic nature of many of the strata of the quartzite and iron formation proves them to be shore deposits, while the dioritic group consists only of the finer material of deep-sea deposits, which explains the point in question. Moreover, the dioritic rocks are not altogether missing on the north side of the ore formation, as we can see by the occurrence of the 6-mile-long chain of diorite extending eastward from the Twin Falls. * * *

The equal dip of the strata to the south in these adjoining formations is not necessarily proof of the younger age of the most southern beds. The whole succession is so near to a vertical position that in many instances it has been left uncertain which way they dip, but suppose their dip is conformable to the south; the upheaval of the diorites by the eruption of the still more southern granite masses pushing the whole incumbent rock series north until all tipped over, is the hypothesis by which I explain the succession of beds as an inverted one, the seemingly lowest beds being actually the youngest [pp. 208-210].

The author describes the exposures along the Menominee River in detail as fine- and coarse-grained greenstone-schists, micaceous chlorite-schists, light-colored, grayish-green porphyritic schists containing well-formed orthoclase crystals, micaceo-feldspathic seams, and beds of pale-red schists composed of orthoclase, hydromica, and quartz, etc. At the Big Quinnesec Falls are also massive diorites. These and the diorite-schists have the same composition, and neither, according to the author, should be classed with the diabases. The whole series of rock beds exposed at these falls “evidently represents one inseparable group of altered sedimentary deposits formed from bottom to top of the same material, in different molecular form and different proportion in the intermixture of the component mineral substance” (p. 214).

The rocks at the Little Quinnesec Falls and at the Sturgeon Falls are similar to those above described. Some little distance below the mouth of the Sturgeon River are said to be exposures of serpentine, and below these are great outcrops of feldspar, porphyries, granites, etc., some of which are thought to be like the granite and porphyry dikes cutting the greenstone schists of the “diorite group” in the Marquette district.

Reviewing what we have seen of the formations along the Menominee River, said to be the youngest of the Huronian group, I again point out the great similarity in the composition and structure of this very large series of rocks with the dioritic formation of the Marquette district; also its intersection by the serpentine group, which in the Marquette district is under similar circumstances associated with the diorite formation. Further in favor of this analogy is the intersection of the Menominee diorites by porphyritic granite in dike form, as is the case with the diorite group of Marquette. These porphyritic granites are in their part in close relationship with the felsite porphyry of the Pemenee Falls, merging by insensible gradations with the granite, which is only a more completely crystallized form of the same lava mass. On the other hand, there exists not the slightest resemblance between the dioritic rock belt of the Menominee River and those rock beds of the Marquette district which represent subdivisions 15 to 20 of Major Brooks.

The exact order in which the different rock masses composing the dioritic formation succeed each other—whether the dark-green diorites of the Twin Falls and in other places are the lowest and the lighter-colored diorites at the Quinnesec Falls

the higher ones—is at the present state of our knowledge uncertain, but it is most likely the case; so the dark-colored, coarsely crystalline hornblende rocks exposed a mile above the Pemenee Falls may be older beds than those at the Quinnesec Falls. The massive belts of this series of altered sedimentary rocks, interlaminated with the schistose members, can, as I think, not all be considered as regular links in the stratified succession; some of these, and particularly the larger masses, as they occur at the Quiver Falls, I believe to be intrusive, in the same qualified sense in which I have considered some of the massive dioritic rock belts of the Marquette district, and still in another sense they represent only a more altered portion of the stratified beds connected with them. Considering the granite on the south and west side of Menominee Valley as an eruptive rock, like the porphyry of the Pemenee Falls, I can agree fully with Major Brooks in this part of his chronological system; these rocks undoubtedly came to the surface after all the other Huronian strata of sedimentary origin were formed, as their eruption to the surface caused the upheaval of the others. I therefore have always represented the dike granites of the Marquette district as actually the youngest rocks in the group, but I suppose this was not the original meaning of Major Brooks's system. In all his stratigraphical descriptions he has not made a proper distinction between sedimentary succession and interstratification, counting up the beds just as they came in a crosscut; his groups VII, IX, and XI are a proof of this assertion [pp. 221-222].

In conclusion the author compares the rocks of the Menominee with those of the Marquette district, all of which are regarded as Huronian in age.

1883.

IRVING, R. D. Iron ores: Geology of Wisconsin, Survey of 1873-1879, vol. 1, pt. 3, pp. 613-636. 1883.

After describing in general the iron ores found in Wisconsin, Irving describes briefly the geology of the different iron-ore districts. In the Menominee district the principal Huronian rocks are said to be hornblendic and micaceous schists, clay slate, chloritic schist, actinolitic schist, limestone, diorite, diabase, and iron ore. The diorite and diabase are thought by the author always to be of eruptive origin, and to occur in part as interbedded contemporaneous flows and in part as intrusions. The schists are intricately folded. Any mapping of the folds must be in a large measure hypothetical, because of the numerous faults by which the beds are crossed and because of the existence in them of masses of eruptive material.

The ore bodies of the range are irregular, lens-shaped masses or portions of the belt richer than the rest. These lenses, with one or two exceptions, differ from most of those met with in the Marquette region, in that the latter are distinctly intercalated, the beds above and below them closing about them, while in this case the iron oxide simply impregnates certain areas of the stratum, whose subordinate layers continue undeflected through the ore bodies. The ores are of the peculiar "soft specular" variety already noted as found only in the Menominee region [p. 621].

There are two ore horizons in the district according to Brooks, the lower of which was numbered VI in the series. This is the horizon on which all of the Michigan mines are located. The second horizon is higher in the series, but its exact position is unknown.

On a later page in the same article several analyses of Menominee ores are given, most of them being copied from Wright's report.

CREDNER, H. Elemente der Geologie, pp. 400-410. Leipzig. 1883.

Credner divides the pre-Cambrian formations into the Urgneiss formation (the Laurentian) and the Ur-Schiefer formation (the Huronian). In the latter he places the Menominee rocks, stating that the dolomitic limestone in this district is near the lower limit of the series. He gives a section across the district from north to south, which is a copy from his paper on this district. The Ur-Schiefer formation in the Menominee, as well as elsewhere, is unconformable under Lower Silurian sediments. In this district the iron ore is overlain in places by sandstones and conglomerates, which are found sometimes extending down into cracks in the ores. A section is published to illustrate this relation. A few other references are made to the Menominee rocks in the author's discussion of the Archean, but nothing new is recorded concerning them.

IRVING, R. D. The copper-bearing rocks of Lake Superior: Mon. U. S. Geol. Survey, vol. 5, pp. 392-400, with maps, including a general map of the Lake Superior region. 1883.

In connection with his discussion of the Keweenawan rocks, Irving briefly describes the characteristics of the lithology of the Marquette and of the Menominee Huronian. The rocks belonging to these series afford, at first glance, a strong contrast to the Penokee Huronian. Close study, however, shows that there is a general stratigraphical equivalence between the three series, and perhaps even a direct connection between them. The author compares the different series and shows their points of resemblance and of difference. The diorites of the Marquette and Menominee regions he suspects to be altered diabases. The granite of the Menominee district has not been satisfactorily shown to be Huronian. It may be eruptive. Many of the less common kinds of rocks in the Marquette and Menominee districts are thought to be due to metamorphic changes, which may be connected with the complex folding observed.

In the Menominee, as well as in the other Huronian areas, the Huronian schists are limited by granites and gneisses. Usually the latter rocks are unconformably beneath the schists and in all cases, save that of the so-called Huronian granite in the Menominee district on the south side of the Menominee River, the granite and gneiss complex plainly rises from beneath the schists. Most of the crystalline schists associated with the granites and gneisses are older than the Huronian schists.

1884.

WINCHELL, N. H. The crystalline rocks of the Northwest: Am. Nat., vol. 18, pp. 984-1000. 1884.

In this article there is nothing new concerning the geology of the Menominee district. The author simply classes all the crystalline rocks of the Lake Superior region into six groups and states his views as to the equivalency between these groups and those established by other waiters on the different crystalline areas of the Northwest, among which is included the Menominee area.

IRVING, K. D., and VAN HISE, C. R. On secondary enlargements of mineral fragments in certain rocks: Bull. U. S. Geol. Survey No. 8. p. 39. 1885.

One of the specimens described by the authors to illustrate their contention that fragments of minerals in clastic rocks are often enlarged by the deposition of secondary material around them is from the bed of Cambrian sandstone immediately above an unconformable contact with Huronian iron ores at the Cyclops and Norway mines, near Norway, in the Menominee district. It is described as—

a very much indurated, buff to brown sandstone—at times almost a vitreous quartzite. The thin section is composed almost entirely of interlocking grains of quartz each with its distinctly outlined fragmental core. There is a little independently deposited interstitial quartz and a little fragmental feldspar.

WHITNEY, J. D., and WADSWORTH, M. E. The Azoic system and its proposed subdivisions. Bull. Mus. Comp. Zool. Harvard College, vol. 7, pp. xvi and 331-565. 1884.

One paragraph in this volume which is an argument in favor of the indivisibility of the pre-Cambrian formations criticises Rominger's views relating to Menominee geology. The authors declare that Rominger's—

idea that the Marquette and Menominee schists are Huronian means nothing beyond this, that they appear to him to be lithologically similar to the rocks called Huronian in Canada; while so far as his actual work goes he reaches conclusions regarding the relations of the granitic and schistose rocks indentical with those advocated by Foster and Whitney thirty years ago. The result of Rominger's work is decidedly opposed to the division of the Michigan Azoic into two or more formations [p. 494].

1885.

SWANK, JAMES M. Iron ores in the United States: Mineral Resources U. S. for 1883-84. 1885.[a]

In his summary description of the iron-producing districts of the United States the author declares that the Menominee district ranks second in productiveness to the Marquette district. About 1876 the Menominee Mining Company of Milwaukee obtained control of a large extent of country in this portion of Michigan and at once began active operation. In 1877 only 10,405 tons of ore were shipped, but thereafter the output increased rapidly, until in 1882 it rose to 1,032,611 tons, falling in 1884 to 698,047 tons. The Chapin mine was the largest producer in the entire Lake Superior region in 1883 and 1884, its product being 265,830 tons in 1883 and 290,972 tons in 1884. The ores are generally red hematites, partaking of the same general characteristics as the similar ores of the Marquette district, except that they are, as a rule, softer. Analyses of specimens of ore from the Vulcan, Cyclops, Norway, and Quinnesec mines are given (pp. 265-266).

IRVING, R. D. Preliminary paper on an investigation of the Archean formations of the Northwestern States: Fifth Ann. Rept. U. S. Geol. Survey, pp. 175-242, with general map of Lake Superior region. 1885.

The problems that confront the investigator of the ancient rocks of the Lake Superior region are outlined by Irving in this paper and the progress made in solving them is stated. General descriptions are given of the series of supposed Huronian rocks in the different areas, among them descriptions of those occurring in the Marquette and Menominee areas, which are grouped together.

Their rocks are highly folded and their structure is often very difficult to work out. Moreover, the metasomatic changes which the crystalline members of the series have undergone have often been extreme, added to which difficulties are frequent interruptions by drift covering.

[a] "Mineral Resources of the United States" has been published annually by the United States Geological Survey since 1883. Up to and including the year 1894 it appeared as an independent publication. Later it was published as part of the "Annual Report of the Director," and beginning with the year 1900 it is again issued as an independent report. It contains statistics of the ore production in all the mining districts within the United States and occasionally descriptive notes concerning these districts. In this monograph only those volumes will be referred to which contain new information of geological interest concerning the Menominee district.

The greenstone-schists and the greenstones at the Big Quinnesec and the Little Quinnesec Falls are believed to be eruptive, the schists "representing merely an extreme degree of metasomatic change, which in some measure has influenced all the greenstones."

While declining to acknowledge the possibility of establishing a scheme of stratigraphy for these districts without the aid of good maps, Irving thinks that there is no question that Brooks's scheme is faulty with respect to the various greenstone layers included among the sedimentary beds. These greenstones are believed by Irving to be altered basic eruptives, some of which are contemporaneous flows, and others intrusive masses. The jaspers and ores of the Menominee, like those of the Marquette district, are believed to be of sedimentary origin. In the Menominee district much of the silica in the jaspers is chalcedonic, and many great belts of ferruginous rocks seem to be mainly composed of it. The Menominee area is thought to connect westward with the area of the upper Wisconsin Valley, but detailed mapping of this westward extension had not been completed when the author wrote his paper.

One plate in the report illustrates an unconformity between the ores and the Potsdam sandstone at the Cyclops mine, Norway.

In the petrographical portion of the paper the author refers to the existence in the Menominee district of clay slates, some of which are finegrained graywackes in which the feldspathic ingredients are largely represented by kaolinized material, while others present distinct gradations into true mica-slates and mica-schists, in which at least a considerable proportion of the material is of original crystallization. Other rocks are also described, but only the limestones are referred to as existing in the Menominee district proper. The cherts, however, are mentioned as being in part at least of direct chemical origin. All the quartzites in the Huronian are thought to be—

> merely sandstones which have received various degrees of induration by the interstitial deposition of a siliceous cement, which has generally taken the form of enlargements of the original quartz fragments, less commonly of minute independently oriented areas, and still less commonly of an amorphous or chalcedonic silica, two or even all three forms of the cementing silica occurring at times together in the same rock * * *. It appears that they have undergone no other alteration than that found to affect sandstones in the newer, undisturbed, and generally unaltered formations [p. 236].

1886.

IRVING, R. D. Origin of the ferruginous schists and iron ores of the Lake Superior region: Am. Jour. Sci., 3d series, vol. 32, pp. 255-278. 1886.

Although the argument in this paper is based particularly on observations made in other districts, the author, nevertheless, refers to the Menominee ores as having resulted from the alteration of an iron carbonate whose origin was sedimentary. The Menominee rocks are much folded, like those of the Marquette region, and in them the alteration of the carbonate has proceeded much further than in the unfolded series of the Penokee and other districts. In these districts all the phases of the altered carbonates are met with, but the quantity of unaltered material is much less than it is in the less folded rocks. The process by which the alteration has been effected and the proof that this alteration is responsible for the existence of the ores need not be referred to in this place. An account of these discussions is given in the literature chapter of the Marquette monograph.[a]

The author refers to the Menominee iron-bearing series as being so folded that the rock belts for the most part are in an approximately vertical position. The most abundant of the ferruginous rocks are cherty schists charged with varying quantities of magnetite, hematite, and brown oxide of iron, and containing more or less iron carbonate. These schists graduate into graphitic and carbonaceous slates that are sometimes highly contorted and at other times are nearly free from contortions.

> These contortions have no parallel in the adjoining layers, and often seem to have little relation, in axial directions, to the general system of folding of the strata. They are taken to indicate the relatively great resistance to folding offered by these schists, on account of the siliceous induration they received prior to the folding process [p. 265].

The iron carbonate occurs in the schists as an original ingredient in varying proportions. Actinolite is present in some of them. The siliceous matter in them is more commonly cherty or flinty than jaspery, but at times it is jaspery over large areas. The iron ores lie in these schists, not as lens-shaped masses around which the schists bend, but as irregular bodies lying directly in the course of the schistose banding or as layers within the schists. The ores appear to have originated in one of two ways, or in a combination of them, viz, from direct oxidation of the bands of carbonate in place, and from deposition within the schist of oxide of iron from percolating waters. All the indications point to the derivation of both ferruginous rocks and iron deposits by a process of silicification from stratiform shales impregnated with carbon and iron carbonate.

[a] Mon. U. S. Geol. Survey, vol. 28, 1897, pp. 5-148.

PUMPELLY, R. Report on the mining industries of the United States (exclusive of the precious metals), etc. Rept. Tenth Census U. S., vol. 15. With maps. 1886.

PUTNAM, BAYARD T. Notes on the samples of iron ore collected in Michigan and northern Wisconsin. Rept. Tenth Census U. S., vol. 15, p. 421. 1886.

In his introduction to the discussion of analyses of Menominee iron ores Putnam gives a brief outline of the geology of the Menominee district. He recognizes two belts of iron-bearing rocks, as did Brooks before him. The Southern belt embraces the region now known as the Menominee district. Since the completion of the Chicago and Northwestern Railway to Quinnesec in 1877 the mines on the eastern portion of the Southern belt have been extensively wrought, yielding, as Pumpelly declares in his introduction to the general discussion of the iron ores, 491,347 tons during the census year 1880. The ores consist—

> principally of a soft, specular, blue hematite, which runs high in iron and low in phosphorus. Although quite soft, the ore usually resists hydration and rarely changes color except in handling. * * * When examined fresh from the mine the ore is seen to be made up of innumerable fine crystalline particles of specular hematite, which are somewhat loosely agglutinated. * * * The ore usually occurs in irregular pockets or lens-shaped masses in a banded quartzose ferruginous schist, which is often magnetic [p. 437].

Sketch maps of the Emmett and Breen mines, of the Vulcan, the East Vulcan, the Curry, the Saginaw and Stephenson, the Norway, the Quinnesec, the Chapin, the Ludington, and the Cornell mines, and sections through many of them, illustrate the paper. At the Emmett mine the ores consist of an upper blue variety and a lower brown variety, both of which dip southward under a swamp. The blue ore is protected from the action of the swamp water by a covering of clay, while the brown ore is saturated with ground water which rises through the underlying schist. The blue ore contains but 0.008 per cent of phosphorus, while the brown ore contains 0.103 per cent of this element. At the Vulcan mine the ore lens dips south and pitches west. One of the ore samples from this mine contains a small

proportion of titanium, thus proving an exception to the Menominee ores in general, which are usually free from this metal. In one of the pits of this mine the ore is overlain by a ferruginous siliceous schist, which is so richly impregnated with iron near the ore body that it sometimes itself constitutes a lean ore. At the Norway mine the ore is between a foot wall of soap rock and a hanging wall of "conglomerate ore," composed of irregular angular pieces of hard specular ore cemented by soft brown hematite.

1887.

BIRKINBINE, JOHN. The iron ores east of the Mississippi River: Mineral Resources U. S. for 1886, pp. 65-67. 1887.

The author gives a brief history of the operations in the Menominee district since 1877, describes the work done at the Hamilton mine, and furnishes the usual statistics of the output of the principal mines on the range as well as of the district as a whole.

IRVING, R. D. Is there a Huronian group? Am. Jour. Sci., 3d series, vol. 31, pp. 204-216, 249-263, and 365-374. 1887.

In this article Professor Irving gives his reasons for regarding the series of nonfossiliferous sediments lying between the top of the Archean crystalline schists and the bottom of the Potsdam sandstone in the Lake Superior region as worthy of being considered a distinct system coordinate in importance with the Paleozoic, etc., with the Huronian as a distinct group in the system. The arguments made use of have been outlined in the Marquette monograph.[a] In his description of a section through the Menominee district, the author declares that the chief difference existing between the Marquette and the Menominee rocks lies in the much closer folding of the latter. All the arguments that apply in favor of the existence of the two formations in the Marquette district apply also in the Menominee district. A more detailed elaboration of the arguments is given in the paper on the classification of the pre-Cambrian formations, referred to below.

1888.

IRVING, R. D. On the classification of the early Cambrian and pre-Cambrian formations; a brief discussion of principles, illustrated by examples drawn mainly from the Lake Superior region: Seventh Ann. Rept. U. S. Geol. Survey, pp. 365-451. With maps, including a general map of the Lake Superior region. 1888.

[a]Mon. U. S. Geol. Survey, vol. 28, 1897, pp. 110-112.

The main portion of this paper is a discussion of the value of unconformities in classifying nonfossiliferous sedimentary beds. The illustrations taken from the Lake Superior region afford examples of great unconformities in all the areas that have been recognized as Huronian.

In the Menominee district there are many outliers of the Potsdam sandstone reposing horizontally on the upturned edges of the Huronian schists. A picture (p. 410) illustrates the appearance of a contact of sandstone on the steeply inclined beds of the iron-bearing schists near Norway. At the immediate contact of the two series the sandstone is filled with fragments of the schists. The iron-bearing rocks are thus demonstrably older than the sandstones.

Beneath the Huronian is another series of rocks, comprising granites, gneisses, and hornblendic and micaceous schists. These rocks are closely folded, and upon them, in eroded basins, the Huronian schists are deposited. The upper series is a relatively little-altered iron-bearing series and the lower one a deeply altered series of gneiss and schists, cut by immense masses of intrusive granite. There is evidently a great discordance between the two series—a discordance that is further marked by the existence of a great basal conglomerate at the Falls of the Sturgeon River. The folding in this district is often so sharp that there is a seeming conformity between the upper and the lower series in many places. A generalized cross section of the Menominee rocks in the vicinity of Quinnesec illustrates the author's interpretation of the geology of the district (p. 435).

LARSSON, PER. The Chapin iron mine, Lake Superior: Trans. Am. Inst. Min. Eng., vol. 16, pp. 119-128. Map and cross sections. 1888.

Larsson's article is devoted mainly to a description of the methods employed in mining at the Chapin mine, although in its introduction brief reference is made to the geology of its ore deposits. Up to July, 1887, the ore of this mine had been found in three lenses, conforming in dip and strike with the Huronian clay slates and jaspers associated with them, and pitching about 30° west.

A cross section of the ore formation shows on the north or hanging side of the ore about 200 feet of clay slates, and farther north a heavy belt of magnesian limestone. The slates and the dolomite are generally separated by a conglomerate of broken dolomite and soft slates.

The foot-wall rock is also a soft slate, containing a higher percentage of iron and less magnesia than the hanging slate. Farther south occur alternate beds of slates and lean ore or jasper [p. 119.].

The paper is accompanied by a geological map of the Chapin mine property, a longitudinal section of the workings, and two cross sections exhibiting the geological relations between ore, slate, and dolomite.

FULTON, JOHN. Mode of deposition of the iron ores of the Menominee iron range, Michigan: Trans. Am. Inst. Min. Eng., vol. 16, pp. 525-536, with 9 figures. 1888.

According to this author the Menominee range is composed of three distinct groups of Huronian rocks. The "supporting group" consists of 1,200 feet of light-colored, siliceous limestones, called the Norway limestone belt.

The next or flanking group which is estimated at a thickness of 1,000 feet is called the Quinnesec ore formation. It consists, in the portion next to the limestone, of siliceous or jasper slates, largely impregnated with iron oxide. These are succeeded by argillaceous hydro-mica black and flesh-colored slates. This formation embraces the deposits of the iron ores.

The third group consists of a series of dark-gray, slaty, or schistose beds, with occasional quartzose bands, having a thickness of 2,000 feet. It is called the Lake Hanbury slate group [p. 525].

The three groups succeed one another conformably, dipping at high angles to the south in that portion of the range east of Quinnesec and to the north in that portion west of this town. Their relative ages can not be determined from their relative positions, as "the limestone is the floor of the series east of Quinnesec, while west of this it is uppermost" (p. 527). There is a well-marked unconformity between the Huronian rocks and the overlying Potsdam sandstone, but the geology of the older rocks is complicated by "frequent and violent flexures and strangely postured dips" (p. 527).

The rocks of the three groups are sedimentary. The iron ore at the Quinnesec mine is thin bedded, as are also the foot-wall jasper slates. The limestone is thick bedded. The ore occurs at two or three horizons, which, so far as is known, are not constant. At the East Vulcan mine one of the ore bodies is at the contact between the siliceous or jasper slates and the aluminous slates or "soapstone." A second is in jaspers south of the black slates. At the Curry mines there are also two horizons at which the ore occurs. The first, most northerly, is in jasper slates and the second at the contact between the jasper and black slates.

The Norway deposit is peculiar, being separated from the limestone by about 10 to 40 feet of brown sediment, locally termed "soap rock." The ore body is mainty composed of a brecciated deposit of red and blue iron ore, occasionally mixed with jasper slates, and cemented in great masses [p. 531].

The underground workings reveal the existence of a fold in the limestone.

The large open pits of Cyclops are very peculiar, as they are the residuum of a period of denudation and destruction of the ore body. These pits occur in the jasper slates, without any regularity. * * * The ore was evidently carried into them by some eroding current from the wreck of an original deposit. Just where it came from, or under what conditions it was swashed into these large pits can not be determined. * * * The example of a pool of ore at East Vulcan illustrates the supposed condition of these Cyclops deposits [p. 532].

At the Quinnesec mine a similar "pool" of ore is found infolded in the Potsdam sandstone. A little east of this mine a flexure occurs in the Huronian rocks, west of which fold the beds dip north.

The blue ores of the Quinnesec and of the West Vulcan mines are in the form of lenses whose tops have been eroded. These are thought to represent the original form in which all the ore in the range once occurred. They are embedded in jasper and clay slates, and are stratified like these rocks.

After thus describing the characteristics of many of the deposits the author proceeds to outline a theory to explain their origin.

The most acceptable exposition indicates that their normal form was that of thinly bedded ferriferous carbonates, with some admixture of dusty magnetite, and that they have been wholly altered to hematite by heat in their lower geological horizon, together with the heat evolved in the pitching and folding of the rock-measures in which they are found. Chemical agencies also contributed to this result [p. 535].

The author concludes by declaring that the structure of the range can not be explained as "a continuous monoclinal structure." "The more evident structure should consist of a series of crust flexures, repeating the iron-ore measures at intervals, as they rise on the crests or flanks of anticlinal waves" (p. 536).

The paper is accompanied by a map of the district and nine geological sections through mines.

FULTON, JOHN. Methods of mining in the Menominee range, Michigan: Trans. Am. Inst. Min. Eng., vol. 16, pp. 891-905, with 8 figures. 1888.

The introductory portion of this paper describes the position of the ore bodies with respect to the jaspers and slates in the Menominee district. These ore bodies are reported as being found in three or more horizons in the jasper slates and also on the contact between these and the clay slates that usually overlie them. The remainder of the paper is devoted to a description of the methods of mining on the range.

1889.

LAWTON, CHAS. D. Mineral resources of Michigan, 1888, pp. 190-208. 1889.

In this report on the mines and mineral resources of Michigan the author announces the discovery of a large percentage of gold in the rock from a pit near the bank of the Menominee River, south of Quinnesec. He also gives an account of the condition of the iron mines on the Menominee range at the close of the year 1888. In his introduction to that part of the paper which deals with the Menominee district he outlines the geology of the district as worked out by Brooks.

WINCHELL, N. H., and WINCHELL, H. V. On a possible chemical origin of the iron ores of the Keewatin in Minnesota: Proc. Am. Assoc. Adv. Sci., Thirty-eighth Meeting, pp. 235-242. 1889. Also Am. Geologist, vol. 4, pp. 291-300. 1889.

Although this paper is devoted mainly to a theory in explanation of the origin of the iron ores in Minnesota, Professor Winchell nevertheless argues against Irving's view that the ores of all the iron-ore districts in Michigan and Wisconsin are derived by metamorphic processes from an iron carbonate.

BROWNE, D. H. The distribution of phosphorus in the Ludington mine, Iron Mountain, Michigan: Am. Jour. Sci., 3d series, vol. 37, pages 299-310, with figures. 1889.

The ore of the Ludington mine occurs in several lenses lying in clay slates. The main deposit, which is 700 feet long and about 60 feet wide, strikes N. 75° W. and pitches 45° W. Its dip is 70° to 80° N. The ore is of a soft, laminated hematite, whose layers alternate in places with thin seams of calcium-magnesium carbonate. The contact of the ore body with the hanging wall is curved, while that with the foot wall is more nearly

a plane surface. Upon mapping the phosphorus contents of the different samples of ore taken from the mine it was found that the foot-wall sides of the deposits are apt to contain less phosphorus than the hanging-wall sides, and that the western (lower) ends of the lenses contain less phosphorus than the eastern (upper) ends. The ore increases in phosphorus from the foot wall to the hanging wall, and from the west to the east. Sometimes a streak of ore rich in phosphorus crosses the high-grade ore, but in general the relations just mentioned obtain. These relations are illustrated in the paper by a large number of sections through the different rooms in the mine from which ore has been removed.

The explanation offered to account for the regularity in the distribution of the phosphorus is as follows: The ores were aqueous deposits upon the hanging-wall slates.

If we suppose that the ore was formed in hollows in the hanging wall, and was covered by the foot-wall slates, and that this bed has been tilted up from the north side through an angle of 100° to 110°, it will be readily understood that the original trend of the deposit becomes the complement of the present pitch of the ore. This supposition explains * * * the fact that what is now the hanging wall seems to have been the original bed of the deposit. It is improbable that the tilting has been from the south side upward through an angle of 70° to 80°; for if this had been the case the ore would pitch east at the same angle at which it now pitches west [p. 306].

The author does not think that Van Hise's explanation of the origin of the ores in the Gogebic district can be applied to the conditions in the Menominee district, because the slates associated with the Menominee ores contain no unaltered carbonate. The suggestion of Irving that the ore was washed into its present position from previously precipitated beds of carbonate appears to him more plausible, but he would modify the theory by making the original deposits hydrous oxides and carbonates of iron intermixed with calcareous materials. By the action of acidulated waters upon these the iron was dissolved and the solutions thus formed were evaporated in shallow lakes or valleys, yielding the ore deposits now worked.

The theory of the aqueous deposit of these ore bodies, as drawn from chemical evidence, is then briefly as follows: From previously deposited beds of bog iron ore, by the action of acidulated water, iron, lime, silica, and phosphorus were dissolved. The first solution contained a large amount of phosphorus in proportion to the amount of iron dissolved. On coming into hollows in the surface of the exposed slates the acid solution, losing acid by evaporation, deposited iron, as hydrated oxide, which carried down an amount of phosphorus proportionate to the amount of iron precipitated. As the acid became still weaker crystals of carbonate of lime and magnesia settled out, forming a layer of carbonates. A second inflow of water would tend to dissolve these crystals and precipitate another layer of iron. In similar manner, by successive inundations, the depressions became filled with alternating layers of iron ore and calcium-magnesium carbonates, each layer being as a rule lower in phosphorus than the preceding one. * * * Moreover, as both calcium and iron phosphate are of lower specific gravity, and more soluble than the hydrated oxide of iron, the tendency of the water was to carry these phosphates toward the lower end of the lake, and to deposit them in shallow water, along banks of previously precipitated silica and in places where precipitation was most rapid. * * * After the deposition was complete, further action of the water would stir up the upper layers of ore and mix them with suspended sand or clay, while the iron and phosphorus were carried farther along, to be deposited in other depressions to the northeast. As jasper occurs as vein matter, and in laminæ cleaving in the same line as the ore, it would seem either that the jasper has been produced by precipitation with the iron, or that subsequent action of water has eroded the beds of iron thus formed and substituted silica for the iron removed.

A study of the vein map of the sixth level at the Ludington mine * * * seems to show that the jasper is a later formation than the ore. It will be seen by reference to fig. 17 [figure 22 in the article] that the jasper deposit widens toward the foot wall. * * * The greater width of the jasper at the foot wall also suggests an erosion of the original ore bed and a subsequent deposition of silica. Had the silica been the primary deposit the ore would be widest at the foot wall instead of at the hanging [pp. 307-308].

For the explanation of the silica deposits "bedded in the same plane with the ore," the author adopts Van Hise's hypothesis, "with the provision that subsequent erosion must be taken into consideration." The "surface deposits or washes of ore formed at Keel Ridge, Quinnesec, and Norway mines" are thought to be accumulations of the detritus worn away from outcropping edges of ore during the glacial erosion. After the deposition of the ore it was greatly modified in its chemical peculiarities by the action of surface water, removing phosphorus in one place and adding it in another.

The theory of aqueous deposit will explain, as will no other, the marked regularity of isochemic lines [lines drawn through those portions of the deposit containing equal quantities of phosphorus] and their peculiar curves, the regular decrease of phosphorus from hanging wall to foot, the alternation of carbonate of lime and oxide of iron, the ripple-marked hanging wall, the uniform lamination of the ore, and the hydrated muddy deposit next the foot wall. It also suggests explanation of the general features of the Menominee range, and the gradual change from high phosphorus and low iron ores resembling altered bog ores at its western extremity, through regular deposits of high iron and lower phosphorus, to the immense washes and surface deposits of exceedingly low phosphorus ore which mark its eastern termination (p. 309).

1890.

IRVING, R. D. The greenstone schist areas of the Menominee and Marquette regions of Michigan; explanatory and historical notes: Bull. U. S. Geol. Survey No. 62, pp. 11-30. Map of Menominee district opp. p. 24. 1890.

In this introductory note to Dr. Williams's study of the greenstone-schists of the Marquette and Menominee districts Irving gives an historical summary of the views held by his predecessors with respect to the relations existing between these schists and the bedded sedimentary rocks associated with them. The general problems connected with the subject have been outlined in the Marquette monograph.[a] These green schists occur intermingled with granites and also form large continuous areas, which they entirely occupy, except for

some unimportant dikes that intrude them. Some of these rocks are now hornblende-schists, others are chlorite-schists, while still others are massive greenstones. In the Menominee district the schists occur south of the ore belt. They are well exposed at the Big and the Little Quinnesec Falls and at the Sturgeon Falls on the Menominee River, and again in the vicinity of the Fourfoot Falls, north of Bass Lake. These schists, it will be remembered, were regarded by both Brooks and Rominger as layers of sedimentary material that have been metamorphosed since their deposition. By Brooks they were considered to be the uppermost beds of the Huronian series and by Rominger as the basal layers of this system. To Irving the regularity of the alternations in the schists seems less than one would think to be the case from Brooks's maps. The rocks seemed to him to grade into one another and into the massive beds. The schistosity appears to be of secondary origin and the original structure of the rocks seems to have been massive. In the Menominee district a series of detrital iron-bearing rocks lies between the green schists and great areas of granite and gneiss to the north. The iron-bearing rocks are similar to those of the Marquette district. They are, however, rarely intruded by greenstone eruptives, and are much more crumpled than are the Marquette rocks.

[a]Mon. U. S. Geol. Survey, vol. 28, 1897.

In the same region are two belts of greenstone-schists closely analogous in general appearance with those of the Marquette region. The southern one of these borders for a long distance the southern granite area, separating the granite from the detrital rocks farther north. The inclination of the greenstone-schists is almost vertical, there being generally a slight southern departure from verticality. Very high southern dips, often approaching verticality, also prevail among the layers of the detrital succession itself, although here frequently occur reverse dips to the northward, often at a flatter angle [p. 25].

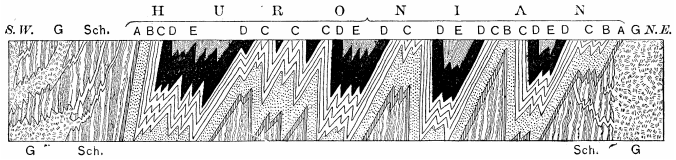


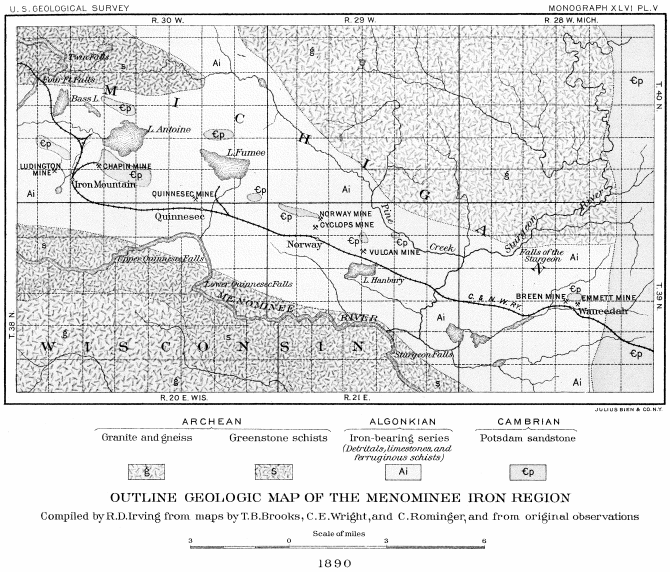
FIG. 12.—Hypothetical section across the Menominee region in the vicinity of Quinnesec Valley. After R. D. Trying, 1890; A, basal sericitic quartz-slates; B, quartzite; C, limestone;. D, iron horizon; E, slates and quartzites; G, granite; Sch, schists of the Laurentian. Scale, 13,000 feet to the inch.

With respect to the age of the greenstone-schists, Irving writes:

In my own studies in the Menominee region, made in the summers of 1883 and 1885, I became early impressed with the close similarity between the greenstone-schists of the Menominee River and those which underlie the iron-bearing series of Marquette; with the entire similarity between the rest of the stratiform rocks of the region and those of the Marquette district; with the essential identity in character of the granite areas lying, respectively, on the northern and southern sides of the Menominee River; with the granitic intrusions met with in the greenstone-schists bordering the southern granite, and with the striking contrast between the nature of this contact and that of the northern granite and the detrital rocks which border it to the south. In the latter case, the granite, instead of sending intrusions into the rocks which rest against it, has furnished fragments to them, as may be most beautifully seen at the Falls of Sturgeon, Sturgeon River, on the eastern side of sec. 8, T. 39, R. 28 W., Michigan. These considerations naturally led me to the conclusion that the whole structure in this district is similar to that already described as obtaining in the Marquette region, namely, that the granitic masses had intruded themselves in the shape of great bosses into rocks now represented by the greenstone-schists, after which followed a protracted period of disturbance and denudation before the deposition of the overlying detrital and iron-bearing rocks of the region. Taking Major Brooks's detailed map of the Menominee district, published in the atlas of the Wisconsin survey, I platted on it all of the exposures described by Rominger and not mapped by Brooks, which exposures amount in all to a large number. Examining, then, the more important of the exposures of the region, I encountered still others, which were also platted upon the same map. Two sections were then constructed across the district from southwest to northeast, upon which were platted all of these exposures, with their dips; and it should be said that very many new facts in this direction have been developed of late years by mining

It has thus become evident that a structure such as is indicated in the accompanying fig. 3 [reproduced as fig. 12, p. 93] would not only coincide with the recorded facts as well as the sections of Brooks * * * but very much better than those [pp. 29-30].

With reference to the conglomerates at the Falls of the Sturgeon, the author says that the granitic fragments occur in a fine-grained, slaty rock, in which there is a great deal of sericitic material, which at times gives the slate somewhat the look of a crystalline schist. This fact, together with the slight inclination from the vertical toward the north, led Credner to include the conglomerates with the Laurentian granite. Brooks's view is regarded as the correct one—i. e., the conglomerate is at the base of the sedimentary series. The granite sheet described by Rominger as interleaved with the conglomerates could not be found. Irving also points out the fact of Rominger's inconsistency in making the same granite yield fragments to the sedimentaries and subsequently to intrude them. The nature of the pebbles and the structure of the matrix which holds them are clear evidence to Irving that "we have here to do with a detritus derived by water action from the granitic and gneissic area immediately to the north. The slight inclination from the vertical toward the granite which these conglomeratic schists sometimes show is, of course, no argument against their having been deposited upon the granite as a substratum." (Footnote, p. 30.) The map accompanying the paper shows the distribution of the Archean, Algonkian, and Cambrian areas within the district. Although largely a compilation, it outlines definitely for the first time the limits of the iron-bearing series. A reproduction of it forms Pl. V.



[Plate V. Outline geological map of the Menominee iron region, by R. D. Irving, 1890]

WILLIAMS, G. H. The greenstone schist areas of the Menominee and Marquette districts, Michigan: Bull. U. S. Geol. Survey No. 62, pp. 31-131 and 192-217. 1890.

Dr. Williams's work is purely microscopical. The aim of his paper is "to trace each of the rock types represented within the areas studied from its least altered to its most altered form, and to discover what may have been the agencies which produced the changes noticed." The object of the author's investigations "was to discover, if possible, the origin of the greenstone-schists of the Lake Superior region, and at the same time to afford a contribution to our knowledge of the metamorphism of basic eruptive rocks in general" (p. 31).

The areas in the Menominee district selected for special study are five in number, embracing the vicinity of the Sturgeon Falls and the areas around the Little and the Big Quinnesec Falls, the Fourfoot Falls, and the Twin Falls. At the Sturgeon Falls the rocks on the Michigan side of the river consist of five bands of saussuritized gabbro and four bands of greenstone-schists. The gabbro constitutes Brooks's bed XV. In thin section it shows a gradation from an almost massive pyroxene-bearing saussuritized gabbro to schistose varieties composed of sauseurite, quartz, and hornblende. The green schists associated with this gabbro are plainly the result of dynamic agencies. In some of them broken feldspar crystals may be detected, but others are now composed exclusively of chlorite, quartz, and calcite. These schists are believed to be derived from the gabbro by pressure and shearing. Associated with them are several bands of light-colored sericite-schists which the author considers as having been produced from the same gabbro by chemical processes that are essentially different from those that gave rise to the green schists.

At the Little Quinnesec Falls the rocks are mainly diorites, diabases, chlorite-schists, and sericite-schists. The great gabbro ridge of Major Brooks, described as extending along the Michigan side of the river, is in composition a diorite, originally containing a brown hornblende that has been replaced by a green variety of the same mineral. It is possible, according to the author, that the brown hornblende may in turn have been derived from diallage and the rock may have been a diabase. By further alteration the green hornblende passes into a tremolitic mineral and into a colorless chlorite. The schists are believed to be pressure-changed diabases. The slaty rocks recorded by Brooks as occurring here are thought to be altered basic eruptives, since they grade into massive diabases, and under the microscope their thin sections show evidence of the close relationship existing between them and the massive beds. The author gives a clear statement of the evidence from which he concludes that the massive rocks pass into schists by pressure action. He illustrates his remarks by the picture of a hand specimen taken from the western end of the "diorite ridge" near the falls. It shows a rock traversed by cross gashes, which the author explains as due to the stretching of the rock after solidification.

At the Big Quinnesec Falls the rocks below the falls are dark, more or less schistose greenstones that were once diabases. At the falls and for a half a mile above them are exposed light-colored granular greenstones which graduate into sericite-schists. At the Horserace Rapids the rocks forming the steep walls of the gorge are coarse-grained diorites. These rocks and those at the falls are cut by bands of granite, gneiss, and schistose porphyries that are closely related genetically with the granite south of the Menominee (Brooks's Huronian granite bed XX). The rocks below the falls show the effects of pressure in a striking degree. They were once diabasic, but at present they show only obscure traces of their ophitic structure. The barrier rock of the falls was regarded by Credner as very similar to a gabbro. Williams, however, finds it to be essentially a diorite, although originally it may have been a hornblende-gabbro, or possibly a normal gabbro. The coarse-grained diorites of the "Horserace" (above the falls) are dioritic varieties containing talc, which has been derived from hornblende. The rocks appear to be much-squeezed diabases. The green schists are cut by dikes of granites and of quartz-porphyries that are usually foliated like the schists themselves. Usually their foliation is parallel to the foliation of the surrounding rocks without respect to the direction in which the dikes run; thus it may sometimes be parallel to the sides of the dikes and at other times may be inclined to them. Most of the acid bands are regarded as apophyses of the granite to the south. If they are offshoots of the granite, this rock is younger than the schists; and if the schists are the uppermost members of the Huronian series, the granite must be the youngest rock in this series. The writer does not attempt to decide as to the age of the green schists, however, and consequently he makes no supposition as to the age of the granite with respect to the sedimentary beds of the Huronian.

With reference to the acid dikes, the author writes:

The dikes when small are fine grained and felsitic, but when larger their texture is coarser, and they have frequently a well-developed schistose structure parallel to that of the adjoining schists. After a careful examination of this locality and of the exposures between it and the river, there is no doubt in the writer's mind that the granite, "Augen-gneiss," biotitic gneiss, and schistose porphyry (or "porphyroid," as Credner called this rock) visible near the Upper [Big] Quinnesec Falls and along the Horserace are also dikes or apophyses connected with the main southern granite area. The schistose or banded structure of these rocks, where such exists, is a secondary feature, produced by the same dynamic agencies which rendered the greenstones themselves schistose [p. 111].

The granite of the main southern granite area is a typical granite with a tendency to a porphyritic structure. Like all the rocks in the vicinity it bears the marks of having been crushed.

At the Fourfoot Falls the greenstones are again well exposed. On the Wisconsin side of the river they are schistose and on the Michigan side on the strike of these schists the rocks are massive. A quarter of a mile below the Chicago and Northwestern Railway bridge is an exposure of black slate with the typical structure of a sedimentary rock. Above the railroad bridge a few steps begin the greenstone-schists, which are entirely different from the slate, but are similar to the green schists already described. At the Twin Falls the greenstones are of a dark, aphanitic variety, and when schistose, resemble a chloritic slate. Transitions between massive diabases and greenstone-schists and between these latter rocks and chlorite-schists are traced by the author step by step, so that there can seem to be no question but that the schists are squeezed eruptive rocks.

In summarizing the evidence as to the origin of the green schists derived from their study in the field and laboratory, the author shows that the foliation of the schists is no proof of their sedimentary character. The foliation of these rocks is parallel to the foliation of the sedimentary beds of the iron-bearing formation, but not always to the strike of their bedding. Both the schistosity of the greenstones and of their associated granites is a phenomenon due to pressure, which probably acted in two different periods, in one of which the genuine sediments received also their foliation.

The most convincing proof that the rocks of the Menominee and Marquette greenstone areas are of igneous origin is not to be derived, however, from their field relations, but rather from their microscopical structure. It is true that there are many cases where rocks of widely dissimilar origin resemble one another so closely that not even the minutest study of their internal structure is able to distinguish them with certainty; nevertheless there are in other cases well-marked peculiarities of structure which may be regarded as unfailing indications that the rock possessing them has crystallized out of a molten magma [p. 195].

The structures that are characteristic of eruptive rocks and that have been recognized in the Menominee greenstones are the ophitic, the porphyritic, the micropegmatitic and granophyric, and .the poikilitic. The original rocks still recognizable in the Menominee district and those from which the schists have been derived are gabbros, diabases, diabase-porphyries, diorites, and diorite-porphyries among the basic phases, and granites, granite-porphyries, and quartz-porphyries among the acid areas. The evidence of the microscope indicates that the greenstones solidified at the surface.

In the Menominee Valley this evidence consists (1) of the fine texture of the rocks, and (2) of the alternation of bands of different types, which probably in their original position represented successive flows. Fineness of grain is universal in the Menominee greenstones, and we may be certain that it was a primary feature in spite of the extensive alteration of these rocks. It is especially noticeable in the case of the gabbro, which is almost always a coarse-grained rock when it has solidified at any depth. The succession of massive beds, like the pale gabbros and the dark diabases seen at the Lower [Little] Quinnesec Falls, are difficult to account for except by supposing that they were once horizontal sheets that flowed over one another and which were subsequently elevated into their present nearly vertical position. Traces of tuff material are not as distinct here as in the Marquette region, although indications of its existence are by no means wanting. We might reasonably expect that any original scoriaceous or amygdaloidal structure would have disappeared in the course of the profound chemical changes through which these greenstones have passed [pp. 200-201].

The author's paper is illustrated by maps of the districts studied and by 12 lithographic reproductions of thin sections of characteristic rocks.

1891.

VAN HISE, C. R. An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy: Am. Jour. Sci., 3d series, vol. 41, pp. 117-136. 1891.

The author believes that many of the difficulties that have arisen among geologists with respect to the correlation of the pre-Cambrian rocks is due to the neglect to note the existence of a physical break in the series of strata placed by Irving in his Huronian group. He shows that such a break occurs in the Marquette district and that here there is a well-defined upper and a distinct lower series, separated from each other by a great unconformity and a basal conglomerate. In the Menominee district the evidence of this break is lacking, possibly because the knowledge of the relations existing between the Menominee rocks is less exact than it is in the case of the Marquette sediments. It is thought probable, however, that in the Menominee district the equivalents of both the lower and upper Marquette rocks occur. The Menominee proper—that is, the portion of the Menominee district east of the Menominee River—is thought to correspond in position with the Lower Marquette and that portion west of the river with the Upper Marquette.

GOETZ, GEORGE W. Analyses of Lake Superior ores: Trans. Am. Inst. Min. Eng., vol. 19, pages 59-61. 1891.

The author records the results of analyses of ores from 24 mines in the Menominee district on both sides of the Menominee River.

1892.

VAN HISE, C. R. Correlation papers—Archean and Algonkian: Bull. U. S. Geol. Survey No. 86, pp. 72-208, 470-529. With general map of Lake Superior region. 1892.

This volume contains a summary of all the work done on the pre-Cambrian rocks of North America up to within a few months of the time the volume was published. The evidence collated from the writings of those geologists who had investigated Lake Superior geology is discussed and conclusions are drawn from it by the author. With the abstract of the literature we have nothing to do in this review, nor with the matter dealing with the classification of the pre-Cambrian formations in the Lake Superior region. The latter subject is freely discussed in the chapter on literature in the Marquette monograph,[a] where the discussion rightly belongs, since many of the conclusions arrived at with reference to the separation of the pre-Cambrian series were reached very largely by studies prosecuted in the Marquette district. There are, however, a few direct references made to the Menominee district which should be considered here.

In 1890 the author examined the rock succession at Iron Mountain, finding above the ore formation at the Ludington and Chapin mines a conglomerate which bears fragments of ore and jasper. "It therefore appears that after this material reached its present condition in the ore-bearing series it was eroded and furnished débris for a newer series" (p. 156). In company with Professor Pumpelly he again in 1891 and 1892 examined the ore formation. In a quarry east of the Chapin mine, and also in the deeper workings of this mine, it was discovered that the ores resting almost directly upon the limestone bear a considerable percentage of carbonates, and in the first-mentioned locality they grade directly downward into the limestone.

[a]Mon. U. S. Geol. Survey, vol. 28, 1897, pp. 5-148.

It is therefore probable that the ore formation of these districts, in part at least, is but an upward continuation of the limestone formation, perhaps differing from it originally only in that the upper part contained a greater quantity of original carbonate of iron.

Above the ore formation at Quinnesec, test pits show the presence of a typical chert and jasper conglomerate, in every respect like the basement conglomerates of the Upper Marquette [p. 156].

The additional evidence with respect to the physical break in the clastic series lying between the green schists and the Potsdam sandstone is summarized as follows:

In the Menominee district as evidence in favor of a physical break within the clastic series are the conglomerates described by Brooks at the Pine and Poplar rivers district, and in the Commonwealth section. * * * Also, the structural break indicated by these conglomerates is supported by Brooks's major divisions of the Menominee rocks. His inferior Huronian comprises the lower quartzite of great thickness, a great marble formation, and the great iron-ore horizon, consisting of magnetitic, hematitic, and jaspery schists, with deposits of iron ore. In this formation are the Norway, Quinnesec, Ludington, Chapin mines, etc. Brooks's middle Huronian, presumably above the unconformity, includes quartzites, clay slates and obscure soft schists. Within these soft slates is the upper iron-bearing horizon, including such mines as the Commonwealth, those at Crystal Falls, etc. [Pp. 180-181.]

The author does not believe that a correspondence can be made out between the subordinate members of the Menominee and Marquette districts, and yet he thinks that the Menominee district in Michigan corresponds as a whole to the Lower Marquette series.

VAN HISE, C. B. The iron ores of the Marquette district of Michigan: Am, Jour. Sci., 3d series, vol. 43, pp. 116-132. 1892.

Although this article deals mainly with the manner of occurrence of the ore bodies in the Marquette district, those of the Menominee district are referred to in a few words. The ores of this district are said to occur in two formations, one of which belongs with the Lower Menominee and the other with the Upper Menominee. From the general work done in the district it seems that the ores are all secondary concentrations upon impervious formations. They are particularly likely to be of large size when the impervious beds are folded or when two of them combine to form pitching troughs.

1893.

WINCHELL, N. H. The crystalline rocks—some preliminary considerations as to their structure and origin: Twentieth Ann. Rept. Minnesota Geol. and Nat. Hist. Survey for 1891, pp. 1-28. 1893.

The first part of this article is a general discussion of the nature of the evidence that should guide the geologist in his conclusions as to the origin of the metamorphic rocks. The second part illustrates the author's use of this evidence. He declares that field evidence is of more value in determining the sedimentary origin of a banded rock than the evidence of a microscope. He illustrates by reference to the greenstone-schists of the Menominee district. He reproduces the figure of the hand specimen with cross gashes published by Williams, and seems to conclude that the rock which Williams declared to be a squeezed gabbro is a squeezed sedimentary rock. The greenstones, it seems from a careful reading of the author's words, are thought to be sedimentary deposits, in large part tuffaceous.

WADSWORTH, M. E. Sketch of the geology of the iron, gold, and copper districts of Michigan (dated March 26th, 1892): Report of State Board of Geol. Survey for the years 1891 and 1892, pp. 75-174. 1893.

The Azoic or Archean rocks of Michigan, according to the author, embrace three distinct formations, named, from their typical exposures in the Marquette district, the Cascade, the Republic, and the Holyoke. The Cascade is the oldest. In the Menominee district it contains gneisses in which are embedded gneissoid fragments, and true granites which hold an intrusive relation to the gneisses and other foliated rocks. In sec. 2, T. 40 N., R. 30 W., a basic dike, now an amphibole-schist, was seen

to be intrusive in quartzite, and in its turn to be cut by a felsite dike. The Republic formation corresponds to Van Hise's Lower Huronian.

The heavy quartzite which extends in the Menominee district from Sturgeon River along Pine River * * * is thought to belong to the base of the .Republic formation, as it is found in various places close to the Cascade gneiss and granite, dipping away from that formation, and is cut by dikes of the granite on sec. 12, T. 41, R. 30 W. This quartzite is probably Republic, if the overlying ores are Republic, which they are here considered to be, although no direct proof of this supposition has yet been obtained. The ground for this belief rests chiefly on the physical character of the ore formation [p. 103].

In addition to the quartzite and iron ores the dolomites so abundantly exposed in the Menominee district are also placed in the Republic formation. The author calls attention to the existence of "eruptive argillite or schist" in dikes at the Cyclops and Norway mines. In connection with the discussion of the origin of the greenstone-schists, Wadsworth states that the rock on the Michigan side of the Menominee River, below the Little Quinnesec Falls, and at the Big Quinnesec, is a conglomeratic greenstone or a tuff, and not an eruptive diabase or diorite, as Williams supposed. Similar tuffs are very common in the Marquette district.

HUBBARD, L. L. Macroscopic minerals of Michigan: Report of State Board of Geol. Survey for the year 1891 and 1892, pp. 174-176. 1893.

In this list of minerals occurring in Michigan the author mentions chalcopyrite, pyrite, quartz, hematite, limonite, martite, laumontite, malacolite, orthoclase, staurolite, tourmaline, azurite, calcite, dolomite, siderite, and malachite as existing in the Menominee district.

PATTON, H. B. Microscopic study of some Michigan rocks. Report of State Board of Geol. Survey for the years 1891 and 1892, pp. 184-186. 1893.

As the result of his investigation of thin sections of Marquette and Menominee rocks Patton identifies a great variety of schists in these two districts, besides slates, graywackes, and several kinds of eruptive rocks, but he gives no details with respect to any occurring in the Menominee district.

WILLIAMS, G. H. The microscope and the study of the crystalline schists: Science, vol. 21, p. 1. 1893.

In a reply to Professor Winchell's article on the crystalline rocks, referred to above, Dr. Williams takes exceptions to some of Winchell's remarks with respect to the comparative value of field and microscopical evidence in the study of the crystalline schists. He calls attention to the fact that the figures reproduced by Winchell from the author's paper are figures of specimens taken from rock masses that were so clearly eruptive in origin that there was no necessity for their study under the microscope. In conclusion, he writes:

In reality, what are known in the Lake Superior region as "greenstones" and "greenstone-schists" are not one thing, but a great variety of different things. Some of them are massive lavas, others accumulations of ash material, stratified by gravity or water. They possess structures of diverse origin, which may to the field geologist appear very much alike.

BIRKINBINE, JOHN. Iron ores: Mineral Resources U. S. for 1891, pp. 10-46. 1893.

The author, besides giving the usual statistics concerning the iron-ore industry in the United States, abstracts from Commissioner Lawton's reports on the Michigan iron mines several statements relating to the distribution of the ore-bearing beds in the Menominee district, but no information is given concerning the iron-bearing series in addition to that given in the reports of Brooks, Wright, and Rominger.

VAN HISE, C. R. An historical sketch of the Lake Superior region to Cambrian time: Jour. Geol., vol. 1, pp. 113-128, with general geological map of the Lake Superior region. 1893.

In this general sketch of the geology of the Lake Superior region the Lower Menominee rocks are made equivalent to the Lower Marquette and to the Lower Huronian in other portions of the region. The map is the same as that published in the Correlation Paper.

VAN HISE, C. R. Sketch of the pre-Cambrian geology of the Lake Superior region, with references to illustrative localities: Compte-Rendu, Fifth Sess. Inter. Geol. Cong., pp. 489-512, with maps. 1893.

In this paper the author gives a synopsis of the knowledge concerning the pre-Cambrian geology of the Lake Superior region. The facts recorded in it are not very different from those mentioned in the Archean-Algonkian Correlation Bulletin and in other papers by the same writer. With respect to the Archean of the Menominee district, of which Irving's map is reproduced, the author makes the following statement:

In the Menominee district the schists and granites of the Basement Complex may be seen in typical exposures both south and north of the Huronian rocks. The northern schist area is well exposed at Twin and Fourfoot Falls, 3-5 miles northwest of Iron Mountain, while the northern granite appears some miles northeast of Iron Mountain. The southern schists are finely exposed southeast of Iron Mountain at the Upper [Big] Quinnesec Falls, at the Lower [Little] Quinnesec Falls, at Sturgeon Falls, and near the crossing of the Menominee by the Milwaukee and Northern Railway. At the Horserace, above Upper Quinnesec Falls and one-half mile to the south, before the solid granite is reached, numerous dikes of this rock may be seen cutting the schists. On the Milwaukee and Northern Railway the granite rocks appear about 4 miles south of Iron Mountain. At this point and east and west of the railroad the intrusive relations between the granitic and schistose rocks are finely shown [p. 494].

The Lower Huronian consists of (1) conglomerates, quartzites, quartz-schists, and mica-schists; (2) limestones; (3) various ferruginous schists; and (4) basic and acid eruptives, which occur both as deep-seated and as volcanic rocks. The Lower Menominee belongs here.

It may be best studied at Iron Mountain and vicinity and at Norway and vicinity. At these places the iron-bearing member and the limestone are well exposed [p. 496].

In the Menominee district the only locality at which the supposed Lower Huronian is known to be in direct contact with the Basement Complex is at the falls of Sturgeon River. Here the Basement Complex has its typical character. It consists of coarse, black, hornblendic gneiss, which is cut through and through by red granite. Both occur in large masses, and along the numerous contacts the granite and gneiss are often minutely interlaminated, evidently by the intrusion of the latter. At many places dikes of granite may be seen passing from large granite masses and penetrating the schists, and then gradually dying out. In places the schists are so cut by stringers of granite as to have a genuine pegmatized appearance. Upon the irregular eroded surface of this Basement Complex rest masses of the broken ledge 2 or 3 feet thick, which pass upward into a schistose conglomerate containing numerous well-rounded bowlders and pebbles of the granite-gneissoid schist, in every respect like these rocks in the Complex below. The matrix of the schist is sheared and crystalline, but the larger pebbles and bowlders of granite have escaped any considerable crushing. There are several alternations of coarse conglomerate and fine siliceous schist before the conglomerate finally grades into the overlying quartzite. The geology has not been worked out in detail here, and that this formation is the lower quartzite of the Lower Huronian rests upon the authority of Brooks [pp. 499-500].

The Upper Huronian is not as well exposed on the Michigan side of the Menominee River as it is on the Wisconsin side. "The lowest formation of the Upper Huronian may be seen above the Lower Huronian iron formation at Iron Mountain and Quinnesec. The series can, however, best be studied about the Commonwealth mine and 2 or 3 miles to the westward in the vicinity of Lake Eliza" (p. 503). The Upper and the Lower Huronian are often separated by unconformities and basal conglomerates. "In the Menominee district the basal conglomerate of the Upper Huronian is not well exposed, but has been detected at the Chapin and Quinnesec mines by shafts and drill holes" (p. 506).

HULST, N. P. The geology of that portion of the Menominee Range east of the Menominee River: Proc. Lake Superior Min. Inst, for March, 1893, pp. 19-29, with map. 1893.

The author gives an abstract of the general geology of the Menominee district as worked out by Brooks and adds detailed sections of several of the mines in that portion of the district east of the Menominee River. The ore bodies are described as being found in beds of banded lean jasper, which is always associated with the richer ore. The ore may occur anywhere within the jaspery horizon. It is crossed by the stratification planes, which are extensions of those in the jasper. Often there are spots in the jasper composed of a substance that appears to be in a transition state between jasper and ore. The silica seems to be gradually disappearing from the jasper by solution, leaving a mass continually growing richer in the ore material.

The ore bodies usually pitch west at from 30° to 50°. Some of them rest upon a foot wall of soapstone or are under a hanging wall of this substance. Others possess no distinct walls, the merchantable ore suddenly giving away to the lean ore, or vice versa, according to no rule. The productive portions of the range appear to be located at points where the formations have been faulted, eroded deeply, or sharply folded.

The limestone is thought to be beneath the ore-bearing formation and not above it. The northerly dip of this rock at the Quinnesec, Pewabic, Chapin, and other mines in the western portion of the district is explained as due to an overturn of the series. Attention is called to the fact that the discovery of bowlders of limestone in the iron formation by Wright is corroborative evidence in favor of this view.

The descending succession at the Chapin and the Pewabic mines, obtained by cross sectioning, is as follows:

Section at Chapin mine.

	Feet.
Quartzite	140
Jasper	
Quartzite	
Quartzite and jasper	
Quartzite, slate, and jasper	
Slate	
Quartzite and slate	
Quartzite and jasper	
Banded ore, containing Millie ore body	300
Quartzite and slate	55
Slate	
Jasper	170
Ore body	
Gray slate	75

Section at Chapin mine—Continued.

	Feet.
Ore	185
Gray slate	
Jasper	
Gray slate	
Jasper	
Gray slate	
Jasper	
Ore	
Gray slate	
Limestone	

Section at Pewabic mine.

	Feet.
Quartzite	600
Red slate	
Jasper and ore, containing Pewabic ore body	215
Gray slate	112
Quartz	about 15
Gray slate	
Quartzite	77
Quartz and slate	about 10
Slate conglomerate	50
Red slate	77
Quartz and gray slate	85
Quartzite	
Quartz and sand	
Slate conglomerate	
Quartzite conglomerate	116
Red slate	50
Jasper	40
Red, gray slate	
Limestone	

The normal dip of the iron-bearing series is to the south. The cause of this southerly dip the author ascribes to the southern granite, the Huronian granite of Brooks. This is supposed to have flowed out upon the sediments when

they were approximately horizontal, and by its weight to have caused them to sink beneath it.

Although the principal iron-bearing horizon is above the limestone, a second one is surmised to exist below this bed, since the Loretto mine on the Sturgeon River has been opened in rocks dipping south, apparently under the limestone north of the main ore belt.

The map accompanying the article is practically a reproduction of the Brooks map.

1894.

WINCHELL, H. V. Historical sketch of the discovery of mineral deposits in the Lake Superior iron region: Second Ann. Rept. Proc. Lake Superior Min. Inst. 1894. Also Twenty-third Ann. Rept. Minnesota Geol. and Nat. Hist. Survey for 1894, pp. 116-155. 1895.

After quoting from Messrs. Foster and Whitney's description of the geology of the Menominee district, the author states that in 1866 Messrs. Thomas and Bartley Breen discovered the first workable deposit of ore on the Menominee range, but not until 1870 was any systematic work done on the deposit. In that year the first openings were made that afterwards led to the development of the Breen mine. The Vulcan and the West Vulcan ore bodies were discovered by Dr. N. P. Hulst in 1872, the Quinnesec in 1873 by Mr. J. L. Buell, and the Chapin in 1878 by Dr. Hulst.

SMYTH, H. L. Relations of the Lower Menominee and Lower Marquette series in Michigan (Preliminary): Am. Jour. Sci., 3d series, vol. 47, pp. 216-223. 1894.

Nearly all writers on the geology of the Marquette and Menominee districts have maintained the general equivalency of the iron-bearing series in the two districts. This opinion is based on the unconformability of the clastic series in each district above a series of gneisses and crystalline schists, and upon the lithological similarity that exists between certain members in both series.

The author's work north of the Menominee River iron-bearing area confirms Van Hise's view that there is an unconformity in the Menominee series corresponding to the unconformity between the Lower and the Upper Marquette rocks. The sequence in the two districts is represented to be as follows:

Marquette district.	*Menominee district.*
Upper Marquette.	Upper Menominee.
Unconformity.	Unconformity.
Lower Marquette.	Lower Menominee.
Unconformity.	Unconformity.
Archean.	Archean.

Although the sequence appears to be similar in both districts the rocks of the one region have not been traced into the other, so that it can not be said that this similarity proves the formations in the two districts to have been formed contemporaneously. The likeness of the Lower Menominee to the Lower Marquette formations is rendered more striking when their lithological similarities are compared more carefully than has heretofore been done. The Lower Menominee (which is that portion of the Algonkian most prominent in the district under consideration) consists of the following strata:

(1) A basal quartzite from 700 to 1,000 feet thick.

(2) A crystalline limestone from 700 to 1,000 feet thick.

(3) Red, black, and green slates, not known to exceed 200 to 300 feet in thickness. In these slates occur the iron ores of Norway and Iron Mountain.

(4) The highest member (except the volcanics) is a jasper, best developed at Michigamme Mountain in sec. 4, T. 43 N., R. 31 W., and in sec. 33, T. 44 N., R. 31 W.

Iron ores occur at three horizons—(1) in upper portion of the quartzite near its contact with the limestone; (2) in the slates; (3) in the Michigamme jasper (not present in the Menominee district as defined in this monograph). Lean martite ores are widely distributed at the first horizon, but only one workable deposit has been found in this position in the series. The important deposits are those occurring in the slates.

"These occur as local concentrations in a ferruginous rock, composed of banded jasper and iron ore, which, perhaps, is the modified representative of portions of the slates carrying a large proportion of nonclastic material of original deposition."

The lithological similarity of the Menominee with the Marquette series is thus expressed:

Menominee.	*Marquette.*
Michigamme jasper.	Jasper banded with ore. } (iron formation).
Slate (principal iron formation).	Magnetie-actinolite schist }
Limestone.	Quartzite.
Quartzite.	
Archean.	*Archean.*

The correspondence is not as close as it was supposed to be, the absence of limestone from the Marquette district being especially noticeable.

The Michigamme jasper was traced north by its magnetic properties into an area where the rock exposures consist of a lower quartzite and an upper magnetite-actinolite rock. The magnetic line corresponding to these beds was traced still farther north until it comes within 2½ miles of a line of magnetic attraction passing through the actinolite-schists of the Marquette series. The Menominee rocks dip eastward while the Marquette rock is thought to dip west. The intervening space between the two magnetic lines is covered with drift, but presumably beneath it is a synclinal fold, with the Michigamme jasper and the Marquette actinolite-schists on the corresponding opposite sides. If this supposition is correct the quartzite composing the lower portion of the Michigamme jasper on the Menominee side of the syncline is the same as the quartzite under the magnetite-actinolite-schists of the Marquette series, and as a consequence the whole of the latter series is represented in the Menominee district by the higher members of the Menominee series.

The conclusions of the author as summarized by himself are as follows:

1. The Lower Menominee quartzite, limestones, and slates are all older than any formation in the Marquette area.

2. The Michagamme jasper was deposited in a continuous sheet over both [Marquette and Menominee] districts, and in the Marquette district constitutes both the iron-bearing formation and, for most of the area, the lower quartzite.

3. The principal ore horizon of the Menominee has no equivalent in the Marquette district.

VAN HISE, C. P., Summary of current pre-Cambrian North American Literature: Jour. Geol., vol. 2, p. 453. 1894.

This article consists of a résumé of Hulst's article on the Menominee district supplemented by the following comments:

The sections give additional evidence that in the Menominee district, as in the Marquette, there are two unconformable series. The Chapin, Ludington, and Hamilton appear to belong to the Lower Huronian. The horizon of quartzite, slate, and conglomerate is evidently the basal conglomerate of the Upper Huronian. The Millie, Pewabic, and similar ore bodies are in the Upper Huronian. That the ore bodies occur in disturbed areas and frequently rest upon soapstone or other impervious formations accords perfectly with what has been previously ascertained as to the manner of concentration of the Lake Superior iron ores.

1895.

ROMINGER, C. Geological Report on the Upper Peninsula of Michigan, exhibiting the progress of work from 1881-1884; Iron and copper regions: Geol. Survey Michigan, vol. 5, pp. 1-84. 1895.

In this report Dr. Rominger supplements his earlier report on the Marquette and Menominee districts by recording his observations made between the years 1881-1884. Very little additional information is given concerning the Menominee rocks, most of the author's time having been spent in the Marquette and the Gogebic districts.

The "granite seams intersecting the dioritic rock series" south of the Big Quinnesec Falls and the porphyries of Pemenee Falls are identified as u analogous" to the granites and porphyries cutting the green schists north of the city of Marquette. At Pemenee Falls the porphyries occur not only in dikes, but in "a succession of porphyritic beds of immense thickness" (p. 7).

With respect to the diorite group the author states that the fine-grained dioritic rocks near the Quiver Falls are all augitiferous, as is also the range of diorites running across the N. ½ of T. 40 N., R. 30 W. "The hornblende in them appears to be the result of alteration of the augite." The rocks of the Big and of the Little Quinnesec Falls are typical diorites, but the barrier rock of the Sturgeon Falls is a gabbro, as are also the so-called diorites in sec. 35, T. 39 N., R. 29 W., and in the northwest quarter of sec. 16, T. 38 N., R. 28 W. Diallage was recognized in dikes of a dark-green rock, supposed to be serpentine, which cut the green schists a short distance above the Sturgeon Falls and in exposures of a similar rock in the W. ½ of sec. 26, T. 39 N., R. 29 W., near the road leading to Menominee. This rock and certain other finer-grained ones in the vicinity consist of blades of diallage in a cement of serpentine. The rock in sec. 12, T. 39 N., R. 30 W., that in sec. 9, T. 37 N., R. 28 W., on the Menominee River, and at many other places in the district, also contains more or less augite.

The ore-bearing rocks of the Menominee district east of the Menominee River are regarded as younger than the Felch Mountain ore beds, as young, perhaps, even as the older beds of the author's mica-schist group. In the northwest quarter of sec. 17, T. 41 N., R. 31 W., a little beyond the limits of the district studied in this volume, the micaceous schists have been explored for iron. No "real good ore" was found, but interlaminated with the schists in their "lowest position right in the surface of a superficially decomposed diorite belt underlying these beds, and in clefts of the diorite, pockets of a compact hydrated iron ore [were found], which to all evidences has been a secondary deposit of infiltration a long time after the deposition of this schistose series" (p. 37).

The arenaceous slate group, comprising the "upper series of the Huronian sedimentary layers," contains even a greater quantity of limonitic ore than had been supposed. "This younger group of sediments, inclosing limonitic ore deposits, shows by its topographical distribution an independence from the preceding lower strata, which proves considerable changes in the ocean level during the time intervening between the deposition of the first and the latter" (p. 73).

In the Quinnesec mining district no interruption in the progress of formation of sedimentary layers is indicated, as we find on the north side of the—

Quinnesec iron range, its latest strata, the great belt of compact siliceous limestones, conformably succeeded by this very large group of sericite-argillite-schists, graphitic slate-rock layers, chert and quartzite belts, with interposed accumulations of limonitic iron ore, but farther northwest, partly in Wisconsin territory, the most common case is to find this upper series of rock resting on dioritic and granitic masses, and none of the lower strata developed (pp. 73-74).

WINCHELL, N. H. The origin of the Archean greenstones: Twenty-third Ann. Rept. Minnesota Geol. and Nat. Hist. Survey for 1894, pp. 4-35. 1895.

The author again (see p. 101) turns to the subject of the origin of the greenstones in the Lake Superior region. He begins his article with a misstatement of the conclusions reached by Williams in his discussions of the Menominee and Marquette green schists, asserting that "the tendency of the conclusions reached by Dr. Williams is to refer the greenstones as a body to dynamic metamorphism of massive irruptive rocks" (p. 4). The object of the present paper is to give the reasons of the author's present belief "that the great bulk of the 'greenstones' as an Archean terrane ought to be classed as pyroclastic, i. e., that they originated from eruptive agencies, as tuff and all kinds of volcanic débris, sometimes very coarse, and were distributed and

somewhat stratified by the waters of the ocean into which the materials fell" (p. 5). The main point of Professor Winchell's paper seems to be a criticism of Williams for not spreading his conclusions respecting the origin of the Marquette and Menominee greenstones over the greenstone-schists of the entire Lake Superior district, and for not recognizing tuffs among the Menominee rocks, although he distinctly regarded the latter as of surface origin. Winchell again criticises Williams's explanation of the cross gashes in the hand specimen figured by him, and declares that the schistosity of the Menominee greenstones is not always an effect of pressure and shearing. (See pp. 94-98.) The author argues against the general conclusion that the phenomena observed in these rocks are due principally to dynamic metamorphism, but in doing so he misinterprets many of Williams's statements, and evidently puts meanings into them that they were never intended to convey. Everywhere the author argues against the "irruptive hypothesis" for the greenstones, presumably supposing that this was Williams's hypothesis, whereas it was in reality mainly an eruptive hypothesis. The only fault that the present paper really shows to exist in Williams's work is the neglect of the latter to observe the fragmental structure of certain greenstones in the neighborhood of the Little and the Big Quinnesec Falls, and this neglect had already been referred to before by Wadsworth. Professor Winchell finally agrees with Williams that the present condition of the greenstone-schists is due to dynamic metamorphism, although he does not distinctly say so. He emphasizes the fact that the rotted condition of the schists is due to weathering, a fact which Williams also admits.

The paper concludes with a discussion of "the greenstones as a geological terrane," but the discussion is mainly with respect to these rocks in Minnesota, a subject with which we are not here concerned.

VAN HISE, C. R., and BAYLEY, W. S. Preliminary report on the Marquette iron-bearing district of Michigan, including a chapter on the Republic Trough by H. L. Smyth: Fifteenth Ann. Rept. U. S. Gaol. Survey, Chap. V, pp. 631-650. 1895.

In his discussion of the general geology of the Marquette district Van Hise correlates the Lower Marquette series with the Lower Menominee of Smyth. He places the succession as follows, attempting no correlation between the upper series:

Upper Marquette.	*Upper Menominee.*
——UNCONFORMITY.——	
Lower Marquette.	*Lower Menominee.*
Negaunee iron formation, 1,000 to 1,500 feet	Michigamme jasper. Slates bearing rich ores.
Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick Ajibik quartzite, 700 to 900 feet Wewe slate, 550 to 1,050 feet	Slates and altered volcanics, maximum thickness, 2,000 feet.
Kona dolomite, 550 to 1,375 feet	Crystalline dolomite, 700 to 1,000 feet.
Mesnard quartzite, 100 to 670 feet	Basal quartzite, 700 to 1,000 feet.

The succession for the lower series would thus be very closely parallel in the two districts, with the following exceptions:

(1) The Wewe slate, the Ajibik quartzite, and the Siamo slate are placed opposite one member of the Menominee series. These three formations are, however, all fragmental, and are equated with a fragmental formation. Together they mark a time of mechanical deposition in each district between the nonfrag-mental limestone and the nonfragmental iron formation, and thus include the physical change involved in passing from a nonfragmental to a fragmental, and then again to a nonfragmental formation. The chief difference is that in the Marquette district two layers of mud were separated by a layer of sand. Another difference is that in the Menominee district volcanics are much more important, and this may account for the absence of conditions favorable to sand deposits. However, it is interesting to note that amygdaloids are found in the Lower Marquette series in the Siamo slate—that is, toward the higher part of this great fragmental formation. The Fence River volcanics in the Michigamme district occupy a similar horizon.

(2) The pure, nonfragmental iron formation of the Marquette district is equated with slates bearing the rich ores of the Menominee district and the Michigamme jasper. The only substantial difference, however, is that in the Menominee and Michigamme districts both the slates and the jasper bear, with the nonfragmental, a considerable amount of fragmental material. In other words, the conditions in these districts were not favorable to pure nonclastic sediments as they were in the Marquette district [p. 649].

1896.

VAN HISE, C. R. Summary of pre-Cambrian North American literature: Jour. Geol., vol. 4, pp. 748-750. 1896.

The author, commenting upon Smyth's article on the relations of the Lower Menominee and the Lower Marquette series, declares that additional evidence seems to be necessary to prove that the iron-bearing slates of the Menominee district are the equivalents of the slates associated with the eruptives farther north. If these are not equivalent, the Michigamme jasper and these iron-bearing slates are the equivalents of the iron-bearing formation and the quartzite below it in the Marquette district, in which case the iron-bearing horizon of the Menominee may have an equivalent in the Marquette district.

VAN HISE, C. R. Summary of the pre-Cambrian North American literature: Jour. Geol., vol. 4, pp. 753-754. 1896.

In criticism of Winchell's conclusions that the greenstone-schists of the Lake Superior region constitute a single terrane, and that the bulk of them are pyroclastic, Van Hise declares that south of Lake Superior they constitute three distinct terranes in three distinct and unconformable series. Some of them are pyroclastic, some are extrusive, and some are intrusive in origin.

NEWETT, GEORGE A. Mines and Mineral Statistics, pp. 47-62. With map. 1896.

This is the report of the commissioner of mineral statistics for Michigan. So far as the Menominee district is concerned, it consists principally of a description of the condition of the various mines in the district. The map is an outline map showing the location of the principal mines on the range. Several sections through the Aragon mine and two through the Pewabic accompany the report. The longitudinal section through the Pewabic

mine exhibits the distribution of the high and the low phosphorus ores.

BIRKINBINE, JOHN. Iron ores: Seventeenth Ann. Rept. U. S. Geol. Survey, pt. 3, pp. 23-43. With maps. 1896.

The report of Birkinbine is almost wholly statistical. It, however, contains several maps of interest, one of which exhibits the location of the active, suspended, and abandoned mines in the Menominee district.

W. S. GRESLEY. Organic markings in Lake Superior iron ores: Science, n. s., vol. 3, pp. 622-623. 1896.

The author announces the discovery of markings resembling traces left by organisms in fragments of iron ore from the Chapin mine, Iron Mountain. The specimens showing the markings were picked up from the ore piles on the docks at Erie, Pa. They were submitted to Messrs. H. S. Williams, of Yale; Charles Schuchert and C. D. Walcott, of Washington; and C. R. Van Hise, of the University of Wisconsin. Some of them were pronounced by these gentlemen to be very similar to the trails left by worms in mud rocks.

[WINCHELL,, N. H.] Supposed pre-Taconic organisms: Am. Geologist, vol. 18, pp. 123-124. 1896.

Professor Winchell refers to the above note by Gresley in an editorial in which he declares that while the markings may be of organic origin, they will nevertheless "not be admitted as a demonstration of Archean life without a many-sided scrutiny, the more as all other similar claims seem to be so rapidly crumbling."

VAN HISE, C. R. Principles of North American pre-Cambrian geology: Sixteenth Ann. Rept. U. S. Geol. Survey, pt. 2, pp. 743-843. With maps and illustrations. 1896.

The major portion of this article is a discussion of the relations existing between the different rock series in North America that are of pre-Cambrian age. Among others, the Lake Superior region is discussed, but no special description is given of the Menominee district, although mention is made of it in several places. The Huronian in this district is divided into the Upper and the Lower Menominee series, the latter of which is in general equivalent to the Lower Marquette series, the corresponding members in the two being as follows:

Lower Marquette.	*Lower Menominee.*
Negaunee iron formation, 1,000-1,500 feet.	Slates bearing rich ores.
Siamo slate, including interstratified amygdaloids, 200-625 feet.	Michigamme jasper.
Ajibik quartzite, 700-900 feet.	Slates and altered acid and basic volcanics, maximum thickness, 2,000 feet.
Wewe slate, 550-1,000 feet.	Crystalline dolomite, 700-1,000 feet.
Kona dolomite, 550-1,375 feet.	Basal quartzite, 700-1,000 feet.
Mesnard quartzite, 100-670 feet.	

1897.

VAN HISE, C. R., and BAYLEY, W. S. The Marquette iron-bearing district of Michigan, with atlas, including a chapter on the Republic Trough, by H. L. Smyth. Mon. U. S. Geol. Survey, vol. 28, pp. 575-579. 1897.

In this volume the same discussion is given concerning the correlation of the Menominee and the Marquette rocks as is found in the preliminary account of the Marquette district, published by the same authors in 1895.

GRESLEY, W. S. Traces of organic remains from the Huronian (?) series at Iron Mountain, Mich., etc.: Trans. Am. Inst. Min. Eng., vol. 26, pp. 527-534. 1897.

This article contains descriptions of the fossil markings the discovery of which was announced by the author in 1896 (p. 114). For several years the ore piles on the docks at Erie, Pa., had been industriously examined with the view to discovering fossils that might be present in the ores. Since no ores are used at Erie except those of the Lake Superior region, it appears probable that the specimens obtained came from this region. On the authority of the dock superintendent the majority of the specimens described in the article are declared to have originated in the Chapin mine, at Iron Mountain. The markings are of various kinds, most of the varieties being represented by drawings on four plates. Of those thus represented some are thought to be the impressions of plants, others of corals, and others of footprints. The greatest number are thought to be trails left by crawling animals. One specimen resembles the mold of sun cracks. The best characterized of these markings are reproduced as Pls. VI and VII.

1899.

CLEMENTS, J. MORGAN, and SMYTH, HENRY LLOYD. The Crystal Falls iron-bearing district of Michigan; with a chapter on the Sturgeon River tongue, by William Shirley Bayley, and an introduction, by Charles Richard Van Hise: Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3; pp. 1-151. With 2 maps, 9 plates, and 6 illustrations in text. 1899.

In his introduction to this report Van Hise correlates the formations of the Marquette, Crystal Falls, and Menominee districts as follows:

MARQUETTE DISTRICT.	CRYSTAL FALLS DISTRICT.	MENOMINEE DISTRICT.
Upper Marquette series.	*Upper Huronian.*	*Upper Menominee.*
(1) Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation.	(1) Michigamme formation, bearing a short distance above its base an iron-bearing horizon.	(1) Great slate formation.
(2) Ishpeming formation, composed of the Goodrich quartzites in the eastern part of the district and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	(2) Quartzite in eastern part of district.	
(Unconformity.)	(Unconformity.)	(Unconformity.)
Lower Marquette series.	*Lower Huronian.*	*Lower Menominee.*
(1) Negaunee iron formation, 1,000 to 1,500 feet.	(1) The Groveland formation, about 500 feet thick.	(1) Vulcan iron formation, containing slates.
(2) Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick.	(2) Hemlock volcanic formation, 1,000 to 10,000 feet thick. In western part of district also occupies the place of (1) and (3).	(2) Antoine dolomite.
(3) Ajibik quartzite, 700 to 900 feet.		
(4) Wewe slate, 550 to 1,050 feet.	(3) Mansfield formation, 100 to 1,900 feet thick.	
(5) Kona dolomite, 550 to 1,375 feet.	(4) Randville dolomite, 500 to 1,500 feet thick.	
(6) Mesnard quartzite, 100 to 670 feet.	(5) Sturgeon quartzite, 100 to 1,000 feet thick.	(3) Sturgeon quartzite.
(Unconformity.)	(Unconformity.)	(Unconformity.)
Archean.	*Archean.*	*Archean.*

PLATE VI.
ORGANIC MARKINGS IN THE LAKE SUPERIOR IRON ORES. AFTER GRESLEY.

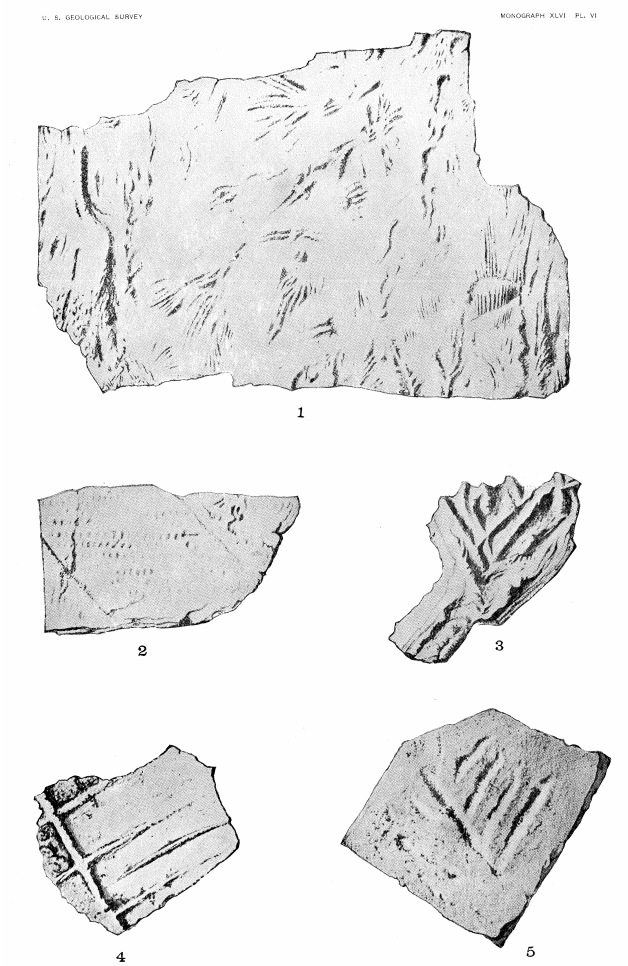
FIG. 1.—Probably remains of marine plants or corals (?). *Oldhamia* (?). On a thin layer of softish, fine-grained, sandy, purplish iron ore. Locality, Chapin mine, Iron Mountain, Mich. Magnified two diameters.

FIG. 2.—Shows roughly-parallel rows of small, shallow depressions; some plant (?), or possibly flattened tracks of some crawling animals, on the surface of a layer or band of red, earthy iron ore. Locality uncertain.

FIG. 3.—Perhaps casts of remains of plant stalks. On the surface of a fragment of purplish-red ore. Locality uncertain, but the same as that of fig. 2.

FIG. 4.—Perhaps filled-up sun cracks. Occurring as ridges on laminæ of a fragment of soft, blue iron ore. Locality unknown, but the same as that of figs. 2 and 3.

FIG. 5.—Perhaps the imprint of the cast or mold of a fragment of a marine plant. On the surface of softish laminæ of red hematite. Locality unknown.



ORGANIC MARKINGS IN THE LAKE SUPERIOR IRON ORES. AFTER GRESLEY.

PLATE VII.
ORGANIC MARKINGS IN THE LAKE SUPERIOR IRON ORES—AFTER GRESLEY.

FIG. 1.—Tracks of crawling animals on nearly flat surface of a slab of bluish-purple laminæ of sandy iron ore. Note the parallelism of these tracks. The grooves running diagonally across them may have been made by plants scraping over the bottom of the sea or lake. Locality, Chapin mine, Mich.

FIG. 2.—A few individual footprints of 1, enlarged four times.

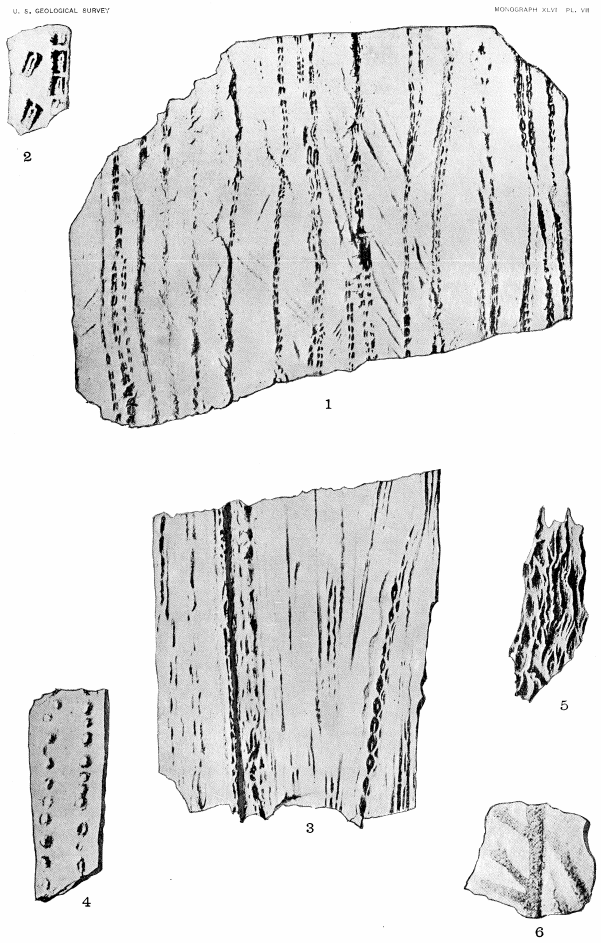
FIG. 3.—Possibly plant remains, or animal tracks (?) apparently somewhat side squeezed. On a surface of a fragment of a band of fine-grained purplish-red iron ore. On the reverse or opposite side of this specimen (which is about three-fourths inch thick) are very uniform parallel striæ of fine grooves, very suggestive of flattened bark or ribbed plant structure. Locality, Chapin mine, Iron Mountain, Mich.

FIG. 4.—Probably track of some crawling animal. Upon a bedding plane of a bit of soft, sandy, purplish iron ore. Locality uncertain.

FIG. 5.[a]—About one-eighth of the surface of one side of a fragment of soft, bluish, fine, sandy iron ore, exhibiting side-squeezed (?) or distorted animal footprints (?), distorted rain spots (?), or shriveled plant remains (?). Locality uncertain.

FIG. 6.—Possibly a bit of a marine plant. On the surface of purplish laminæ of ore. Locality, Chapin mine (?), Iron Mountain, Mich.

[a]Compare with this parts of figs. 1 and 2 of Pl. VI.



ORGANIC MARKINGS IN THE LAKE SUPERIOR IRON ORES. AFTER GRESLEY.

He states that in the Menominee district there appears to be no quartzite at the base of the Upper Huronian corresponding to the Ishpeming quartzite in the Marquette district, nor is there in the former district any great volcanic formation corresponding to the Clarksburg formation of the Marquette area. The Lower Huronian formations in the three districts are practically parallel, except for the volcanic deposits in the Crystal Falls district.

The distribution of the formations in the three districts indicates that the transgression of the Huronian sea was from the southeast toward the northwest; the Menominee area having been submerged before the central portion of the Crystal Falls district and the western part of the Marquette district. Practically the same view is expressed by Smyth in Chapter V of the report (pp. 140-145), as the result of magnetic observations west of Republic.

CLEMENTS, J. MORGAN, and SMYTH, HENRY LLOYD. The Crystal Falls iron-bearing district of Michigan, with a chapter on the Sturgeon River tongue, by Wm. Shirley Bayley, and an introduction by Charles Richard Van Hise: Mon. U. S. Geol. Survey, vol. 36. With 18 maps, 36 plates, and 24 figures in the text. 1899.

This report contains a more detailed account of the geology of the Crystal Falls district than that referred to in the immediately preceding paragraphs. So far as the Menominee district is concerned, it contains practically the same statements as the preceding article.

NEWETT, GEORGE A. Mines and Mineral Statistics of Michigan. 1899.

The annual statistical and mine report of the commissioner of mineral statistics for Michigan contains the usual statistics of the Menominee and other ore districts and items of interest concerning the mines.

1900.

VAN HISE, C. R., and BAYLEY, W. S. Description of Menominee district: Geologic Atlas U. S., folio 62, U. S. Geol. Survey. With geologic and topographic maps. 1900.

This is a preliminary report on the geology of the Menominee district. Its conclusions are practically the same as those embodied in the present monograph, of which it is actually a summary. The geological map is less complete than that accompanying the present volume, since several areas on the former were left without the color of any of the formations of the district because of lack of evidence as to the nature of the underlying rock.

The correlation of the various formations in the different iron-ore districts on the south side of Lake Superior is given as follows:

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

PENOKEE DISTRICT.	MARQUETTE DISTRICT.	CRYSTAL FALLS DISTRICT.	MENOMINEE DISTRICT.
Lake Superior sandstone.	Lake Superior sandstone.	Lake Superior sandstone.	Lake Superior sandstone.
(Unconformity.) Keweenaw series. (Unconformity.)	(Unconformity.)	(Unconformity.)	(Unconformity.)
Upper Huronian.	*Upper Huronian.*	*Upper Huronian.*	*Upper Huronian.*
1. Upper slate member.	1. Michigamme formation (locally replaced by Clarksburg volcanic formation). One might divide the Michigamme sedimentary formation into three members: (a) Upper slate member.	1. Michigamme formation (consists of three members equivalent to those of the Marquette district, but 2 and 3 given below can be separated in mapping only in the southern part of the district).	1. Hanbury slate, bearing in lower portion calcareous slates, etc., containing siderite.
2. Iron-bearing member. (In east part of the district volcanic fragmentals are associated with 1 and 2.)	(b) Iron-bearing member.	2. Groveland iron-bearing formation in southern part of district.	2. Vulcan formation consisting in descending order of— (a) Curry iron-bearing member.
3. Quartz-slate member, having— (a) A thin belt of quartzite at its top; (b) A main belt of slate below; and (c) A thin belt of quartzite at its bottom at various localities.	(c) Lower slate member. 2. Ishpeming formation of quartzites and detrital ores, and the Bijiki schists in western part of district.	3. Mansfield slate.	(b) Brier slate. (c) Traders iron-bearing member.
(Unconformity.)	(Unconformity.)	(Unconformity.)	(Unconformity.)
Lower Huronian.	*Lower Huronian.*	*Lower Huronian.*	*Lower Huronian.*
(Evidence of the former existence of an iron-bearing member above the cherty limestones is seen in the presence of ore and jaspilite grains in basal portion of quartz-slate member. 1. Cherty limestone member.	1. Negaunee iron-bearing formation. 2. Siamo slates, containing interstratified amygdaloids. 3. Ajibik quartzite. 4. Wewe slate. 5. Kona dolomite.	1. Negaunee iron-bearing formation in northeastern part of district. 2. Hemlock volcanic formation. 3. Randville dolomite.	1. Negaunee iron-bearing formation. 2. Randville dolomite.
	6. Mesnard quartzite.	4. Sturgeon quartzite.	3. Sturgeon quartzite.
(Unconformity.)	(Unconformity.)	(Unconformity.)	(Unconformity.)
Archean.	*Archean.*	*Archean.*	*Archean.*

In the table it will be noted, by comparing the column given for the Crystal Falls district with that contained in Monograph XXXVI of the United States Geological Survey, that the succession has been somewhat changed. When the monograph was published, it was supposed that the Groveland iron formation and the Mansfield slate of the southern part of the district belong in the Lower Huronian; but the work in the Menominee district shows beyond reasonable question that these formations, which have a comparatively small areal extent in the Crystal Falls district, really belong in the Upper Huronian.

Discrepancies in columns.—In the four districts the correlation of the series placed opposite one another and separated by the unconformities, and the correlation of the unconformities, may be regarded as practically certain; also the correlation of individual members within the parallel series has in many cases a very high degree of probability. However, an examination of the table shows various discrepancies. These discrepancies are due in a given case to one or more of the following causes:

During the time a series or formation was being deposited throughout all or a part of one district, all or a part of another district was still undergoing erosion. As the sea advanced overlap resulted. * * *

The inter-Huronian erosion cut to different depths in the different districts, as a consequence of which formations of the Lower Huronian may have been largely removed in one district and may have been comparatively untouched in another. * * *

A formation may have a greater vertical range in one district than in another; the conditions may have remained uniform in one district, and therefore deposits of the same kind continued, while the conditions changed in another district, and therefore more than one formation was deposited. * * * The order of formations in the Upper Huronian might at first thought be regarded as very different in the various districts. However, if one reduces the order of succession to a general statement, it is as follows: (1) An upper fragmental slate member; (2) an

iron-bearing member, largely nondetrital; and (3) a lower fragmental member, which consists of quartzites, slates, and, at its base in some districts, large quantities of fragmental iron-formation material.

* * * * * * *

The attempt to correlate the various formations of the two Huronian series in the four different iron-bearing districts south of Lake Superior shows very significantly that the geologic history of pre-Cambrian time was extraordinarily complex. From Archean to Cambrian time, in the Marquette, Crystal Falls, and Menominee districts, the areas three times emerged from the sea and were three times overridden by the sea. In the Penokee district there was a fourth emergence and transgression of the sea. The epeirogenic or land-making movements were accompanied by orogenic movements, or mountain growths, of varying power, but some of them exceedingly intense. In Huronian time, in all the districts except the Menominee, there were important and long-continued periods of volcanism. The great events of Keweenawan time are only mentioned, since they do not particularly concern the Menominee district. The erosive forces at periods when the districts were land areas found rocks of very different characters. Here they were resistant; there easily denuded. As a consequence, when the sea encroached at the close of Archean, Lower Huronian, and Upper Huronian times, the country in detail was very irregular—was, in fact, bluffy, but not mountainous. Therefore certain areas were covered by the sea, while other immediately adjacent areas were above the water and were being- actively eroded. As a consequence of all these complex conditions have unconformity, overlap, changes in the characters of contemporaneous sediments along the strike and across the strike, disturbances in the successions due to volcanism, close folding and attendant metamorphism, and all of these phenomena in a region which is largely covered by glacial drift.

VAN HISE, C. R. The iron-ore deposits of the Lake Superior region: Twenty-first Annual Rept. U. S. Geol. Survey, pt. 3, with maps and other illustrations. The Menominee district, pp. 388-400. 1901.

In this paper Van Hise gives a summary of the facts known concerning the geology of the various iron-ore producing districts in the Lake Superior region, and a brief discussion of the processes that resulted in the deposition of the ores.

The account of the Menominee district is, in the main, abstracted from the preliminary report on the district by Van Hise and Bayley (see p. 121). The development of the Menominee ores is said to combine the features that characterize the development of the ore deposits that occur in the Penokee-Gogebic and the Marquette districts. The occurrence of the ore bodies is declared to be in practically every case on the lower portions of slopes; that is, at the places where descending waters have been converged from a wide variety of sources. The time of the concentration must have been after the folding which produced the troughs in the district and after the period of erosion which removed the Hanbury slates that once covered the ore formations; that is, in the interval between Upper Huronian and Upper Cambrian times.

The map of the Menominee district accompanying the paper is a reproduction of that published in folio 62 of the Geologic Atlas of the United States.

CHAPTER III. PHYSIOGRAPHY.

TOPOGRAPHY.

The Menominee district is but a small portion of a large area, which lies between Green Bay and Lake Superior and the margin of the valley of the Mississippi River, and which may be characterized physiographically as a southeasterly inclined peneplain. In that portion of the area discussed in the following pages the relief is strong, though in no sense mountainous. The highest elevation is in Hughitt Bluff, at Iron Mountain, the top of which is between 1,560 feet and 1,580 feet above sea level. The banks of the Menominee River, where this stream leaves the area, have an altitude of 800 feet. While this difference in height is only 760 or 780 feet the slopes of the elevations are comparatively steep. The heights of the hills are thus emphasized and the surface of the area appears to the eye much more rugged than it actually is (see map, Pl. VIII).

The Huronian trough, or the Menominee district proper, as has been explained, lies between the Menominee River on the south and an area of granite and schist knobs on the north. Its surface comprises two plains sloping gradually toward the southeast. The lower one, which has an elevation of about 1,000 feet in the center of the district, gradually rises to 1,200 feet in its extreme northwestern portion and descends to about 900 feet in its extreme southeast corner. It also inclines southward toward the Menominee River at the rate of about 25 feet to the mile. This plain forms the valleys between the residuals of the higher plain which constitute the hills.

The higher plain, like the lower one, slopes to the southeast. In the western portion of the area its surface is at an elevation of about 1,500 feet, while in the eastern portion, near the Sturgeon River, it recedes to 1,200 feet. Only a few remnants of the higher plain remain. They are arranged in two series, constituting two well-defined ranges of hills trending a little south of east, or in the direction of the prevailing strike of the Huronian rocks composing them. In nearly every instance the hills consist very largely, if not exclusively, of the hard, vertical, or nearly vertical, Randville dolomite, and of the even more resistant jaspilites of the Vulcan formation, and are topped by the horizontal beds of the Lake Superior sandstone. The intervening valleys between the hills are underlain mainly by the soft slates of the Hanbury formation, although along the northern border of the trough the valley floor may extend across a narrow belt of the Randville dolomite.

The plan of the topography thus corresponds very closely with the geological structure of the district. The ridges follow the strike of the more resistant rocks and

end where these pitch beneath the overlying softer slates. The valleys occupy the synclines of slate between the anticlines of the harder rocks and open out toward the west to correspond with the widening out of westward-pitching synclines of the softer rocks. Glacial deposits have modified to some extent the perfection of the plan, but they have not affected the topography greatly, except in the northwest corner of the area, where high and irregularly shaped sand hills constitute all the elevations.

DRAINAGE.

The area is drained by two longitudinal streams, the Menominee River, where it borders the area on the south, and Pine Creek, and by two cross streams. The latter are the Menominee River, where it borders the area on the west, and the Sturgeon River near its eastern side.

The major streams traversing the district—the Menominee and the Sturgeon rivers—are both apparently antecedent. They both cross the hard rock beds transversely to their strike and flow through gorges over cataracts and rapids. The Menominee River shows its disregard of the geological structure by cutting indifferently through crystalline greenstones and soft sand and clay deposits. Along the southern side of the district its meanders wind in and out of the green schist area, always keeping near the boundary between the schists and the Hanbury slates. Where the stream enters and leaves the schist area there are falls, and within the area its channel is marked by many small cascades and rapids (see pp. 132-133).

The Sturgeon River enters the district near its northeast corner and flows across it for a distance of 6 miles. Where its channel traverses the quartzite bordering the north side of the trough is one of the most picturesque and wildest gorges in the Upper Peninsula of Michigan. This gorge is only a few hundred feet in length, but its walls, cut in snow-white quartzite, rise almost perpendicularly above the bed of the stream, confining the water to a narrow channel, through which it rushes with great rapidity over several little cascades.

The principal drainage of the district is through Pine Creek, which, though small in volume, extends nearly the entire length of the trough. It has been referred to above as a longitudinal stream; and, within the limits of the Menominee district, as defined in the preceding chapter, its course is longitudinal. Just beyond the boundary of the area, however, it crosses the quartzite belt in a narrow gorge, known as the “rock dam” (see pp. 189-192), where it is transverse.

The stream rises some distance north of the Menominee area and enters the district from the north. It flows south for a few miles after entering the district and then turns to the southeast, keeping very close to the base of the quartzite bluffs forming the northern side of the Huronian synclinorium. In its southeast course it follows a belt of dolomite lying south of the quartzite until within a few miles of its mouth. Here it crosses a slate valley to its center and then turns abruptly eastward and follows along the north side of a more southerly belt of dolomite to the Loretto mine, where it empties into the Sturgeon River. Through most of its course its bed is composed of sand and gravel, and nowhere within the confines of the district mapped does it reach the underlying rocks.

ORIGIN OF THE TOPOGRAPHY.

It appears quite evident that Pine Creek, with its present small volume of water, could not have carved the large valley in which it flows. It is also plain that the wide valley floors with the residuals of a higher plain rising above them could not have been the result of the action of the present Menominee River. The higher ridges are much nearer the channel of this river than they are to the channel of Pine Creek. Moreover, there is no distinct valley on both sides of the river which is at all commensurate in size with the magnitude of the river. The country to the south of the river has not been mapped, but the impression gained while traveling across it is to the effect that a distinct valley is lacking. This is in accord with the view that the Menominee is in its present position a new stream that has been turned from its old course by recent events.

The major features of the topography of the district not only antedate the Glacial epoch, but they were determined before Upper Cambrian time. Not only are the hills of the region capped by the horizontal Upper Cambrian sandstone, but remnants of this formation have been found in the cross gorges at Iron Mountain, Quinnesec, and Norway, and in the longitudinal valleys at several places. At Iron Hill a miniature sandstone mesa, with perpendicular sides 10 feet high, stands near the banks of the little stream near the quarter post between secs. 32 and 33, T. 40 N., R. 29 W. It is entirely isolated from the surrounding rocks and is plainly a remnant of a bed that once completely occupied the lowlands.

Although very resistant to weathering agencies, the sandstone has, nevertheless, been almost completely removed from the valleys, while it has escaped erosion mainly on the tops of the ridges. The topography which has resulted from the removal of this covering is therefore very similar to that which characterized the surface at the beginning of Upper Cambrian time. The present valleys correspond to the pre-Cambrian valleys and the present hills to elevations that existed on the pre-Cambrian[a] surface. The floors of the valleys may have been lowered somewhat since the sandstone disappeared, but since the bases of sandstone remnants are in several widely separated localities either at the present valley surfaces or only a few score feet above them, the differences in elevation between the pre-Cambrian valley floors and those of the present valleys can not be great.

The present topography of the district is thus mainly resurrected pre-Cambrian topography. It had its origin in

the interval between Huronian and Upper Cambrian times, and was protected until very recently by the blanket of sand laid down upon it by the Upper Cambrian sea. If erosion was no more rapid in early Cambrian time than in later time, the interval between Huronian time and Upper Cambrian time must have been extremely long.

[a]The term "pre-Cambrian" is here used to cover that portion of time antecedent to the time represented by the Lake Superior sandstone, which belongs in an Upper Cambrian horizon. Rocks of Lower and of Middle Cambrian age have not yet been identified in the Lake Superior region.

PRE-CAMBRIAN TOPOGRAPHY.

The pre-Cambrian topography, though in the main similar to that of the present, nevertheless differed from it in some minor respects. The hills of the earlier period were not so lofty as those now existing, but they were sharper and more rugged. Moreover, both hills and valleys were cut by deep and narrow gorges, which have been preserved to us by sandstone fillings. The Cuff mine, for example, is situated at the top of an ancient north-facing bluff, for the sandstone, which forms a thin covering over the surface at the shaft, is found again at considerable depths at the north ends of the mine levels. Prospect Bluff was narrower in these earlier times. Its north side sloped steeply and its apex was sharp. A deep gorge crossed Hughitt Bluff on the property of the Pewabic mine. North of the Quinnesec mine, well up on the slope of a high hill, was formerly a deep basin in which were accumulated bowlders of ore and hematite sand worn from shores carved in Huronian rocks. Finally, drill borings have shown that a deep and narrow channel crossed the plain east of the Norway mine.

The surface upon which the sandstone was laid down was then, apparently, rougher than that of the present time, although in their major features the topography of the pre-Cambrian land surface and that of the present land surface were similar. The presence of gorges and valleys in the pre-Cambrian land surface at places where they do not now exist may explain the occurrence of ore deposits in certain positions within the Menominee area where the present topographic conditions are not especially favorable to their development (see p. 401).

CHAPTER IV.
THE ARCHEAN SYSTEM.

The sediments composing the Menominee trough are bordered on the north for nearly their entire extent by a complex of granites, gneisses, hornblende-schists, and a few greenstone-schists that are cut by dikes of diabase and dikes and veins of granite. This has been designated the Northern Complex,

On the south, along the Menominee River, the trough is bordered by a series of dark-green or black basic schists and light-colored acid schists, designated hereafter as the Quinnesec schists. These are cut by large dikes of gabbro, diorite, and diabase; by smaller dikes of granite, quartz-porphyry, and felsite; and by veins of quartz. The porphyries and many of the granite dikes are apophyses of a large mass of granite which intrudes the schists and constitutes a boss whose surface occupies hundreds of square miles in Wisconsin. No portion of this boss falls within the limits of the Menominee district. Its northern boundary approaches within one-half or three-quarters of a mile of the Menominee River at the Big Quinnesec Falls, but only a few of its apophyses cross the river into Michigan. It is this granite which Brooks regarded as Huronian in age (see p. 61). It undoubtedly intrudes the Quinnesec schists and is younger than these; but that it is as young as Brooks supposed is doubtful, since none of its apophyses intrude the Lower Huronian sediments. It is to this complex of acid and basic schists, cut by dikes, that the name Quinnesec schists is applied. A second area of Quinnesec schists occurs in the central part of the west end of the trough. Only its east end comes within the limits of the map. It appears as a narrow wedge-shaped, area widening toward the west. It is surrounded on the north, east, and west sides by the Menominee sediments. To the west it crosses the Menominee River into Wisconsin, where it has not yet4been studied in detail. The rocks are greenstone-schists and ellipsoidal greenstones, cut here and there by basic dikes. The area bordering the Menominee River to the south of the trough is referred to in the following pages as the southern area of Quinnesec schists, and that within the west portion of the trough as the western area.

SECTION 1. QUINNESEC SCHISTS.

RELATIONS TO OVERLYING FORMATIONS.

In neither the southern nor the western areas have contacts of the Quinnesec schists with the sedimentary rocks of the Huronian series been seen. There is no positive proof that the green schists are older than the Huronian rocks. There can be little doubt, however, that the schists belong in the Archean. They have all the complex lithological and structural features that are recognized as characteristic of typical Archean greenstone-schists elsewhere. They are mainly volcanic or intrusive rocks which have been subjected to intense metamorphism and which, in consequence of this, have acquired a marked schistosity. No ordinary sediments have been discovered among them. Moreover, the schists are in every respect identical with similar schists in the Marquette district of Michigan that have been demonstrated to be unconformably beneath the Lower Huronian sediments[a] of that district, and they are also identical with greenstone-schists in the Vermilion district of Minnesota that possess similar relations to the oldest Huronian sediments of that district.

Exposures of the two series are found in closest proximity on the Menominee River near the Fourfoot Falls. The Chicago and Northwestern Railway bridge crossing the river at this place is built on ledges of the schist. Below the bridge is a long exposure of black

slate belonging to the Hanbury formation of the Upper Menominee. The schists and the slates are separated by a distance of about 150 paces, and this interval is occupied by sand and glacial drift (see also p. 289).

[a]Mon. U. S. Geol. Survey, vol. 28, 1897, pp. 152-168.

THE SOUTHERN AREA.

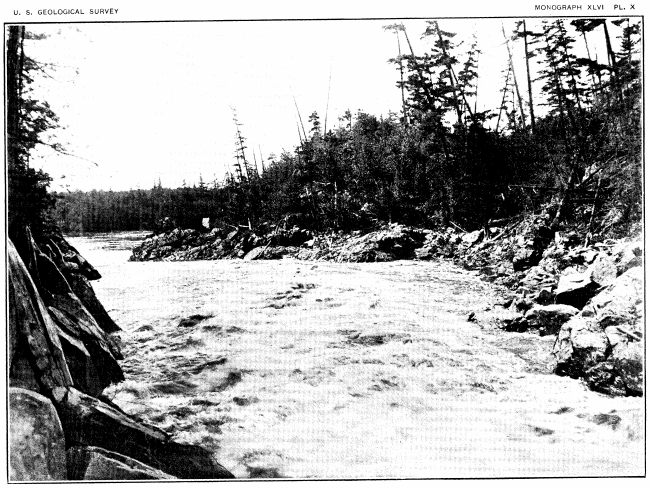
DISTRIBUTION.

The southern area of Quinnesec schists borders the south side of the Menominee trough. Its northern boundary extends along the Menominee River from a point a short distance below the mouth of Pine Creek to the eastern limit of the area mapped. The line enters Michigan at the south town line of T. 40 N., R. 31 W., runs a little south of east to the Big Quinnesec Falls, where it crosses to the Wisconsin side and continues its course in a nearly straight line to the Little Quinnesec Falls. Here it recrosses the river into Michigan, where it remains. From the Little Quinnesec Falls it runs approximately parallel to the stream as far as the mouth of the Sturgeon River. At this point it leaves the river, runs nearly southeast to the southeast corner of T. 39 N., R. 28 W., and then a little south of east to the southeast corner of sec. 4, T. 38 N., R. 28 W., where it is lost beneath a covering of sand. The southern boundary of the schists has not been definitely determined. It is somewhere in Wisconsin, a considerable distance south of the Menominee River, which is practically the limit of the area discussed in this report.

TOPOGRAPHY.

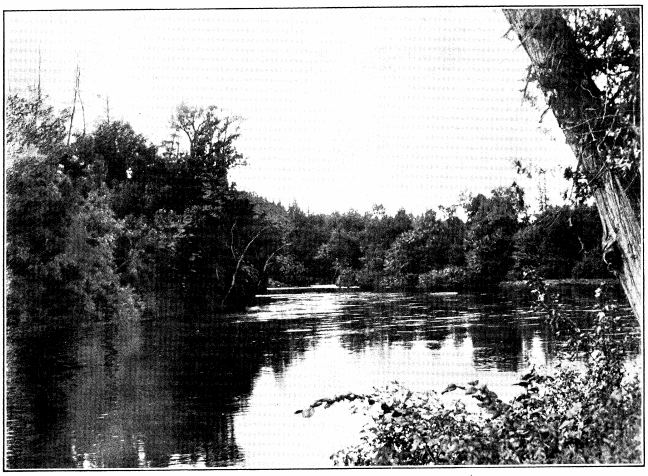
The topography of the southern area underlain by Quinnesec schists is rough and broken, at least it is so over most of the valley of the Menominee River, where the area has been most carefully studied. In the bed of the river, where the channel is cut through the schists, are great ledges of rocks forming rapids and falls, and along its banks are often craggy precipices and shelving rock walls. Three noted falls exist within that portion of the district here described. These are the Big and the Little Quinnesec Falls and Sturgeon Falls (Pl. X, A), all of which are over the harder and more massive ledges of the schists or of the intrusives associated with them. The most famous rapids are the Horserace Rapids (Pl. XI, A), the head of which is situated a few hundred yards below the bridge of the Chicago, Milwaukee and St. Paul Railway. At this place the river dashes through a narrow rock-walled gorge, over a rough and rugged, channel in a series of plunging falls and seething caldrons. The schists here have been greatly metamorphosed by the intrusion through them of enormous dikes of .granite and porphyry. These harder portions produce the falls and the softer, less metamorphosed portions between the intrusions give rise to the caldrons. Although less than half a mile long, the Horserace is dreaded by the lumberman more than any other stretch in the river, since here are formed every year great jams of logs that are extremely expensive to break. In Pl. XI, *B*, is shown the rock-bound channel filled with logs. Between the various falls and rapids are comparatively long stretches of quiet water (Pl. X, *B*). The general character of the stream may be judged from the fact that the fall of the river is about 260 feet in the 20 miles of its course between the point west of Iron Mountain, where it enters the southern area of schists, to the point where it crosses the east range line of T. 38 N., R. 29 W., near the southeast limit of the map. When it is realized that only about 14 miles of this course is in the schists, and that in this distance nearly all the fall is made, some idea may be gained as to the roughness of the stream. The fact that more than half of this fall is made at Sturgeon Falls and at the Big and Little Quinnesec Falls, affords abundant opportunity for the development of immense power at these localities when economic conditions for its utilization are more favorable than they are at present. At the Little Quinnesec Falls, where about 10,000 horsepower is available for use, there is now a paper mill which employs less than half of this power, and at the Big Quinnesec Falls is an air-compressor plant. The greater portion of the power of the stream in this area is, however, not used for any purpose.

U. S. GEOLOGICAL SURVEY MONOGRAPH XLVI PL. X



A. VIEW FROM BRINK OF STURGEON FALLS, LOOKING DOWNSTREAM.

The barrier rock is a saussuritized gabbro, seen to the left. The rocks to the right, limiting the basin below the falls, are gabbros and schists derived from gabbros and diabases.



B. MENOMINEE RIVER ABOVE STURGEON FALLS.

One of the quiet basins in the Quinnesec schist area produced by the backwater above the falls.

[Plate X. *A*, View from brink of Sturgeon Falls, looking down stream; *B*, Menominee River above Sturgeon Falls]

Away from the river the country underlain by the schists is very rough, though lofty eminences and deep valleys are not noticeable. The topography is made up of many ridges and elongated hills having steep slopes covered with thin layers of soil, or precipitous sides of bare rock. On the tops of the hills bare flat ledges are met with, here and there covered with patches of soil an inch or so thick.

On the Michigan side of the river a thick mantle of sand and glacial drift lies upon the schists and obliterates their characteristic topography, but very close to the river bank, where recent erosion has removed the sand, and along the Wisconsin shore, for a few miles from the bank, the rugged nature of their surface is well shown.

COMPOSITION AND STRUCTURE OF THE ROCK SERIES.

The Quinnesec schists of the southern area consist mainly of schistose basic and acid igneous rocks and a few basic tuffs.[a] The former comprise chlorite-schists, amphibolites, schistose diabases, schistose diorites, and schistose gabbros. With these are large, almost massive layers of gabbro and diorite that are supposed to be interbedded sills or flows, and dikes of gabbro, diorite, diabase, and granite. The basic schists constitute by far the greater part of the schists of the area, but in the vicinity of the Horserace Rapids and of the the Big Quinnesec Falls, the basic rocks are associated with large quantities of acid ones. The acid rocks are in some places nearly massive granites, in other places they are gneisses, and in still other places they are finely banded and schistose rocks like the Saxon granulites. The last-named rocks occur in bands of different widths, nearly always striking conformably with the strike of the foliation of the basic schists with which they are associated. The schistosity of the bands is parallel to the schistosity of the adjoining schists, irrespective of the direction of the band itself. Although rather irregular in their distribution, the different schists may be observed to occur in more or less well-defined belts extending for comparatively short distances in. approximately straight lines. These belts strike a little north of west at the Sturgeon Falls, a little south of west at the Little Quinnesec Falls, and about northwest at the Big Quinnesec Falls. Their schistosity strikes approximately parallel to the trend of the belts, but not always exactly so. The dip varies slightly in different ledges, but is never far from perpendicular. On the northern and eastern peripheries of the granite boss in Wisconsin the foliation of the schists is very well developed. Here the schistosity is nearly parallel to the contacts with the granite, changing with the trend of this boundary and following in a general way its sinuosities. This fact suggests that the schistosity of these rocks is due to pressure and that its direction is determined by the directions of the lines along which the stresses acted, i. e., along lines at right angles to the boundary of the granite boss.

[a]Although tuffs are only rarely found in the area included in this study, they are by no means rare in the extension of the schist area south of the Menominee River. About midway between this river south of Norway and the "Soo" Railroad in Wisconsin, there are great hillocks and bare bluffs that are composed exclusively of coarse greenstone conglomerates like those so abundant in the northern Archean complex in the Marquette district, and interlaminated beds of fairly well-banded greenstone tuffs. The area has not been studied, but from the great magnitude of these deposits at the locality referred to, it appears probable that volcanic fragmentals play a much greater part in the constitution of the Quinnesec-schist complex than would be inferred from studies confined to that portion of the schist area in the neighborhood of the Menominee River.

LITHOLOGY.

There is very little to add to the account of the lithological features of the Quinnesec schists given by Williams[a] in his bulletin on the Marquette and Menominee greenstone-schists. In this report the author presents excellent descriptions of all the various forms of schists met with along the Menominee River and describes in detail the character of the intrusion traversing them. There seems to be no need of duplicating these descriptions in the present volume. In the following pages a brief summary of Williams's discussion will, however, be given, and a few additions will be made to his descriptions in order that the great similarity between the Archean in this and other districts may be clearly perceived, and that the great contrast always existing between the Archean and the Huronian rocks of the Lake Superior region may again be emphasized.

[a]Williams, George Huntington, The greenstone schist areas of the Menominee and Marquette regions of Michigan, with an introduction by Roland Duer Irving: Bull. U. S. Geol. Survey No. 62. 1890.

For purposes of description the Quinnesec schists may be divided into greenstone-schists, chlorite-schists, amphibolites, gneisses, and sericite-schists. The massive rocks associated with them may be classed as greenstones and granite. The greenstones include gabbros, diorites, diabases and basalts; the granites include granite and granite-porphyry. Because of the close genetic relationship existing between the greenstones and the greenstone-schists on the one hand and between the granites and the acid schists on the other hand, the former will be described together, as will also be the latter.

GREENSTONE-SCHISTS AND ASSOCIATED GREENSTONES.

The term greenstone-schists is applied to those basic schists which show clearly by their composition and structure that they were derived from basic igneous rocks. They grade on the one side into massive gabbros, diorites, diabases, basalts, and basic tuffs, and on the other side into the chlorite-schists and amphibolites. Specifically they might be termed gabbro-gneisses, diorite-gneisses, etc., but their present mineralogical and chemical composition is so different from that of the corresponding massive rocks that it is thought best to refer to them under the generic term greenstone-schists. The term is a convenient one, partly because it is so comprehensive, and partly because some such term is absolutely necessary to the prosecution of field work in regions of ancient schist

complexes. The term comprehends all dark-colored schistose feldspathic rocks derived from massive igneous rocks and their tuffs. In the Menominee district the greenstone-schists comprise schistose gabbros, diabases, diorites, basalts, diabase tuffs, and basalt tuffs. They vary in color from greenish gray to greenish black, in texture from coarse grained to aphanitic, and in structure from almost massive to perfectly schistose. The more massive phases are sometimes poikilitic. The finer-grained rocks are usually more schistose than the coarse-grained ones, though not always so. The most perfect schistosity, amounting almost to perfect fibrosity, is met with only in the aphanitic phases. The rock of nearly every exposure, or at least of every group of exposures, possesses a characteristic appearance which differs from that of corresponding rocks of other ledges, so that a detailed description of the macroscopic features of all the different greenstone-schists of the district would be nothing more or less than a description of individual specimens. The same statement applies to the description of the massive greenstones. A detailed description of this kind does not seem necessary in this place, especially since Williams has so well described nearly all the several phases of the greenstones and their schists in the bulletin referred to above. Only the principal and predominating types of the schists will be described in the-following pages, the unusual types being referred to only in the descriptions of interesting localities.

COARSE-GRAINED VARIETIES.

The material of the coarse-grained schists, which may represent dikes, or flows of coarse lavas in a series of finer-grained lavas, differs very little from the material of the coarse-grained, massive greenstone dikes cutting through the schist series. Most of these rocks are light-gray diabasic aggregates of a white feldspathic mineral and a greenish-gray hornblendic one, with occasionally here and there an irregular grain of magnetite or ilmenite. Others are darker in color and greener in tinge. In these the hornblendic mineral predominates and the feldspar is often epidotized. In most specimens the feldspar is in diabasic forms, in others it is in the irregular grains characteristic of gabbro, and in still others it is in rounded phenocrysts. Near slickensided surfaces the characteristic gabbro or diabasic structure disappears, and the rock becomes a typical chlorite-schist or amphibole-schist.

Gabbros and their derived schists.-—The barrier rock of Sturgeon Falls (see Pl. X, A) is an excellent example of one of the most massive phases of the coarse-grained rocks. It is not known whether it is a dike or an immense flow. It exhibits many lithological features of the massive dikes, and at the same time it possesses phases that are identical in character with those of many of the coarser-grained schists.[a] The most massive phase of the rock is light gray in color. On a fresh fracture it is mottled in white and dark-greenish gray, the consequence of the presence of a greenish-white feldspar and a brownish, lustrous amphiboloid. The texture is moderately fine, but is subject to sudden local variations which develop comparatively coarse-grained patches in the main mass. Under the microscope the rock is discovered to be a gabbro in which there still remain remnants of colorless diallage, but in which the plagioclase has been almost wholly altered to a gray and opaque saussurite. Most of the original diallage has been changed to a compact brown amphibole, which, together with calcite, albite, chlorite, and quartz, are the principal secondary products present. All specimens exhibit the action of dynamic forces that have more or less profoundly affected the different constituents.

[a]Cf. Williams, op. cit., p. 68.

The rock seems in places to have been crushed and a mosaic of the component minerals to have been formed. Hornblende, generally colorless, is unusually abundant. Colorless chlorite and zoisite are also developed, and all are mixed indiscriminately. In one part of the section a vein is seen to traverse the rock. This is filled with limpid quartz in long, wedge-shaped areas, which extend from one side of the small fissure to the other. This quartz is traversed by long, colorless fibers of the greatest delicacy, and it also contains a good deal of the colorless chlorite, both in solid masses and in those peculiar vermicular groups to which Volger has given the name helminth. These curious groups, which resemble piles of little coins, are sometimes straight, sometimes curved. They are so minute as to be visible only with a high magnifying power.[a]

In the more schistose phases of the rock the constituent minerals, while the same as those in its less schistose phases, have suffered much greater changes.

The feldspar is remarkably fresh and its twinning lamellae are quite distinct, but it is everywhere crushed, broken, and faulted. The crystals are often plainly seen to be separated into a number of fragments which are removed a considerable distance from one another. Frequently a fine-grained mosaic has been formed by the crushing of the larger feldspar crystals. In other cases * * * the feldspar is not so much broken, but it is altered around its edge to an opaque gray saussuritic mass, while its interior is hardly changed. * * * The diallage is more altered than in the rocks last described. * * * The crystals are very much bent and twisted and frequently so changed to the light-colored chlorite that only a few minute remnants of the brightly polarizing mineral remain in this nearly isotropic base. * * * Fibrous hornblende now becomes more abundant than the compact, and leucoxene patches are seen at intervals.[b]

[a]Williams, op. cit., p. 71.

[b]Ibid., p. 72.

The compact massive or slightly schistose rock passes gradually into softer, more schistose, ones that have lost all traces of their original structure and of their original mineral composition as well. T he schists are now composed of broken pieces of feldspar which has been almost completely changed—

to an aggregate of calcite and minute brightly polarizing needles or plates of a colorless micaceous mineral (probably sericite) along with occasional areas of secondary quartz. What was once the pyroxene or hornblende is now a colorless or extremely pale-green, scaly mineral, which an examination shows to be chlorite.[a]

The most schistose phases of the rock are examples of fissile, silky, chloritic schists, composed of a fine-grained schistose aggregate of colorless chlorite, quartz, and calcite.

These rocks are schists, indeed, of the most characteristic type, but in the light of their field relations, and still more from the evidence which a microscopical study of the whole series has afforded, it is evident that they represent the most altered form of the massive gabbro, between two areas of which they are included.[b]

The chemical changes undergone by the gabbro in its transition to a schist are shown by the following three analyses made for Dr. Williams by Dr. R. B. Riggs:

Analyses of gabbro and schist from Sturgeon Falls.

	I.	II.	III.
SiO_2	51.46	38.05	45.70
Al_2O_3	14.35	24.73	16.53
Fe_2O_3	3.90	5.65	4.63
FeO	5.28	6.08	3.89
CaO	9.08	1.25	4.28
MgO	9.54	11.58	9.57
Na_2O	2.92	2.54	.55
K_2O	.24	1.94	3.82
H_2O	3.30	7.53	4.70
CO_2	.20	.93	5.95
Total	100.27	100.28	99.62

Rock powder dried at 105° C.
I. Freshest gabbro from barrier rock of Sturgeon Falls,
II. Schistose gabbro from south side of I.
III. Silvery chlorite-schist from band between two bands of saussuritized gabbro.

[a] Williams, op. cit., p. 73. [b] Ibid., p. 75.

[a]Williams, op. cit., p. 73.

[b]Ibid., p. 75.

The most marked variations noted in the composition of the three rocks is with reference to the lime, alumina, soda, potash, and carbon dioxide. Williams explains the fact that the intermediate rock (II) differs more from the original type (I) than does the most schistose phase (III) by supposing that the processes of alteration have been different in the two altered phases. In the first case the main product of the alteration has been chlorite; in the second case it is sericite and calcite. It is difficult to conceive a process which, acting upon two portions of the same rock, close together, will cause chloritization in one part and sericitization in the other. The production of sericite in a rock of the composition of a gabbro necessitates the addition of potash and alumina from some extraneous source, through the transporting agency of solutions. It is very difficult to understand how such solutions might be confined to a certain definite band in an altering basic rock and be practically excluded from other portions of the same rock. It is more probable that the three rocks whose analyses are given above originally possessed different compositions, and that this accounts for their differences in composition at present.

Diabases and their derived schists.—The coarse diabases and their derived schists are in all essential respects, except structure, like the gabbro and the gabbro-schists.

Diorites and their derived schists.—The diorites and the schists derived from them are slightly different from the gabbros and their associated schists, but the processes which changed the massive rocks into schistose phases were practically the same in both cases. The rock forming the high bluff skirting the east side of the river below the Little Quinnesec Falls is the best example of the massive diorite met with in the district. It is described by Williams as being in all probability a great dike. Though for the most part quite massive, the rock presents frequent and instructive evidence of the effect of great pressure upon it.

It is seamed and gashed, broken and torn, and contains schistose bands of varying width. Since the continuity of these bands with the massive rock is established, their study is calculated to throw light on the subject of dynamical metamorphism.

Major Brooks designated the rock which composes this ridge as a “massive gabbro,” and correlated it with the above-described saussurite-gabbro of Sturgeon Falls. My studies have, however, failed to disclose in this rock any trace of pyroxene. In addition to its feldspathic constituent, which is generally altered to saussurite, it contains in abundance that peculiar pale-green and more or less fibrous variety of hornblende which is quite universally conceded to be of secondary origin. What the primary form of all this green hornblende was, it is now impossible to ascertain with certainty. It is of a kind well known to originate from the alteration of pyroxene. The rock as a whole also bears decidedly the character of a diabase or pyroxene rock; and yet, not a trace of pyroxene has been discovered in any of the Menominee River greenstones, if we except the light-colored diallage of the Sturgeon Falls gabbro. Whenever the pale-green hornblende can be traced back to an original form, it is seen to be derived from a compact brown or basaltic hornblende.

* * * * * * *

It is, of course, impossible to prove that some of the secondary fibrous hornblende has not been derived from pyroxene. Indeed, it seems very probable that both augite and compact brown hornblende may have existed side by side as original constituents of the rock, and that both finally succumbed to the same process of alteration, although the hornblende resisted this much longer than the augite. * * * Inasmuch, however, as the rocks here under discussion afford no trace of pyroxene, it hardly seems justifiable to call them anything but diorite.[a]

Some of the phases of the rock are porphyrinic. These contain large crystals of saussuritized feldspar in a matrix composed wholly of hornblende in compact, brown and green, or colorless grains, and in light-green fibers, in which are embedded small laths of plagioclase. The hornblende by alteration passes into chlorite and tremolite.

The schists derived from the diorite are largely chlorite-schists. They present no peculiar features distinguishing them from the schists derived from the gabbro, except in those phases where the structure of the original rock is still retained. At one place toward the west end of the diorite ridge a well-marked band of schist traverses the massive rock. The latter is—