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THE MENOMINEE IRON-BEARING DISTRICT OF MICHIGAN

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CHAPTER V.
THE ALGONKIAN SYSTEM
[Continued]

SECTION 2. UPPER MENOMINEE SERIES.

CHARACTER AND OCCURRENCE.

COMPONENT FORMATIONS.

The Upper Menominee series comprises all the beds between the top of the Randville dolomite and the bottom of the Lake Superior sandstone. It includes two formations which have been called the iron-bearing Vulcan formation and the Hanbury slate. The former—the lower of the two—is made up of three members, which in the order of succession are the iron-bearing Traders member, the Brier slate, and the iron-bearing Curry member. The Traders member is in some places further divisible into a lower portion consisting mainly of slates and quartzite, and an upper portion, consisting principally of ore and jasper beds.

SEPARATION FROM THE OVERLYING SANDSTONE AND THE UNDERLYING LOWER MENOMINEE SERIES.

The separation of the series from the overlying Lake Superior sandstone is necessitated by the universal presence of a profound unconformity between the two, the existence of which is made evident not only by many visible contacts showing horizontal layers of sandstone

resting upon the eroded edges of the upturned lower rocks, but by the presence everywhere of immense fragments of the iron-formation rocks in the basal member of the sandstone.

The necessity for the separation of the Upper Menominee series from the Lower Menominee series is not very evident at first sight. Visible contacts between the iron-bearing Traders beds and the Randville dolomite are rare. In those instances where the contacts are seen the two formations appear to be conformable. The folding of the district has been so severe that the slight discordances in bedding that may have once existed have been entirely obliterated by movements of accommodation.

The principal evidence that is relied upon as a basis for the separation of the two series is the character of the lower layers of the iron-bearing Traders member and the structure of many of its ore and jasper beds. In many places immediately over the dolomite, especially along the southern border of the southern dolomite area, a distinct and very definite bed of coarse quartzite occurs, through which small fragments of bright-red jasper and small rounded grains of a black hematite are plentifully sprinkled. The rock is usually not so coarse grained as to warrant its being called a conglomerate, but it has the essential characteristics of the conglomerate at the base of the Ishpeming formation in the Upper Marquette series. The components of the Menominee rock are not so large as those of the Marquette lock, nor are the ore and jasper fragments so abundant. Nevertheless, these fragments possess characters as distinctly fragmental as do those in the Marquette conglomerate. The latter has been employed as evidence that the iron formation underlying the Ishpeming quartzite is of much greater age than the latter, and therefore that the Marquette bedded rocks are divisible into a lower series and an upper series. In this district the iron-bearing Negaunee formation is visible at many places beneath the conglomerate, so that comparison of its nature with that of the fragments in the conglomerate is easy. The character of the fragments is so like that of much of the material in the bedded Negaunee rocks that no doubt can be felt as to their origin. They were plainly derived from the Negaunee rocks by wave action along a shore line. In the Menominee district the coarse quartzite was also a shore-line deposit, and its ore and jasper fragments must have been derived from an older formation. But no source for these fragments has yet been discovered. There is no iron formation in the district corresponding to the Negaunee formation in the Marquette district, nor has there been discovered anywhere in the Archean schists of the district any evidence of the existence of jaspilites interbedded with the greenstones similar to those associated with the green schists of the Marquette and the Vermilion districts. In the two districts last named the jaspilites in the Archean have furnished jasper and a few ore pebbles to the conglomerates at the base-of the Huronian series, so that even if the jaspilites had not been observed in position their presence somewhere in the Archean series would have been inferred from the presence of these pebbles in the lowest member of the overlying series. The basal conglomerates of the Lower Menominee series show no jasper pebbles, though they exhibit specimens of practically all the rocks known to exist in the Archean. The plain inference from these two facts—(1) the absence of jaspers from those portions of the Menominee Archean that have come under observation, and (2) the absence of jasper pebbles from the conglomerates at the base of the Huronian—is to the effect that, the source of the jasper and ore in the coarse quartzite must be referred to the bedded series between the basal conglomerates at the bottom of the Sturgeon quartzite and the jasper-bearing quartzite near the base of the Traders member. From the evident analogy that exists between the geology of the Menominee and that of the Marquette districts, we should expect to find an iron formation above the Randville dolomite. The fact that no such formation exists in this place at the present time is easily explained on the supposition that it was removed by the same erosion processes that were instrumental in producing the débris found now in the quartzite. No remnants of the formation remain, hence it is plain that the shore line must have transgressed across the formation, and at the time the quartzite was deposited it was against the dolomite. In the Marquette district the shore line was in the iron formation at the time the conglomerates now exposed to study were formed, hence these are composed very largely of the débris of the iron formation. In the Menominee district the shore line adjacent to the deposits now exposed was not composed of iron-formation material, hence comparatively little of this material is found in these deposits. The greater portion of it must be in deposits that are now deeply buried, and it is possible that at these depths remnants of the original iron formation may still exist.

The constitution of the Traders member points to the same conclusions as those indicated above. Much of the material of this formation consists of the débris of a more ancient jaspilite formation. The only place for this seems to be at the top of the Randville dolomite. Since it does not exist there at present, it must have been removed by erosion. The assumption necessitates the supposition of a lapse of time between the deposition of the dolomite and the deposition of the overlying iron formations, and it is for this reason that a line of division between an older series and a younger series in the Menominee district is placed at this horizon.

Although no discordance in stratification has been observed between the top member of the lower series and the bottom member of the upper series, the evidence outlined above is sufficiently strong to warrant the assumption of the existence of a time interval between them, and to warrant the separation of the bedded rocks between the unconformity at the top of the Archean and that at the bottom of the Cambrian into a Lower Menominee series and an Upper Menominee series, analagous to the Lower Marquette and the Upper Marquette series in the Marquette district, and to

corresponding Lower and Upper Huronian series in the other iron-ore districts of the Lake Superior region.

DISTRIBUTION.

The rocks of the Upper Menominee series occupy the synclinal areas lying between the dolomite belts and between these and the areas occupied by the Quinnesec schists (see Pl. IX). To the east, like the formations of the Lower Menominee, they pass under the thick covering of Paleozoic beds and are lost to view. To the west they merge together beyond the Menominee River and constitute the surface rocks over the larger part of the Florence district in Wisconsin.

In the central portion of the Menominee district the Upper Menominee rocks comprise three belts, two lying between the three dolomite belts and the third between the southern dolomite belt and the Quinnesec schists along the Menominee River. East of Iron Hill the northern and central belts coalesce and the three belts are reduced to two. At about the meridian of Lake Antoine the central belt coalesces with the southern portion of the northern belt, and the two extend to the Menominee River between the southern dolomite and the western area of the Quinnesec schists. In this portion of the district, however, three belts are still maintained, for the western area of Quinnesec schists, extending eastward from the Menominee River like a wedge, splits the northern Upper Huronian belt into two arms, the southern one coalescing with the central belt as already related and the northern one bending northward and following the Lower Huronian rocks into the Calumet trough.

Over most of the areas described as occupied by these belts the Upper Menominee beds can be traced by means of outcrops and test pits, but in the northwest corner of the district, in that portion described as occupied by the northern arm of the northern belt, the drift covering is so thick that no outcrops are found. The presence of the Upper Menominee sediments here is inferred from the presence of outcrops of the Sturgeon quartzite and Randville dolomite at the northern limit of the district and the presence of outcrops of the Upper Menominee beds in the Calumet trough farther north.

FOLDING.

The character of the major folding of the Upper Menominee series can not be determined by the observation of strikes and dips, since the exposures are very few and the minor folding is very pronounced. From the distribution of the Upper series with reference to the Lower series, however, it is clear that the former must exist in three synclines and two anticlines with approximately east-west axes and in two anticlines and three synclines with north-south axes.

A north-south section across the center of the district, along the range line between R. 29 W. and R. 30 W., cuts all the folds with east-west axes. Where the section crosses the synclines the surface rocks belong to the Upper Menominee beds; where it cuts the anticlines the Lower series is exposed, the Upper beds having been removed by erosion from the anticlinal portions of the folds. A section along the central line of R. 29 W. cuts two synclines and a connecting anticline, the top of which has likewise been eroded; and a section along the line between R. 30 W. and R. 31 W. again cuts three synclines and two anticlines. In the latter case one anticline is over the western area of the Quinnesec schists and the other over the southern dolomite belt.

The central dolomite belt, as has already been explained (see p. 234), is an inverted canoe-shaped anticline entirely surrounded by Upper Menominee sediments. At each end the dolomite terminates in plunging anticlines, overlain by the Upper Menominee beds, which must therefore also be in closely similar anticlines. The two taken together constitute a broad anticline with an approximately north-south axis. In the vicinity of the Loretto mine, near the line between R. 28 W. and R. 29 W., is the axis of another north-south anticline. Here the lowermost beds exposed belong in the Upper Menominee series, hence, so far as the surface is concerned, only the beds of the Upper series are involved in the fold. The east limb of a third anticline must occur at the eastern end of the western area of Quinnesec schists, if these rocks are older than Algonkian, as has been supposed. Its western limb is a dozen or more miles to the west in Wisconsin.

The Upper Menominee beds thus are affected by two, and in a portion of the district by three, closely compressed folds with axes trending a little north of west and by two broad and open folds with axes trending a little east of north.

The minor folding of the series will be discussed in connection with the folding of its individual formations.

VULCAN FORMATION.

DISTRIBUTION.

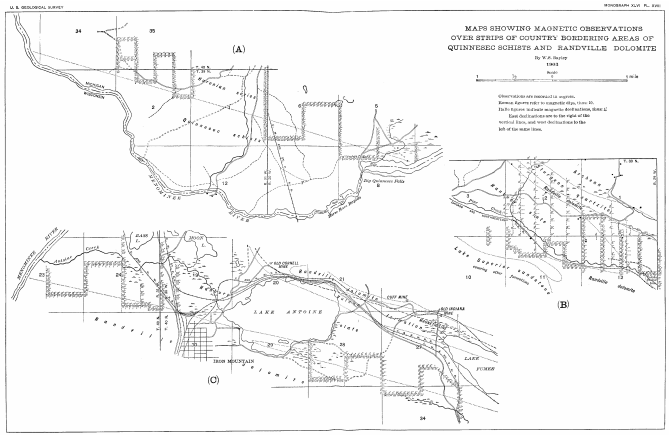
From the position of the Vulcan formation immediately upon the Lower Menominee beds, we would naturally expect the distribution of the ore-bearing formation to be determined by the distribution of the Lower series, and, as a matter of fact, wherever the Vulcan formation exists it is found immediately above the Randville dolomite of the Lower Menominee series and below the Hanbury slate of the Upper Menominee. But at some places within the district where we would naturally expect to find it the dolomite is in immediate contact with the Hanbury slate, or is separated from exposures of the latter formation by intervals so narrow as to show that the Vulcan beds are lacking.

The principal area of the Vulcan formation extends as a belt from 900 to 1,300 feet wide along the south side of the southern belt of dolomite for nearly its entire extent. The belt follows the sinuosities of the southern border of the dolomite area rather closely, but it is much wider in the reentrants caused by the pitching synclines of the dolomite than elsewhere. The widening of the formation

at these places is of course due to the repetition of beds in consequence of the folding. Along only one stretch, about a mile in length, is the iron formation known to be absent. This is in the west half of sec. 1 and the east half of sec. 2, T. 39 N., R. 30 W., where the Hanbury slate lies against ledges of the typical dolomite.

On the north side of the southern dolomite belt the iron formation has nowhere been found, nor has any indication of its presence been detected except at the Loretto mine in the eastern part of the district. Near the dolomite in the central and eastern portions of the belt magnetic lines are weak or absent altogether, and no exposures of the Vulcan formation have been discovered either in ledges or by test pits. On the other hand, rock has been uncovered by test pits in the east half of sec. 11, T. 39 N., R. 29 W., and near the northwest corner of sec. 10, T. 39 N., R. 29 W. In every instance the pits bottomed in slate, which in sec. 11 appears to make an eastward-extending embayment into the dolomite north of the East Vulcan mines, and in sec. 10 forms a portion of the embayment extending westward into the dolomite area east of Norway. In both cases the dolomite and the slate are so near together that there is no room between them for the Vulcan formation. Elsewhere the country bordering this portion of the dolomite belt is thickly drift covered, so that it is not known whether it is underlain by a belt of the iron-bearing formation or not. In the eastern portion of the district the Vulcan beds border the northern margin of the belt from the Loretto mine eastward for a short distance. At the Loretto mine the ore formation exists in an eastward-pitching syncline. Beyond this place it is traced by a line of magnetic attractions to within a short distance of the east end of the area mapped, where the thick deposits of Paleozoic beds prevent further tracing.

The second important area of the formation is that in which, the Traders, the Cuff, the Indiana, and the Forest mines are situated. It stretches for about 5 miles along the south side of the central dolomite belt, beginning north of Lake Antoine and ending, so far as present information indicates, somewhere about the east line of R. 30 W. Beyond this point for a mile and a half there are no outcrops near the southern boundary of the dolomite, nor have any test pits, so far as our present knowledge goes, uncovered the underlying rock. Moreover, the magnetic line which can be traced as far east as the center of sec. 25, T. 40 N., R. 30 W., gradually dies out at this point and can not be rediscovered to the east. We are therefore ignorant as to whether or not the ore-bearing formation continues through this interval. At the east end of the dolomite belt, however, the country has been very thoroughly explored and the underlying rocks have been exposed by pits and trenches. Lean iron-bearing slates are so abundant here that the locality is known locally as Iron Hill, but the slates are different from those of the Vulcan formation and similar to the lean iron-bearing slates discovered at several localities in the Hanbury slate areas. Further, a diamond-drill hole recently put down under the pits to within a short distance of the dolomite reveals the existence only of gray slates like those of the Hanbury formation. The contact of the two formations has not been reached by this drill hole (see pp. 481-483), but the interval between the last-known position of the slate and the nearest exposure of the dolomite is so narrow that there seems to be no room there for the Vulcan formation. Again, a line of auger borings has been carried from the northernmost exposures of the Hanbury slate north across the swamp which separates them from the southernmost exposures of the dolomite belt to within a few feet of the base of a dolomite cliff, and these revealed only slate. While little confidence should, perhaps, be placed in the results of these borings, the evidence of the absence of the Vulcan formation and the presence of the Hanbury slate at this place seems so strong that on the map the color of the latter formation has been carried to the very edge of the dolomite area.



[Plate XVIII. Maps showing magnetic observations over strips of country bordering areas of Quinnesec schists and Randville dolomite]

On the north side of this same dolomite belt the iron formation is known to extend for only a short distance on both sides of the Cuff mine, in the southern portion of sec. 22, T. 40 N., R. 30 W. To the east and west the country is thickly covered by drift and sandstone, and nothing has been learned of the nature of the underlying rock.

The third strip of country in which the iron-bearing beds are to be expected is that which borders the northern dolomite belt. This area, however, is in the valley of Pine Creek. The surface is thickly covered with sand. There is no indication of the character of the underlying rock anywhere west of the Loretto mine except that afforded by a group of pits near the center of sec. 14, T. 40 N., R. 30 W., at the western extremity of the belt. These pits have shown the presence of lean ore associated with cherts, jaspilites, and black slates. The cherts are filled with the u shots and bands of ore characteristic of the cherts in the Hanbury slate, and present to some extent in the jaspilites of the Curry member of the Vulcan formation. In this case the rocks are believed to belong to the Curry horizon.

In the neighborhood of the Loretto mine (Pl. XXIII) the Vulcan formation appears to occupy the entire breadth between the north side of the southernmost belt of dolomite and the south side of the northernmost belt of this rock. A short portion of this distance has not yet been explored, but all that portion which has been opened up by the Loretto and Appleton workings reveals the presence of one or the other members of the Vulcan formation. Of the area east of the Appleton mine nothing is known. The country is here covered with thick deposits of sand and sandstone.

The other areas in which the Vulcan formation may occur are those bordering the Quinnesec schists. From the order of succession on the northern side of the Menominee trough one would expect on the southern side of the trough to find in passing north from the Quinnesec schists of the Menominee River the following formations: (1) The Sturgeon quartzite, (2) the Randville dolomite, (3) the Vulcan formation, and (4) the Hanbury slate. As a matter of fact, the only rocks exposed near the Quinnesec schists are the Hanbury slates. In several places east of the mouth of the Sturgeon River, in the northwest quarter of sec. 26, T. 39 N., R. 29 W. (see map, fig. 22), the slates and the schists are only 750 feet apart on the surface, but west of this point no exposures of any kind have been found north of the schists within the distance of less than a mile.

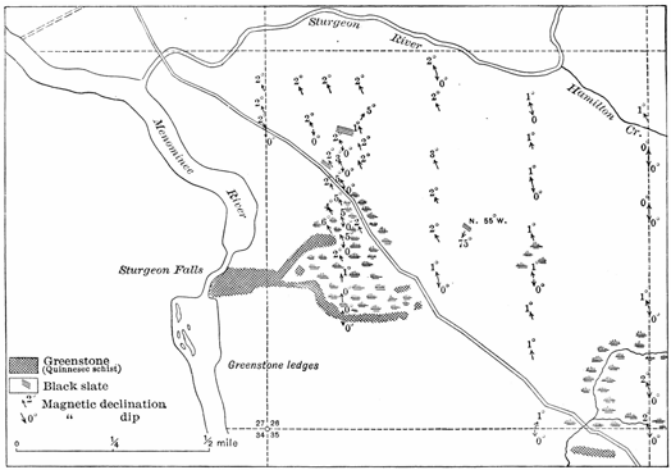


FIG. 22.—Sketch, map of exposures near Sturgeon Falls, sec. 26, T. 39 N., R. 29 W.

The direction of movement of the glacial drift in the Menominee area was from the northeast toward the southwest. The Quinnesec schists occupy relatively high ground, and therefore heavy masses of drift were banked against their northern borders. This may be the explanation of the absence of exposures in this belt. But the Sturgeon quartzite, the Randville dolomite, and the Vulcan jaspilites are hard, resistant formations, probably much more resistant than the Quinnesec schists, hence it is thought to be highly probable that these formations do not rest upon the schists, otherwise they would likely be exposed in some portion of the belt, especially on the banks of the Menominee River where it enters and leaves the schist areas. The absence of the Sturgeon and Randville formations is easily explained on the supposition that they were eroded during the interval that developed the unconformity between the Lower Menominee series and the Upper Menominee series. It is otherwise, however, with the Vulcan formation. This belongs in the upper series along with the Hanbury slate, and unconformity can not be appealed to for an explanation of its absence.

The Vulcan rocks are fully as resistant as the quartzite and the dolomite, and when they exist they usually occupy elevated areas. The belt north of the Quinnesec schists, however, is a depressed area; at any rate, its surface is nowhere above the average elevation of the plain to the north which is known to be underlain by Hanbury slates. Moreover, a magnetic survey of the belt showed no evidence of the presence through it of a definite magnetic line (see map, Pl. XVIII, *A*). Since, then, there is no evidence that the Vulcan formation underlies the belt, while, on the other hand, its topography indicates that it is underlain by the same rocks that underlie the surface immediately to the north, and since slate exposures are found in the eastern end of the belt within about 750 feet of the schists, it is believed that the conclusion that the Vulcan formation does not border the schist area is well substantiated.

The situation is nearly similar about the western area of Quinnesec schists. Only two exposures are known within one-half mile from the schist ledges. One of these is unquestionably an exposure of Hanbury slate. It lies on both sides of the Menominee River and in the bed of the stream, forming a ledge about 900 feet long, in which the rocks are gray slates with a well-marked cleavage dipping high to the north. The north end of the exposure on the Michigan side of the river is south of and less than 350 feet distant from the southernmost ledge of green schists which are exposed under the railroad bridge of the Florence branch of the Chicago and North western Railway in sec. 13, T. 40 N., R. 31 W. The second exposure, within less than one-half mile of the schists, is exposed in the dump of an old shaft in the northwest quarter of the southwest quarter of sec. 15, T. 40 N., R. 30 W. The distance from the shaft to the nearest outcrop of schistose greenstone is about 1,000 feet. The rock exposed in the dump is a ferruginous slate that resembles very closely some of the ferruginous slates of the Hanbury formation (see p. 476). These exposures are both on the southern side of the schist area and are more than 4 miles apart. Absolutely nothing is known of the geology of the intervening strip of country. Nor is anything known of the belt of country bordering this schist area on the north. This area is so deeply buried under sand and gravel that we are not even certain that the northern limit of the schists has been correctly outlined.

No magnetic line was found after careful search surrounding the schist area, and no evidence of any kind was detected that indicated the presence of an ore formation in this place (see Pl. XVIII, *C*). The occurrence of the slate ledges on the banks of the

Menominee within 375 feet of the schist exposures renders the probabilities more favorable to the belief that the Quinnesec schists are surrounded by the Hanbury slate than to the view that they are surrounded by a belt of the Vulcan formation. On the map the color of the Hanbury slate is made to cover the belts bordering the Quinnesec schists in both areas, although it is recognized that in some places portions of these belts maybe underlain by small areas of the Vulcan formation.

From the foregoing account of the distribution of the Vulcan formation it will be noticed that the belts of iron-bearing rocks are not continuous. From the stratigraphical position of the iron-bearing formation one would expect it to occur as continuous belts surrounding the dolomite anticlines, bordering the south side of the northern dolomite monocline and the areas of Quinnesec schist. In several places, however, it is seen that these relations do not exist. It is known that in various parts of the district the iron-bearing formation is absent from the position it would naturally be expected to occupy, and that the Hanbury slates, which stratigraphically overlie the ore-bearing strata, are in immediate contact with the dolomite that underlies the Vulcan formation. Furthermore, at least at one place it is known that the slates are exposed in natural ledges at so short a distance from the western area of Quinnesec schists that there would seem to be no possibility of the occurrence of the iron-bearing formation between them. It is probable that the larger parts of these belts, in which the underlying rock is unknown, are underlain by the Hanbury slate rather than the Vulcan formation, but it is possible that the Vulcan formation underlies portions of them.

TOPOGRAPHY.

The Vulcan formation is so thin that, although in its usual form it is very resistant to denuding agencies, it has produced but little effect upon the topography of the district. Where the formation is well developed it usually forms the slopes of higher ridges of dolomite. Where not so well developed, its topography, except in a few instances, gives no evidence of its existence beneath. Its ledges generally present smooth, flat surfaces that rise very slightly above the surrounding country. At the Traders mine and in Hughitt Bluff, east of Iron Mountain, however, they form marked elevations that can be seen for long distances. Because of the uniformity in hardness of the different components of the formation and the lack of prominent joint cracks through it, differential erosion of its parts is not noticeable, and rough craggy ledges, such as those characterizing the resistant dolomite formation, are absent.

SUBDIVISION INTO MEMBERS.

The Vulcan formation consists of three distinct parts, that may easily be recognized throughout a large portion of the extent of the formation. Where only one of these parts is present it is believed that it is always the uppermost one. On the general map of the district the formation is not differentiated in the mapping, but on the special, large-scale maps, the formation is separated into its parts where the limits of these are known. The lowermost of the divisions is composed of slates, conglomerates, quartzites, jaspilites, and ore deposits. It has been called the Traders member because of the typical occurrence of its ferruginous phases at the Traders mine, north of Lake Antoine. The second or intermediate division comprises a belt of black ferruginous slate. It is known as the Brier slate because it is so well exhibited at Brier Hill, east of Norway. The third or uppermost portion consists of interbedded ferruginous quartzites, jaspilites, and ores. These are worked for ore at the Curry mine, east of Norway, hence they have been named the Curry member.

TRADERS MEMBER.

DISTRIBUTION.

In spite of the fact that the Traders member is better developed than either of the other two members of the Vulcan formation, where all are exposed, nevertheless it seems probable, at present, that its distribution is not coextensive with that of the iron-bearing formation. In some portions of the district only one iron-bearing member appears to exist and this, so far as the evidence now at hand indicates, is the Curry member.

The Traders member has been identified only along the south sides of the central and the southern dolomite belts, except at the Cuff mine, where the iron-bearing beds are either north of the dolomite or folded within it, and at the east end of the district, where the Traders beds occur at the Loretto and Appleton mines in the syncline between the south side of the northern dolomite belt and the north side of the southern belt. The identity of the iron-bearing member at this place is established by the occurrence above it of uneroded remnants of a slate with the lithological characters of the Brier slate. In the western portion of the district a few pits have exposed iron-bearing rocks in sec. 14, T. 40 N., R. 30 W., but for reasons to be referred to later (p. 331) these rocks are believed to belong in the Curry member. Between them and the nearest exposures of dolomite to the north there is apparently abundant room for the occurrence of the Traders member with its average thickness, but the interval is covered, and the nature of the underlying rocks is unknown. Nowhere else along the south side of the northern dolomite belt are iron-bearing beds known to occur, except, as before mentioned, in the vicinity of the Loretto and Appleton mines.

On the south side of the central dolomite belt the Traders rocks are found at the Traders, the Cornell, the Cuff, the Indiana, and the Forest mines. At the two mines first named the iron-bearing rocks have the general characteristics of the Traders rocks elsewhere. They are, moreover, overlain by slates like the Brier slates at the type locality, Brier Hill, and are sheared and brecciated like the unquestionable Traders beds at their contact with the underlying dolomite. None of this rock, however, has yet been discovered in the neighborhood

of these mines. At the Cuff mine, farther east, dolomite is on the south of the ore-bearing beds, and it is reported that diamond-drill holes encountered the same rock beneath sandstone to the north. The Cuff deposits, which rest directly upon the dolomite, are identified as belonging in the Traders member by their position and their character. In all essential respects they are similar to the beds at the Traders and Indiana mines. The ores are in part sheared into specular varieties and in part are brecciated. In the neighborhood of the Indiana mine, which is south of the dolomite, the presence of all three members of the formation has been disclosed by drilling. The lowermost member—that one in which the shaft was sunk—lies between the dolomite and a set of ferruginous siliceous slates which are identified as Brier. This member is therefore in the stratigraphical position of the Traders member. East and west of the Indiana mine a strong magnetic line and the rock pile of an occasional test pit shows the presence of the iron formation on the southern side of the dolomite belt between Lakes Antoine and Fumee, but whether the ore-bearing beds belong in the Traders or the Curry member is not known. It seems probable, however, from the character of the rocks on the dumps of the pits that the Traders member is present, at least for a portion of the distance between the Indiana mine and Lake Antoine, and it is probable that the Indiana beds extend continuously as far east as the Forest mine. At this locality the explorations have developed two iron-bearing members separated by a slate. The northerly one, lying immediately above a dolomite, must be Traders. Beyond the Forest mine to the east the entire Vulcan formation disappears and consequently, of course, the Traders member.

South of the southern dolomite belt the Traders member is well exposed in ledges, pits, and mine workings at many different points between Waucedah and the Aragon mine in sec. 9, T. 39 N., R. 29 W. Through most of this distance all three members of the iron formation have been identified, the Traders member being well developed throughout nearly its whole extent. Indeed, practically all of the working mines of this stretch of country are mining Traders ore. Between the west line of sec. 22, T. 39 N., R. 28 W., and the Sturgeon River, a distance of about 3½ miles, there is no direct evidence of the presence of the Traders member, but since the iron formation is developed with all of its members both at the east and the west ends of this belt, and since a distinct magnetic line shows that the formation extends through this distance, the probable view is that it continues from east to west with all of its members. From the Aragon mine westward to the center of sec. 1, T. 39 N., R. 30 W., where the entire formation disappears, the iron formation is well exposed by test-pitting and mining operations. At the Norway and Cyclops mines the Traders and the Curry members are both developed. West of these mines, in sec. 6, T. 39 N., R. 29 W., however, only one iron-bearing member is exposed. No Brier slate is recognized as being associated with the jaspilites, but, on the other hand, these rocks appear to be bordered on the south by the slates of the Hanbury formation. The Traders member, therefore, appears to be generally absent from this belt of country. At any rate, it has not yet been shown to be present. One or two drill holes put down in this region are, however, reported to have penetrated a series of slates lying between a considerable thickness of iron-bearing beds and a thin series of similar beds, the latter being against the dolomite. Portions of the Traders member may therefore exist at a little depth beneath the surface; but immediately at the surface there is no indication of the presence of the member between the Norway mine and Quinnesec. From the Quinnesec mine westward about a mile there are three belts of iron formation material separated by Brier slates. The belt between the northernmost slate belt and the dolomite is unquestionably a part of the Traders member, and it is believed that the belt to the south of this is also Traders. On this supposition the Traders member in the Quinnesec syncline borders the north and east sides of the basin and forms a narrow anticlinal tongue extending three-fourths of a mile westward through its center. To the east the Traders member disappears in sec. 2, T. 39 N., R. 30 W., with the entire Vulcan formation, and to the west it is believed to thin out in the southwest quarter of sec. 34, T. 40 N., R. 30 W., to reappear again at the Pewabic, Walpole, Millie, and Chapin mines as a narrow belt bordering the dolomite and following it in all its complicated folding. At the anticlines the iron-bearing member extends westward much farther than the dolomite, producing several belts bounded on both sides by Brier slates (see map, Pl. XXVIII, for details). Beyond the old Ludington mine in the southeast quarter of sec. 25, T. 40 N., R. 31 W., the Traders member seems again to disappear, the most westerly point at which its rocks can be identified being on the dump heaps of the old Ludington shafts.

While the Traders member is not as continuous as the Curry member, nearly all the mines of the district have obtained their ores from its deposits, so that a map of the active and abandoned mine shafts would serve to show the approximate distribution of the member.

LITHOLOGY.

The Traders member consists of a conformable set of beds composed of thin layers of light-colored shaly slates, heavily ferruginous quartzose slates, ferruginous conglomerates, ferruginous quartzites, jaspilites, and iron-ore deposits. On the sections of mine workings these are designated the Traders slate, Traders quartzite, and Traders ore-bearing beds.

SLATES.

Macroscopical.—The slates of the Traders member are commonly either light-colored argillaceous phases that may contain considerable talc, or dark-gray sandy hematitic slates that differ from the fragmental ores mainly in containing too little hematite to be profitably mined. These slates are usually at the base of the Traders member, although in some places thin layers of

the lighter-colored slates are interbedded with conglomerates and quartzites a short distance above the base. The relations between the argillaceous and the ferruginous slates have not been observed, as the two phases have not been found together. The latter seem to be more locally developed than the former, which appear to be almost universally present between the Randville dolomite and the adjacent iron-bearing formation. Some of the slates that are described in preceding pages as occurring at the top of the Randville dolomite may belong here. These are almost identical in character with the slates of the Vulcan formation and are not separable from the latter upon structural grounds. Where represented on the maps in this volume the argillaceous slates are denominated "The Traders slate." The ferruginous slates, which are more closely related to the iron-bearing deposits than to the true slates, are distinguished as the "Traders ferruginous slates." They are separated from the remainder of the hematite beds mainly for economic reasons. On the mine plats the argillaceous slates are frequently mapped as "talcose slates." From the fact that they are always found in juxtaposition with the dolomite, and, in appearance resemble very closely the slates that are interbedded with the dolomite beds, they are popularly spoken of in the district as "marble slates."

The argillaceous slates vary from dark purple to white, through various shades of red or yellow. Originally, perhaps, nearly all were white or light yellow, for in most cases the darker color is plainly due to staining by iron oxides. Nearly all phases are dull in luster and thus are usually easily distinguished from certain white leached slates of the Hanbury formation, which are highly sericitic. Here and there, however, where slipping has taken place parallel to the bedding, slickensides have been produced, and along the slipping surfaces talcose or micaceous minerals have developed. On such surfaces the slates are, of course, lustrous; but a fracture across the bedding layers will usually show surfaces that are dull and earthy.

In many places the slates may be seen to grade into fine-grained quartzites through the increase in the proportion of quartz present and the diminution of the clayey constituents. On the other hand, the gradation is sometimes accomplished through the alternation of thin slate and quartzite layers, the latter increasing in number and thickness until the former entirely disappear.

In some localities the slates are much sheared, usually along their bedding planes, but sometimes transversely. In these phases the slaty cleavage is well developed. Most specimens exhibit no cleavage, but split easily along the bedding planes between the layers into thin shaly fragments. Movements of accommodation occurred here. The layers readjusted themselves to the new stresses produced by folding and slipped over one another, as is to be expected of thin slate beds between two resistant rocks like the dolomite and the jaspilite. Where the folding was sharp the movements of readjustment were greater than elsewhere and the slates were more intensely sheared. The resulting rock, with its cleavage surfaces often covered with a coating of talc, kaolin, or other micaceous mineral, like the talcose schists already referred to, furnished nearly impervious linings to many of the synclines in the underlying dolomite and thus provided suitable troughs for the concentration of the ores.

The argillaceous or talcose slates, as has already been observed, are found at or near the base of the Traders member, often interleaved with the coarse quartzites or fine-grained conglomerates to be described later. Where the quartzites and conglomerates are abundant the slate beds are apt to be thin and few; where the quartzose deposits are few and thin the slates are thick. Usually there is a distinct band of slate between the lowermost conglomerate bed and the neighboring dolomite, though it may not be more than a foot thick. At first this was thought to be evidence that the slates under discussion always belong in the dolomite series with the conglomerates at the base of the Vulcan formation. Since, however, beds of slate identical with those immediately above the dolomite are now known to occur between conglomerate beds, it is believed that many of these slates are members of the Vulcan formation. Their character would indicate deep-sea conditions at the beginning of Upper Huronian time. This conclusion is also suggested by the fact that no coarse basal conglomerates were laid down at the base of the Vulcan formation such as were deposited at the base of the Ishpeming formation in the Marquette district. When we consider that the deposits derived from the hard jasper of the Lower Huronian, which, in shallow water along shores, would naturally contain large bowlders of this excessively hard substance, consist of quartzites containing but a few small pebbles of jasper, the inference that the water was comparatively deep at the places where the deposits now occur seems to be fairly warranted. If this inference is correct, we have a ready explanation of the lack of apparent discordance between the Lower Huronian and the Upper Huronian deposits, for it is only close to shore lines that discordance between formations is to be expected.

The ferruginous slates are dark-blue or dark-gray, heavy, sandy-looking rocks that sparkle with reflections from the faces of innumerable little hematite crystals that are scattered uniformly through their masses. These slates grade into lean ores, from which they differ merely in per cent of hematite present. They occur at only a few places, notably at the Traders mine, where they can be plainly seen on the east side of the large open pit.

Microscopical and chemical.—The argillaceous slates of the Traders member are, for the most part, confused aggregates of small kaolin spicules, larger ones of a greenish muscovite, and a few of greenish-brown biotite, a few flakes of light-colored chlorite, many sharp-edged grains of quartz, enlarged here and there by the addition of quartz material, and numerous small round masses of limonite and irregular accumulations of magnetite, all lying in a matrix composed of quartz grains with

indefinite outlines and a few masses of cloudy material stained red by hematite and limonite dust. The cloudy material may be decomposed feldspars. Here and there, scattered through this aggregate, are long columnar masses of limonite, which look as though they might be the alteration products of biotite or hornblende, and small needle-like crystals of zircon. In some places these components are arranged in such a manner as to suggest that they may have been derived from a fairly coarse-grained fragmental rock, but in the greater part of the sections no original structure is discernible. It is evident that most of the present constituents are secondary and that the rock has been subjected to silicification processes. Kaolin is by far the most abundant component after quartz. Its proportion with respect to the latter varies in different specimens, but in all specimens both these constituents predominate largely over all others. In a few specimens there are no other minerals present except the small grains of limonite and an occasional mica flake.

An analysis of a purplish-pink slate from the dump of an old shaft near the center of sec. 5, T. 39 N., R. 29 W., about on the contact of the Traders formation and the Randville dolomite north of the Norway mine, gave Mr. E. T. Allen, of the Survey laboratory, the result exhibited below in Column I. The corresponding molecular ratios are printed in italic.

Analyses of slates of Traders member.

	I.	II.	III.
SiO_2	67.04	67.76	47.85
	1.119		
Al_2O_3	15.01	14.12	18.13
	.147		
Fe_2O_3	3.54	.81	6.14
	.022		
FeO	3.18	4.71	.10
	.044		
MgO	2.11	2.38	14.51
	.052		
CaO	.19	.63	Tr.
	.003		
Na_2O	.29	1.39	.21
	.005		
K_2O	4.00	3.52	2.91
	.043		
H_2O at 105°	.67	.23	.....
H_2O above 105°	3.73	2.98	[a] 9.96
	.207		
TiO_2	.69	.71	.....
	.009		
P_2O_5	.03	.07	.....
S	.02	(FeS_2) = .22	.....
Cr_2O_3	Tr.	(CO_2) = .40	.....
MnO	Tr.	.10	.....
BaO	Tr.	.04	.....
Total	100.50	100.07	99.81

[a] Loss on ignition.

In column III is the analysis of a purple fissile slate from beneath (north of) the ore on the fifth level of the Chapin mine. Between the laminæ are slickensided surfaces covered with talc. The analysis was made by Mr. E. E. Brewster, chemist of the Pewabic mine, to whom great obligations are acknowledged for the favor of publishing this and other analyses furnished by him. In column II is quoted an analysis of a sea-green roofing slate from West Pawlet, Vt.[a] The analyses show clearly that the argillaceous phases of the Traders slates are composed largely of the débris of granitic rocks, such as those forming the northern area of the Archean. The high magnesian content of the rock from the Chapin mine is plainly due to the presence of the talc which infiltrated along the fissile planes in solutions emanating from the dolomite.

The mineral composition of the first slate calculated from its analysis in Column I is approximately 47 per cent quartz, 20 per cent kaolin, 5½ per cent muscovite, 8.8 per cent orthoclase, 6 per cent penninite, and 2½ per cent limonite.

The quartzose phases of the slates differ but little from the argillaceous phases just described. In these much of the quartz is in round or oval grains that are usually homogeneous. Sometimes the original grains are broken up into mosaics of small grains, the outlines of the mosaic aggregates corresponding to the outlines of the original grains. Nearly all the grains are crossed by strain shadows. The matrix in which these are embedded differs little in its character from that of the argillaceous slates. Quartz and kaolin constitute its principal constituents. Sometimes this is traversed by irregular streaks rich in small flakes of brown biotite, and scattered indiscriminately through it are occasional large wisps of muscovite or sericite. The usual limonite grains and some hematite particles are also present.

The ferruginous slates differ markedly from the argillaceous and quartzose phases described above. They consist of nearly equal parts of opaque hematite in individual crystals and groups of crystals and a colorless matrix composed of small clastic quartz grains, wisps of muscovite, cloudy masses of some decomposed feldspar, a little light-green chlorite, and a considerable quantity of crystallized quartz cementing the other components. The hematite is the most noticeable constituent. Its groups sometimes consist of a very few grains aggregated in an irregular manner, and at other times they comprise a great number of grains united in such a way as to form aggregates that are much longer in one direction than in any other. There is thus produced a slight schistosity in the rock, which is accentuated to some degree by the tendency of the muscovite to arrange itself in a direction parallel to the elongation of the hematite groups. These slates, like the argillaceous phases, are mechanical sediments. They, however, have had deposited in them a great quantity of hematite and much silica. Thus they are, in a way, intermediate forms between the argillaceous slates and the jaspilites.

[a] Bull. U. S. Geol. Survey No. 168, 1900, p. 278; also Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 3, 1899, pp. 232 and 243.

CONGLOMERATES AND QUARTZITES.

Macroscopical.—The conglomerates and quartzites are usually at or near the base of the member, in some places resting immediately upon the Randville dolomite, and at other places separated from the dolomite by one or more beds of the shaly slates just described. They vary in thickness from a few inches to 20 feet or more.

They contain fragments, usually small but occasionally large, of quartzite, jasper, colorless and white quartz, and rocks that make up the Archean complex.

The more massive phases have the appearance of coarse, dark-colored quartzites composed of fragments of the above-mentioned rocks, usually varying in size from 4 to 10 millimeters, lying in a dark-purple or brown groundmass made up of small, colorless, brilliantly glistening quartz grains in what appears to be a homogeneous matrix of a dark color and a dull luster. In this rock bands filled with large fragments alternate with others free from them. Further, some of the former contain an abundance of sharp-edged pieces of jasper, while others contain none. Much of the rock is more or less schistose, but never is it as schistose as the more ferruginous phases described below. With increasing schistosity the quartz and other fragments become more and more elongated and the jasper fragments are rotated to a position parallel to the schistosity.

In many cases the conglomerate contains so much hematite and jasper that it is an ore-and-jasper conglomerate or quartzite. In these instances the ore and jasper are sometimes in fragments embedded in a quartzitic matrix like that above described, but more usually the ore is in small grains scattered through the matrix in which larger fragments of jasper are embedded. Often the hematite constitutes such a large portion of this matrix that to all appearances it is a comparatively pure ore.

These varieties are nearly always strongly schistose. On the cleavage surfaces of the less schistose phases the ore fragments appear as little shining oval plates up to 8 mm. in length and little shreds from 1 to 5 mm. long. The jasper fragments are smaller and sometimes have angular outlines, but usually these, too, are oval in shape. They are often of the same dark-purple color as the matrix in which they are embedded, and so are difficult to distinguish. On surfaces that lie across the schistosity the ore particles appear simply as lines parallel to the schistose structure, while the jasper particles are much elongated ovals.

Typical occurrences of the quartzose phases of these conglomerates and coarse quartzites are found near the base of the Vulcan series in the open pit of the Quinnesec mine and in the ledges bordering the south side of the little valley at the Brier Hill mine. They occur also in similar positions in many of the mines, and fine specimens may be found on their dump heaps. The ferruginous types are especially abundant at the Traders, the Cuff, the Millie, and the Pewabic mines and in many of the exploring pits north of the Curry and West Vulcan mines.

As the quantity of hematite in the quartzite increases, the rock tends to lose its fragmental character and to assume a schistose structure. The ore and jaspilite fragments are mashed into lenticular bodies, and the matrix into a mass of thin scales like those characterizing the specular ores of the Marquette district. When in this form the rocks are typical jaspilites. These are well represented in the exposures forming Hughitt Bluff, east of Iron Mountain. Here the jasper-bearing quartzose layers have given rise to purple-mottled jaspers and the ferruginous layers have yielded specular ore bands. All gradations are represented at this place between rocks that still retain evident clastic characteristics and those in which no trace of fragmental material remains. The finer the original grain of these rocks and the more schistose their present structure the more homogeneous are the resulting bands and the more difficult is it to distinguish in them any distinct evidence of their original clastic character. At the west end of Hughitt Bluff the original sediments were fairly coarse; hence the rocks, although very schistose, still yield proofs that they were originally fragmental. In the most fragmental phases the distinction between quartzose and ferruginous layers is not marked. The former are lighter colored than the latter, a little more siliceous, and a little more granular. The latter, on the other hand, contain more hematite and are therefore more schistose and less granular.

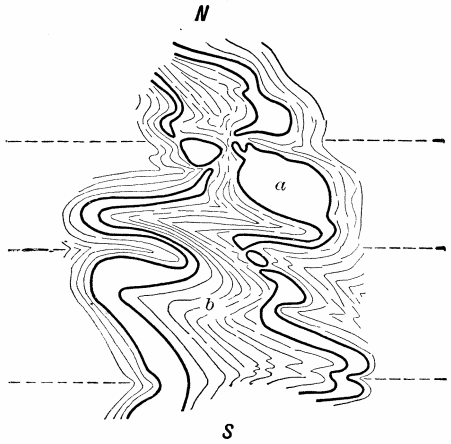


FIG. 23.—Sketch of contortions in jasper bands, west side of Clifford pit, illustrating production of breccias. *a*, Jasper; *b*, schistose hematite. Dotted lines show direction of schistosity. Area figured, about 5 by 3 feet.

In some localities, more particularly at the Traders and Cuff mines, the conglomerates, together with the banded ores and jaspers, have become brecciated through mashing, so that the most apparent structure is the brecciated one. Long, flat, lenticules of jasper and ore are interwoven in such a manner as to give the rock the appearance of a conglomerate. At first sight this pseudo-conglomeratic structure may be taken for a true conglomeratic structure, but a careful examination of the ledges will show that there is a definite and regular alternation of jasper lenses with ore lenses in such a manner as can be explained only on the supposition that they represent the shattered portions of what were originally continuous bands of quartzose and ferruginous materials. Moreover, the rocks are strongly schistose, with the schist planes cutting the bands at all angles. Where the schistosity is highly inclined to the banding the jasper bands are dissected by occasional cracks and their dissevered portions are rotated into positions

tending to conform with the schistosity (see fig. 23). Thus the individual bands may be made up of large numbers of lenses with their longer axes lying athwart the direction of the bands, but parallel to the direction of the schistosity. Their ends frequently fit the ends of the next adjacent lenses. The true conglomeratic structure of the rock is recognized only upon very close inspection of some of the jasper lenses. These, when examined carefully, are seen to be composed of fragments of jasper inclosed in a fine-grained matrix of jasper, sand, and hematite flakes. Under the microscope the fragmental character of all the jasper bands is quite plain.

Microscopical.—Most of the coarse quartzites or fine-grained conglomerates at and near the base of the Traders member are composed of large rounded grains of quartz and small pebbles of the same mineral, often enlarged by the addition of quartz material in optical continuity with the surrounded nucleus, and elongated sharp-edged or subangular fragments of jasper lying in a groundmass consisting essentially of quartz and hematite (see Pl. XIX, *A, B*). The quartz is in small polygonal grains, interlocking with one another to form a mosaic in which the hematite and other rarer components of the groundmass are embedded. No indications of the presence of clastic quartz can anywhere be detected in this mosaic. The quartz must have formed in situ, replacing completely the original cement by which the pebbles and large quartz grains were united. The hematite usually occurs in two distinct forms, but occasionally a third form is observed. The greater portion of the mineral is in irregular-shaped, angular masses that are apparently aggregates of small crystals. Another, but much smaller portion, is in large, well-developed crystals scattered here and there irregularly through the quartz mosaic. Occasionally one of these crystals is half within a large quartz grain, the other half projecting outward into the quartz mosaic. The third form is in little curved streaks, outlining oval areas or forming a ring or several concentric rings surrounding areas constituted exactly like the mosaic of the groundmass. These, for reasons that will be given later (see p. 344), are believed to be pseudo-morphs of concretions in a ferruginous sediment. Their presence indicates that the groundmass of the conglomerates contained originally a considerable quantity of a chemically deposited ferruginous carbonate or silicate which was later replaced by silica and hematite. Further, the entire quartzose groundmass is dotted with a dust of tiny grains of transparent hematite.

In those beds in which the proportion of hematite present is very great, the hematite, in addition to the forms described above, occurs also as occasional fragments intermingled with the enlarged quartz grains. Here and there through the crystalline quartz matrix are also little rounded jasper grains that are peripherally enriched by concentric bands of ore, and ramifying between the quartz and ore fragments are small stringers of very dense hematite, which looks as though it were infiltrated in the form of veinlets after the rock had become silicified. Scattered through the matrix a few wisps of biotite are sometimes observed in the sections and occasionally there is present a shred of muscovite, but usually the only constituents of the rocks are quartz and hematite.

In the few localities where the formation is not much disturbed, as, for instance, near the center of the northeast quarter of sec. 9, T. 39 N., R. 29 W., where the flat lying Traders member is overlain by the Lake Superior sandstone, the fragmental character of the rock is very apparent. Here the ore and the jasper are in distinctly angular pieces and the matrix is a well-defined quartzite made up of enlarged quartz grains. This matrix, however, passes gradually into a finer-grained matrix composed of interlocking grains in which no distinction between nucleal and added quartz can be made out. The fragmental grains seem to have been replaced in parts of the sections by secondary material.

Usually the only evidences of the clastic nature of these rocks is the presence in them of the abundant rounded quartz grains and of a few jasper and ore fragments. Moreover, this evidence is often obscure, for nearly all the beds except the coarsest ones exhibit schistosity, and this structure, even in its less marked stages, is peculiarly effective in obliterating the fragmental character of the constituents, especially in those cases in which a considerable portion of these consist of ore grains. When the quartzites are interbedded with layers very rich in hematite the latter are always much more schistose than the former, often resembling in appearance the typical specular ores of the Marquette district. Where this is the case all evidences of the presence of ore fragments in these bands have disappeared, though the fragmental origin of much of the material in the quartzitic bands interbedded with those bands may still be apparent. When the quartzitic layers become sheared these too lose their clastic structure. The smaller quartz pebbles and the jasper fragments break up into mosaics and the ore pebbles are drawn out into long narrow streaks. In this manner beds of interlaminated quartzite and hematite pass into well-characterized jaspilites that are sometimes indistinguishable from those derived from chemical sediments.

Thus the whole aspect of the quartzites and fine-grained conglomerates is that of a sediment composed of many coarse ore and jasper fragments and fine quartz sand, which has been thoroughly silicified by the deposition of silica between the larger grains and the entire replacement of the cementing material by this substance. In one or two instances that have been observed it has seemed probable that the replaced cement was mainly fragmental quartz sand which had been almost completely dissolved and redeposited before the rocks became schistose, but in most instances no such process is indicated. The structure of the mosaic is identical with that of the jaspers, and it may well be that in the present case, as in the case of the jaspers to be discussed later, the silica has replaced

a ferruginous carbonate or a silicate. If this is so the original deposits were composed of a mixture of chemically deposited substances and detritus from an older jasper and ore formation. At the very base of the formation the detrital portion was in great excess and the resulting rocks were mainly coarse quartzite and fine-grained conglomerates. Interstratified with these at little higher horizons, beds of almost pure jasper now occur, and these were originally beds of chemically deposited carbonate and silicate with no admixture of fragmental material. The mottled jaspers described above must have been composed of ferruginous compounds containing more or less abundant sand grains and small pebbles.

Although the quartzites and conglomerates have been subjected to deformation stresses usually sufficiently intense to cause mashing of the smaller quartz pebbles, nevertheless, in only a few instances have these caused any evident crushing of the larger pebbles or the production of strain shadows in them. In the conglomerate bed at the base of the ore formation in the open pit of the Quinnesec mine, however, the effects of pressure are very marked. In the hand specimen the rock is like the coarse quartzites elsewhere, with the exception that it is distinctly schistose. In thin section the small pebbles, when revolved between crossed nicols, are seen to be crossed by strain shadows which are differently oriented in different portions of the same pebble. In the interior of the grains the areas characterized by the different shadows are physically continuous. Near their peripheries, however, minute cracks develop between neighboring areas. These widen, and, at the borders of many of the grains, particles become entirely separated from the main portion of the grain, forming a granulated zone around it. With the separation of these parts the stresses in them seem to be relieved somewhat, for many of the dissevered particles are free from strain shadows while the neighboring portions of the unbroken grain exhibit them in great perfection. This process of granulation has proceeded so far, especially in the case of the fragments that were originally sharp edged, that the entire area of the original grain is now a mosaic of little grains, each of which is divided by tiny cracks into several portions, all of which, however, are crossed by a uniform shadow. Often these granulated masses retain the outline of the original fragment, but usually they are drawn out into long narrow strings or very flat curved lenses which strongly accentuate the schistosity of the ground-mass. This latter is made up of large and small, apparently fragmental, quartz grains free from strain shadows, occupying areas of various elongated shapes and interspersed with these are streaks of interlocking quartzes forming well-defined mosaics. The quartzes in the mosaics are filled with the usual hematite dust, while those in the fragmental aggregate contain practically no inclusions. About a third of the rock consists of hematite. This is present in dense, opaque lines that run nearly parallel to the schistosity, in long lenticular streaks of massive ore, and in comparatively large isolated crystals within the quartz matrix and sometimes lying partly within this and partly within the areas of the granulated masses supposed to result from the crushing of quartz pebbles. The dense, massive ore appears to fill narrow crevices opened up in the rock parallel to its structure. The crystals were formed after the material of the rock was deposited, but before it was completely silicified and made schistose. The ore streaks, the lines of hematite crystals, and the long narrow lenses of the crushed quartz flowed around the large pebble-like quartz areas in a way known only in rocks of clastic origin that have been made schistose by pressure.

The rock of the Traders mine presents some peculiarities that warrant at least a brief special mention. In the ledge the rock is apparently, as has been stated, a sheared conglomerate or breccia composed of large jasper-like pebbles m a matrix of specular ore. Under the microscope the apparent pebbles are themselves seen to be made up of fragments from some older jasper bed, and the rock, as a whole, is discovered to be a brecciated series of fragmental beds. The ore matrix presents no unusual features. It is an aggregate of crystals, streaks, and flattened masses of hematite inclosing numerous grains of quartz. The appearance of the jasper sections is strikingly like that of many tuffs. In natural light, under low powers, they exhibit the usual features of individual and grouped crystals of hematite lying m a colorless matrix of quartz containing numerous small red inclusions. Under medium powers, however, the nature of the inclusions is seen to be quite different from that of the inclusions of the more normal jaspers. Without exception, they are the fragments of a colorless substance, that seems to be quartz, filled with very fine, red dust that resembles earthy hematite. The fragments vary in their largest dimensions from 0 03 to 0.06 mm., and are extremely variable in shape. Some are rod-like, others rounded, and yet others irregular in outline with sharp corners. The majority, however, are in general triangular or quadrangular, with curved bounding surfaces. In other words, these fragments have the same shapes as the glass splinters in many volcanic ashes. If present in a rock of another character than this, they might be cited as evidence of its volcanic origin. In the present instance there can be no doubt that the rock is a sediment. The fragments are probably fine splinters forcibly broken from a jasper, which, like all rocks with a conchoidal fracture, yielded flakes with curved surfaces. The fragments lie in all positions within and between the grains of the quartz mosaic, the linear dimensions of which are from three to four times as great as those of the fragments. A few sericite shreds occur here and there between the quartz grains, otherwise the mosaic is like that in all the other jaspers of this district.

The rock was probably originally composed of small, sharp-edged fragments of jasper and round ore fragments in a matrix that was subsequently silicified.

JASPILITES.

Macroscopical.—With increasing distance from the base of the formation the conglomerates and quartzites pass upward into cherty or jasper-like rocks, the former gray and the latter dark red or purple in color. The gray cherty rocks are exceedingly rare in the Traders member, being found at only a very few places in the formation and at these places in subordinate amount.

These siliceous rocks occur in layers that vary in thickness from a fraction of an inch to 18 inches or 2 feet. They are always inter-laminated with hematite layers, forming the banded rock known as jaspilite. Some of them on fresh fractures exhibit the quartzitic texture very plainly. The coarser of them approach ferruginous quartzites. Others, however, resemble very closely a typical jasper, which in some cases they are believed to be. The former are often mottled by red and purple blotches that appear to be due to the presence of red jasper grains in a ferruginous quartzose matrix. In the greater number of instances the mottling is in small elongated areas and the rock possesses an incipient schistosity in the direction of the longer axes of the areas. This phenomenon is the result of mashing, which flattened the jasper grains and the smaller components of the quartzose matrix, producing a parallel arrangement of the particles. It is difficult to determine with certainty the relative amounts of the detrital material and true jasper[a] (secondarily deposited) present, but apparently the former is the more abundant in many specimens, and it may predominate in most. In a few instances the structure of the siliceous layers is clearly fragmental. This is beautifully shown in a specimen obtained from the north end of a trench crossing the iron formation just east of the Cuff mine. The rock has a reddish-purple color. Through a purple jasper groundmass are scattered a great many small, irregular-shaped, brilliant-red jasper fragments with sharp edges. Because the rock is not sheared the fragments are easily recognized. Such a rock, if made schistose by mashing and shearing, would no doubt give rise to a mottled variety, like the mottled jaspers referred to in the preceding paragraph. A second type of fragmental texture is well exhibited by some of the siliceous bands in pit No. 2, north of the Curry mine. The dark-purple jasper is dotted with little irregular grains of a gray hematite lying in all possible positions within the bands. These are plainly fragmental. Together with a considerable number of small jasper fragments they constitute large portions of the rocks. In places the ore particles become larger and more numerous, merging into well-defined bands. At the same time the structure becomes dense and the individuality of the constituent grains is lost. Even without the aid of the microscope it is clear that there has been a secondary deposition of ore material between the fragments, welding them into a homogeneous mass.

[a]In this discussion the term "jasper" is applied to the nonfragmental aggregate of cherty quartz and hematite flakes associated with the hematite layers in the iron formations. The term "jaspilite" is applied to the banded rock composed of alternating layers of jasper and hematite. It is true that the latter term was first proposed by Wadsworth to designate the jaspers, on the assumption that the jasper associated with the Marquette rocks is an eruptive rock "more acid than the rhyolites." (Notes on the geology of the iron and copper districts of Lake Superior: Bull. Mus. Comp. Zoology, vol. 7, 1880, p. 76.) But when it was shown that the jaspers are sedimentary in origin the employment of the term in Wadsworth's sense was no longer applicable. Van Hise then suggested that the term be retained as a convenient one to designate the "rocks consisting of alternating bands composed mainly of finely crystalline, iron-stained quartz and iron oxide." (Mon. U. S. Geol. Survey, vol. 28, p. 362.) In this sense the term is used as a convenient descriptive one in this volume. In the preliminary report on the Menominee district (Geologic Atlas U. S., folio 62, U. S. Geol. Survey, p. 4) the discrimination between the terms jasper and jaspilite was not always made, nor in the monograph in which the term "jaspilite" was redefined was this term always used in the newly defined sense (cf.: "The hard-ore jasper or jaspilite," a few lines above the definition quoted above). In the present monograph all the siliceous material in the iron formation which is now composed entirely or largely of interlocking quartz grains (whether originally clastic or not) will be called jasper, and rocks composed of alternating bands of jasper and hematite will be designated jaspilites.

These distinctly fragmental types grade into the mottled jaspers, which are sheared phases of the same rock, and these in turn pass gradually by the loss of their mottlings into the aphanitic, flinty jaspers with a wax-like luster.

The ferruginous layers associated with the conglomerates and the quartzites become more numerous as the latter grade into jaspers, and the alternations of the siliceous and ferruginous materials become more regular. These associated iron oxides usually occur in beds no thicker than the quartzose layers. At various places, however, especially in the basins produced by the folding of the dolomites, they rapidly thicken and replace the quartzose layers along their strike, forming ore deposits, which may be sufficiently large to warrant mining.

The thin-bedded ores are usually gray specular varieties, strongly resembling in appearance the Marquette specular ores from the Ishpeming formation. The readjustments due to folding occurred mainly in the soft ferruginous bands between the harder siliceous ores, and as a result the former have been sheared and the hematite rendered micaceous. In some cases the shearing was so severe that it affected the jasper and ore alike and both became schistose. On fractured surfaces along the schistose planes of the ores, especially when these surfaces have been slightly weathered, there is noticeable a peculiar texture that possesses considerable significance. On such surfaces a distinction can be made out between a fine-grained matrix and numerous comparatively large oval or lenticular areas. The latter give uniform reflection from their entire surfaces, while the matrix reflects from many small surfaces. The appearance thus produced is that of a number of large flattened grains in a groundmass composed of small grains. This texture is characteristic of fragmental sediments. Considered in connection with the fact that ore fragments are known to be present in some of the jaspers (cf., p. 308), the texture is regarded as indicating that many of the ore layers are composed largely of fragmental material.

The ore bands interstratified with the siliceous ones are not always schistose, nor have they always the mottled appearance of the typically fragmental ores. In many cases the interbedded ore is a dense black variety, almost aphanitic in texture, but striped parallel to the bedding with narrow lines that look like lines of sedimentation. The ore of this kind is mainly secondary, having been deposited along the planes between contiguous jasper layers or along bedding cracks that may have been opened within original ferruginous layers. In these cases there is usually a sharp contact line between the ferruginous and the siliceous layers, and the borders of the former are often denser and harder than their interior portions, which are composed principally of original material. In the case of the bands that consist largely of granular or micaceous hematite, the transition from these layers to the siliceous ones is more frequently gradual. The jasper near the ore is highly charged with hematite. Moreover, near the borders of the bands narrow seams of the siliceous material are interlaminated with the broader ferruginous ones. These become more numerous and broader, predominating over the ore bands and finally exceeding them altogether. In many instances ore bands that at first sight look homogeneous are found upon close inspection to be made up throughout of minute interlaminations of hematite and jasper.

Like all other fragmental sediments, the ores contain a variable quantity of impurities. Much of this impurity consists of quartz grains and of the constituents that are usually found in slates. Sometimes the proportion of such substances is so great that the ores are not marketable. They are then known as slates. The blue or dark-gray slates occurring under the ore at the Clifford pit of the Traders mine and in the dump heaps of the Cuff and Indiana mines are of this character. They are ferruginous sediments in which the proportion of ore grains is not sufficiently great to warrant working. On their cleavage surfaces these slates look like fine-grained specular ores, but on cross fractures they have a dull luster and are marked by obscure bands due to sedimentation. Moreover, they have a distinct argillaceous odor and are noticeably lighter in weight than the merchantable ores. With a lens the constituents can easily be made out to be ore particles and grains of a dull yellowish-white mineral.

The distinction between ore and slate at the Traders mine is mainly based on economic considerations. The boundary line between the two oscillates with the demands of the ore market. At the present writing, however, those deposits in which the impurities are distinctly visible as yellowish-white grains disseminated through the mass are unmarketable. The marketable ores are confined to those in which the impurities are jasper fragments or secondary silica aggregated into narrow bands. The guaranteed quality of the Traders ore is: Fe=41.00 per cent, Pr=.020 per cent. Cargo analyses of the ore shipped in 1899 averaged as follows:

Average analysis of ore from Traders mine.

Fe	41.01
SiO_2	39.10
P	.014
Mn	.09
S	.003
Al_2O_3	.97
CaO	.49
MgO	.29
H_2O above 105°	2.55

The surface surrounding the mine has been exhaustively test-pitted and the contents of the pits have been carefully tested for iron and phosphorus. The results of these analyses exhibit well the gradual transition between ore and slate. The numbers are those given to the different pits on the mine plats. Of these the first four pits are regarded as in slate, the balance as in ore. The arbitrary division between slate and ore is at 35 per cent Fe.

Iron content of rock taken from test pits north of the Clifford open pit.

	No. 6.	No. 3.	No. 12.	No. 1.	No. 7.	No. 13.	No. 11.	No. 8.	No. 9.
Fe	29.70	31.50	33.019	33.30	35.10	39.10	44.20	45.30	49.40
P	.011	.008	.....	.011	.011	.040	.009	.008	.022

The rocks constituted by the alternations of the siliceous and ferruginous bands often resemble very closely the jaspilites of the Marquette district. The brilliant red banding of the Marquette rock is, however, noticed at only a few places in the Menominee district. The prevailing color of the Menominee jaspers is dark purple or brown. In a few instances, especially where the siliceous bands contain very little fragmental jasper, the red color may be marked, as in the case of some of the bands in the Quinnesec open pit and in the ledge northwest of the Curry shaft No. 2, which has already been referred to as illustrating the character of the jaspilites of the Negaunee formation (p. 275). On the weathered surfaces the siliceous bands frequently take on a deep-red color, and on the surfaces of joint cracks druses of brilliant-red quartz crystals often cover the ends of the bands, but the color in both instances is only superficial. It rarely penetrates the rock to any great depth.

In most cases, except where the rock is brecciated, the bands are continuous, with a uniform thickness for long distances. Occasionally the bands wedge out, and when this occurs it is without exception the siliceous ones that so disappear, the ferruginous ones wrapping around their ends and coalescing. The result of this is the appearance of lenticular masses of jasper embedded in schistose ore (see Pl. XX, *B*). Sometimes the lenses are small and numerous, measuring one-fourth or one-half inch in their long diameters; sometimes the dissevered masses are spherical rather than lenticular. In both cases the resulting schist is knotty, resembling in general appearance micaceous schists that are studded with staurolite or garnet crystals. Well-marked phases of lenticular and brecciated jaspers are to be seen in the rock piles of the Traders and the Cuff mines and in the pits lying along the contact of the Vulcan formation and the Randville dolomite and stretching from the Norway

mine to the West Vulcan mine. These all exhibit the structure on a large scale. They are plainly nearly all brecciated jaspilites. At other places, notably west of Iron Mountain, the typical lenses occur, and these, so far as can be learned, are not connected with brecciation.

Where folded the siliceous bands are often crossed by cracks and fissures, on the walls of which are druses of quartz or calcite and hematite crystals. Veins of quartz, of calcite, and of dense hematite also traverse the ore and jasper bands indifferently, and not infrequently hematite veins are intercalated in the ore bands parallel to their bedding. The vein ore is always denser and more granular than the surrounding ore, and from the fact that the vein material often lacks schistosity when the intruded ore is schistose it follows that the former must have been deposited after the period of readjustment, during which folding occurred.

Where the rocks are folded the ore bands usually thicken and the ores take on a character very different from that of the ore in the thin beds. They lose their specular habit and their steel-gray color and become granular in texture and dark blue or black in color. This change is noticed to occur particularly at the ends and in the troughs of folds and in places where the rocks have been crushed or jointed. In these places the water that is constantly circulating through the rocks has removed silica and deposited hematite (see pp. 352, 395), thus producing the ore deposits of the district. New hematite has built out the plates of the original ore into grains. At the same time it has filled or partly filled with ore the openings that were produced during the crushing and jointing of the rock. Where the crushing was considerable the ore may present a porous aspect and all joint cracks may be lined with druses of hematite crystals. In other instances the thickening of the ore beds is, in part at least, an original effect and not one due to secondary causes. Some places along the original shore lines were more favorably situated for the accumulation of the ferruginous sediments than others. Here the deposits settled in greater abundance than elsewhere and made thick beds. The ore bodies thus produced may pass gradually along the strike into ferruginous jaspers, whereas when the change is due to secondary enrichment the passage may be comparatively sudden. The ore deposits are thus exceedingly variable in thickness, in some places measuring only a few inches, in others reaching 200 feet or more.

Microscopical.—When viewed under the microscope the jaspilites are found to be in most instances thoroughly crystalline. Even those specimens which in the hand specimen show a distinct mottling exhibit, only in a few cases, a fragmental structure when studied in thin sections. Those which exhibit this structure best are the jaspilites of Hughitt Bluff.

Sections of these rocks show both ore and jasper fragments in a matrix resembling that of the homogeneous jaspers described in succeeding pages. The ore fragments consist of long oval or lenticular masses of a very fine aggregate of quartz grains and tiny hematite flakes. Streaks of a coarse-grained and dense ore penetrate these masses in a direction parallel to their long axes, and usually their peripheries are bordered by zones of the same dense ore. The lenses are also traversed by quartz veins, the structure of which is much coarser than that of the quartz mosaic in the fragments. On the other hand, their material seems to be identical with that of the matrix in which the fragments lie. In reflected light those fragments with least of the dense ore in them have the bright-red color of jasper, while those in which there is much dense hematite are opaque and black. The distinction between the jasper and the ore pebbles is thus due solely to the quantity of hematite in them and to its character.

The groundmass in which these larger fragments are embedded consists of smaller oval and lenticular fragments of the same kind as the larger ones, cemented together by the usual matrix composed essentially of interlocking quartz grains materially larger than those in the jasper fragments. A few of these present the appearance of enlarged clastic particles, but by far the greater portion were clearly formed in place. Tiny nests of a ferruginous carbonate are also noticed here and there. In a few cases zones of coarse quartz border the large jasper and ore fragments and separate them from the mosaic matrix. Carbonate nests also occur frequently in the jasper pebbles and fragments, where it is clearly secondary.

The sections of many specimens, especially of the more schistose phases of the rocks, are mottled with large patches of quartz, many grains of which are granulated on their peripheries. These patches are traversed by broad veins of crystalline quartz like that composing the mosaic which cements the granulated patches together. These rocks look very much as though they had been crushed and shattered and, after shattering, had been healed by deposits of silica. Within the patches, in addition to the quartz, there are often large quantities of a yellowish, probably ferruginous, carbonate, partly in granules and partly in nests, and a great number of small particles of hematite. The cementing mosaic, on the other hand, is free from carbonate and also practically free from hematite dust, though an occasional speck of the mineral may frequently be detected in it, and here and there a bunch of fibrous chlorite.

The more distinctly schistose these rocks the less well preserved is their fragmental structure. The larger fragments in most schistose phases are flattened almost into shreds, and the components of the groundmass mosaic into distinctly lenticular grains. Wisps of muscovite are also developed in the groundmass, and with them is nearly always associated a little calcite or other colorless carbonate. A few little nests of the ferruginous carbonate remain. Coarse-grained quartz veins cut through this schistose groundmass, and occasionally it is crossed by a small vein of dense hematite. The ore bands differ from the jasper bands mainly in the presence of a larger proportion of very

much flattened ore fragments and partly in the presence of subsequently deposited hematite in the form of stringers or narrow veins. The proportion of the latter to the former can not be determined, but in some instances the newly deposited ore is present in large amount.

PLATE XIX.
PHOTOMICROGRAPHS OF ROCKS IN THE VULCAN FORMATION.

FIG. *A*.—Schistose ferruginous quartzite at base of Traders member, west end of Quinnesec open pit. Sand grains are inclosed in a matrix composed of smaller grains and narrow lenses of quartz intermingled with hematite dust and distinct crystals of the same mineral. Some of the hematite crystals are partly within a quartz fragment and partly in the matrix. The schistosity of the hand specimen is due to the wrapping of the quartz-hematite matrix around the large quartz sand grains. Ordinary light, X23.

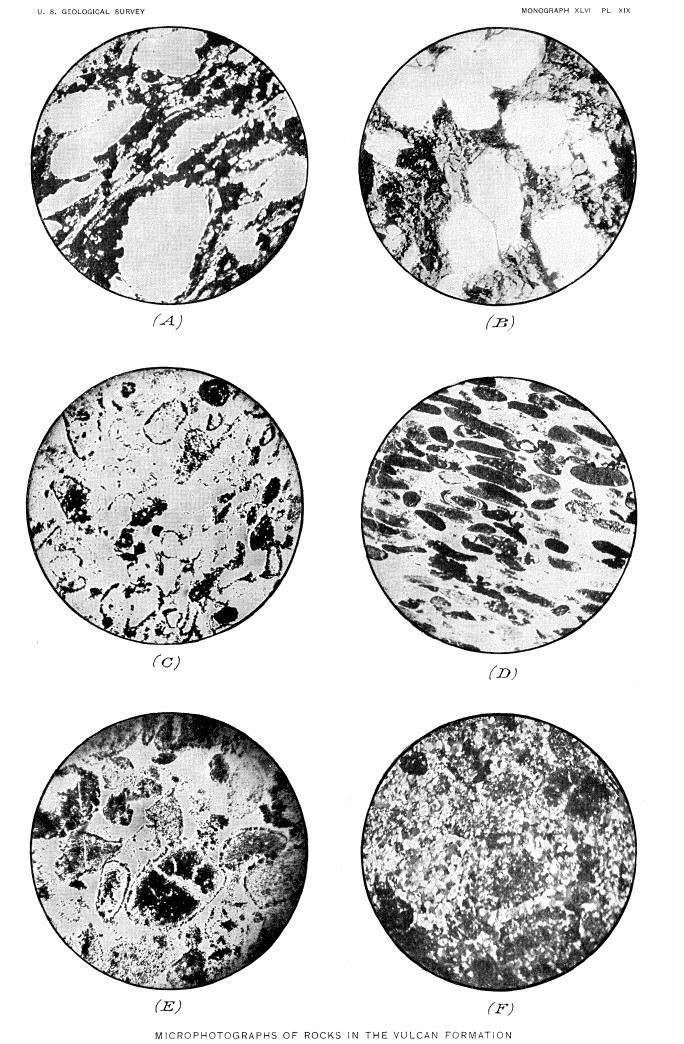
FIG. *B*.—Less ferruginous phase of the quartzite at the base of the Vulcan formation. The sand grains are surrounded by a matrix composed of small grains and masses and crystals of hematite. The fragmented character of the rock is very plain. Between crossed nicols all the quartz in the matrix possesses the crystalline character of that in typical jaspers. Ordinary light, X15.

FIG. *C*.—Jasper band in jaspilite, south side of Curry member, in northwest quarter of sec. 13, T. 39 N., R. 29 W. The section shows a finely crystalline quartz aggregate (which appears homogeneous in ordinary light) crossed by curved and concentric opaque bands, composed of little crystals of hematite. These mark the outlines of what were nodules, which have otherwise entirely disappeared. Ordinary light, X23. Compare with photograph of ferruginous chert derived from greenalite. Mesabi district, Mon. U. S. Geol. Survey, vol. 43, Pl. XV, *A*.

FIG. *D*.—Specular siliceous ore from test pit in the northwest quarter of sec. 13, T. 39 N., R. 29 W., Curry member. The section is made up of elongated nodules of hematite and of jasper in a homogeneous mosaic of fine-grained crystallized quartz. The opaque nodules are hematite. The cloudy ones are jasper, composed of hematite dust in a fine-grained quartz mosaic. One nodule shows a concentric arrangement of the quartz and hematite, characteristic of nodules derived from siderite. Ordinary light, X23.

FIG. *E*.—Spotted jasper from jaspilite, on railroad west of the Verona mine. This jasper consists of nodules of hematite and quartz and sharp-edged fragments of an older jasper in a groundmass of cherty quartz. The particles that are uniformly colored by hematite may be fragments of an old jasper. Those with accumulations of hematite toward their centers are probably nodules. All particles are surrounded by narrow rims of hematite grains that must have been deposited after the rock had practically assumed its present character. Ordinary light, X23. Compare with photograph of ferruginous chert derived from greenalite. Gogebic district, Mon. U. S. Geol. Survey, vol. 43, Pl. XVI, *B*.

FIG. *F*.—Same section. Under crossed nicols the entire field of view breaks up into an aggregate of finely crystallized (cherty) quartz. The outlines of a few of the nodules can be dimly discerned, but on the whole the section becomes a uniform mosaic, typical of the jaspers in general. Crossed nicols, X18. Compare Pl. XV, D, Mon. U. S. Geol. Survey, vol. 43.



The majority of the mottled jaspilites differ from those of Hughitt Bluff in containing no distinctly characterized pebbles of either jasper or ore. Occasionally, when the sections are viewed in natural light, there can be seen in the siliceous layers obscure traces of round or oval quartz masses that look something like pebbles. Sometimes the center of each mass is occupied by a little irregular nucleus clouded red by minute particles of hematite. This is surrounded by a zone of quartz in optical continuity with the nucleus and meeting the peripheries of other grains in interlocking sutures. Although there seems to be no sharp line of demarcation between clouded nucleus and clear periphery, nevertheless the appearance is as though the former were sand grains that had been enlarged by the addition of new material. Again, in some sections the distribution of hematite grains is such as to outline areas of quartz free from ore particles in the midst of an aggregate of quartz and ore, or the hematite is aggregated into small spherical and lenticular masses in which the ore is intermingled with a little quartz or borders a little quartz area. In the first case the sections seem to be composed of colorless pebbles in a crystalline aggregate of quartz and hematite. In the second case the apparent pebbles are probably pseudomorphs of concretions originally present in the sediments. These are much

more common in the jaspers of the Curry member, in the discussion of which they will be referred to again. Between crossed nicols the fragmental structure of all sections disappears, or, at any rate, it becomes very obscure. The entire section in each case breaks up into a practically uniform mosaic of interlocking quartz grains speckled with opaque dots and ovals of hematite and occasional crystals of magnetite (compare PI. XIX, *E* and *F*). In a few of the lenticular areas outlined by the ore the texture of the mosaic varies a little from that of the rest of the section, but only a very little.

The ore layers of these rocks differ from the siliceous ones mainly in the greater quantity of ore present. Most of it is scattered in little irregular masses between grains of quartz like those in the mosaic composing the essential part of the jasper layers, but much of it is in long narrow stringers that may be flattened pebbles or infiltrations along cracks.

Most of the true jaspilites exhibit no evidence of any kind of having ever contained fragmental detritus. Their jasper bands consist of a mosaic of slightly elongated quartz particles crossed by streaks of opaque hematite running in the same direction as the elongation of the quartz grains. The quartz grains are all small, their dimensions varying between 0.07 mm. and 0.14 mm. along their shorter diameters and 0.18 mm. to 0.22 mm. along their greater diameters. The ore streaks are made up of lines of small crystals or aggregates of crystals that seem to lie indifferently between quartz grains and inclosed within them. Besides the ore inclusions the quartz contains also a few liquid inclusions, a few indeterminate cloudy masses, some small independent crystals of hematite, and a quantity of fine dustlike particles that may also be a form of iron oxide. The hematite and quartz look as though they were deposited contemporaneously, the rocks in their microscopical features being identical with the jaspers of the Marquette district.

Occasionally in some sections small round lenticular areas of fine-grained quartz mosaic are distinguishable from a surrounding area of coarse grain, and often these are bounded by a thin zone of ore. In other sections there are lenticular and long, narrow, acicular masses composed of a mixture of quartz and limonite lying in the usual quartz mosaic. Of course these phenomena may indicate the former presence of pebbles in the original sediments, but the bodies are more probably concretions. They are, however, by no means as distinct as those in the conglomerates (see p. 303) or those in the Curry jaspers.

In some of the layers the microscope shows that the jasper consists of bands of the usual quartz mosaic interlaminated with others in which there is an abundance of a cloudy, red substance, which appears to be quartz stained by a thin layer of some iron hydroxide. Occasionally the red matter is in little plumose masses radiating inward from the peripheries of the stained areas, indicating plainly its secondary character. In other specimens round, cloudy areas are in reality portions of several quartz grains filled with tiny liquid inclusions. Between crossed nicols these areas break up into aggregates of grains each of which comprises two parts, one of which is filled with inclusions and the other entirely free from them. Neither of these phenomena can be regarded as indicating the former presence of pebbles.

The most typical jaspers—those which can not be distinguished macroscopically from the typical jaspers of the Marquette district, except by their more purple tinge—differ from the siliceous bands above described mainly in possessing a much finer grain. The grains of their quartz mosaic rarely measure more than 0.03 mm. by 0.04 mm. They constitute a uniform aggregate of interlocking particles thickly peppered with small, irregular flecks of ore and uniformly dusted with minute opaque hematite grains, which under high powers of the microscope are resolved into little rods, tiny oval and irregularly shaped bodies, usually transparent in red and yellow colors, and small, sharp-edged particles that resemble very small fragments. The ore flecks are ragged-edged opaque masses with many sharp projections that look very much like the corners of little crystals extending beyond a compact aggregate of crystals.

The distinction between jasper layers and ore layers in all varieties of the jaspilites is due solely to variations in the relative proportions of quartz and hematite present. Those layers in which hematite is in excess are the ore layers. Those in which quartz predominates are jasper bands. The transition from jasper to ore is usually accomplished in one of two ways. In some cases the dust particles, which have been referred to as being uniformly distributed through the quartz mosaic, become aggregated into streaks and bands. Toward the borders of the jasper layers these grow thicker and thicker and more and more numerous until the hematite exceeds the quartz in quantity and the layer loses its siliceous character and passes into an ore bed. In the second and more frequent type of transition the gradation is plainly the result of a secondary deposition. Mention has been made of the fact that the quartz mosaic of the jasper bands is often dotted with large, isolated crystals of hematite. Through the layers, which in the hand specimen are recognized as jasper, the crystals are sparsely scattered without any definite arrangement that can be detected. As the ore layers are approached, however, the crystals become numerous and on the borders of the bands they merge into groups of crystals with irregular outlines, but usually with their longer axes parallel to the directions of the bands. In the densest portions of the ore layers these aggregates exclude nearly all of the quartz, leaving just enough remaining to enable one to detect the presence of the aggregates.

The ore layers in all the jaspilites thus differ from the jasper layers merely in the presence of a greater quantity of hematite of the same character as that existing in the jasper. The structure of both bands is the same, although the quartz in the ore bands is usually