question the existence of a fold in the Brier slates, the Curry beds, and the overlying Hanbury slates, as indicated on the map. The fold is sharp and somewhat compressed. Along its north limb the Curry member is only 50 feet wide, whereas farther west, where the dip is approximately the same, its width is about 175 feet. If this fold is the same as that discovered on the eighth level of shaft No. 2 (see p. 444, and fig. 44), its pitch must be about 40° W. North of the north side of the fold there are no explorations within less than 280 feet. At this distance there are two pits, and a third is situated 100 feet farther north. These are all in jaspilites, which must belong in the Traders member, the intervening space between them and the fold being occupied by the Brier slate, which would have about its normal thickness. North of the northernmost of the pits just mentioned, and distant from it about 100 feet, is an isolated excavation in talcose slates, such as usually occur between the Randville dolomite and the lowermost Vulcan beds. The dolomite must be only a few feet to the north. The country, however, is covered by the Cambrian sandstone, which constitutes an effectual obstacle to any attempts to map the areal distribution of the Huronian formations in the absence of test pits.

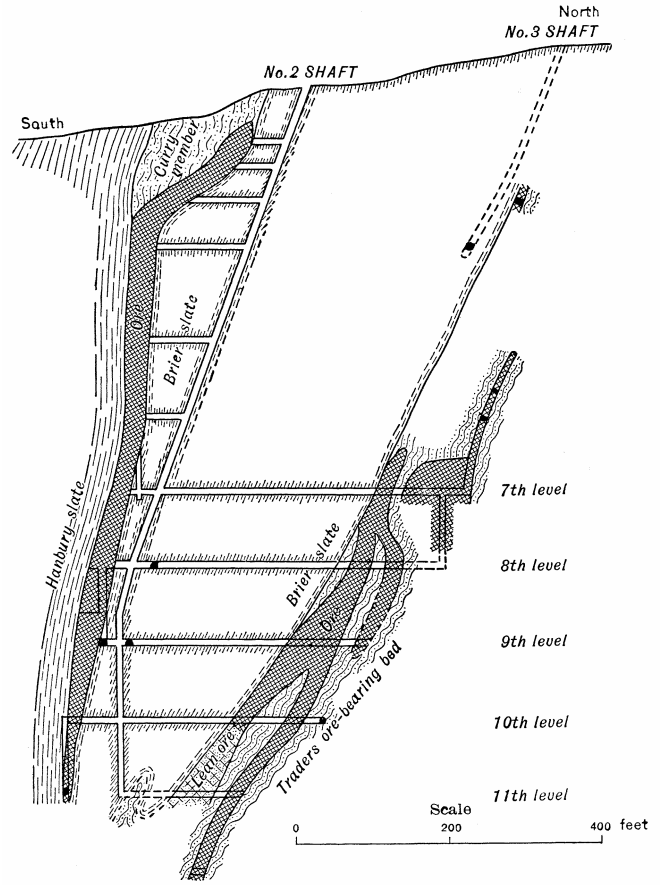


FIG. 45.—Vertical north-south cross section through No. 2 shaft, West Vulcan mine.

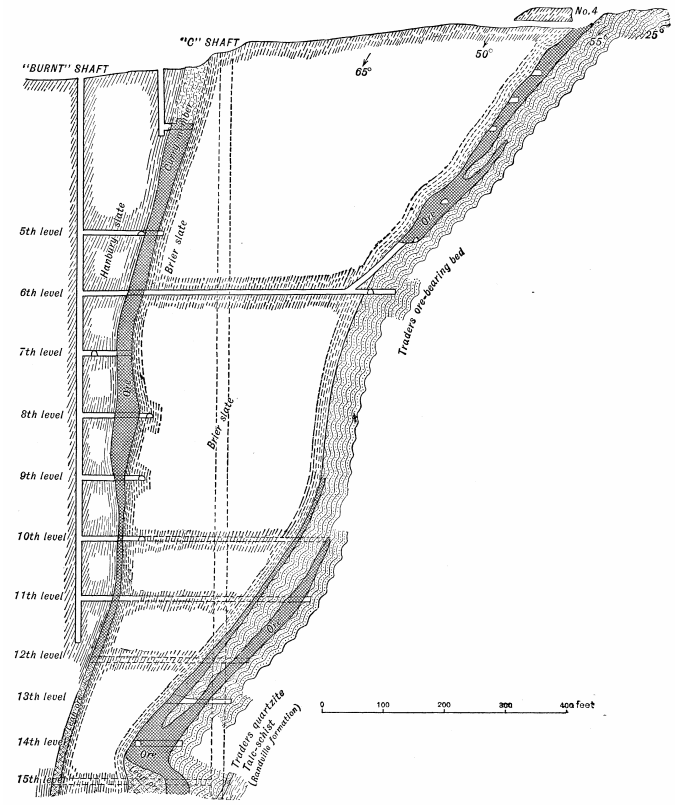


FIG. 46.—Vertical north-south cross section through Burnt shaft, West Vulcan mine.

The ore of the principal West Vulcan shafts is obtained from both the Traders and the Curry horizons, as shown in figs. 45 and 46. The ore of the lower horizon now being exploited occurs immediately below the Brier slates, at the top of the Traders member. The ore of the higher horizon occurs in the Curry member between the Brier slates and the Hanbury slate, extending from one to the other (see figs. 45 and 46). The three contacts of the two iron-bearing horizons with the Brier and Hanbury slates are planes along which movement and brecciation have occurred, and therefore where percolating waters have been active. These ore bodies have a considerable longitudinal extent, but as yet have not shown great width. The southern deposit of the West Vulcan mine at shaft No. 2 shows very well the relation between sharp folding, and therefore brecciation, and differential movement between the iron-bearing member and Brier and Hanbury slates. Here, at the west end of the mine, is a very sharp fold in the slate and iron-bearing member (see fig. 44). This fold appears on the surface to the east of the section line, where it is exploited in part by the Klondike shaft. From the relative positions of the apex of the syncline in the Hanbury slate at the surface and on the eighth level of shaft No. 2, it is seen that the fold pitches almost due west at about 40°. It is probable that the existence of this fold in the Curry member has a great deal to do with the productiveness of the formation at this place, for when folding is not present the Curry member is usually very lean.

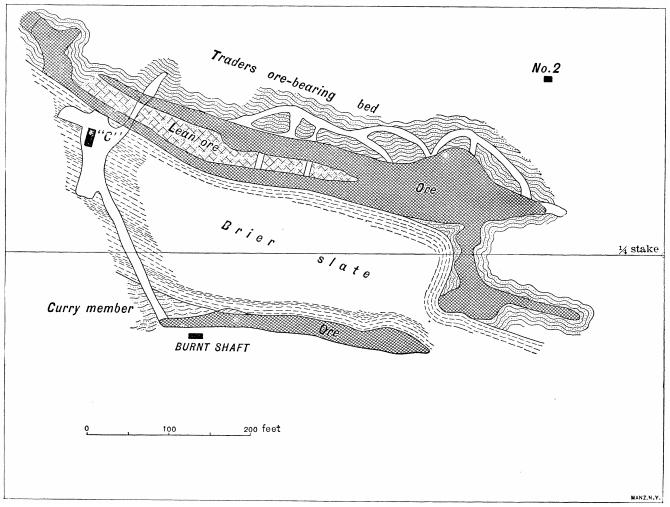


FIG. 47.—Horizontal section of the West Vulcan mine at twelfth level.

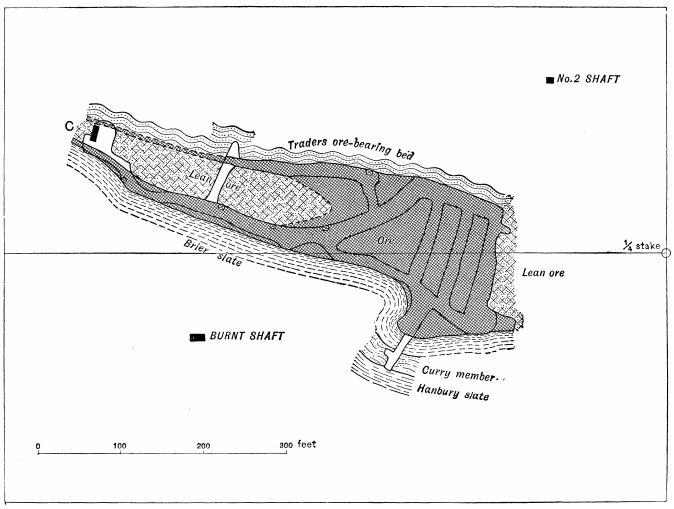


FIG. 48.—Horizontal section of West Vulcan mine at the thirteenth level.

The plan and cross sections of the levels leading from the "C" shaft show the same disposition of ore with respect to the surrounding rocks (see figs. 46 and 47) as at shaft No. 2. The irregular shapes of the ore bodies are beautifully shown on the plan of the twelfth level (fig. 47) and in the cross section (figs. 46 and 49). The southern ore body appears at present to be a western pitching lens, but additional work to the east of the cross section may show that the Curry beds at that place have been pinched out and that they reappear again farther east. It will be noted that the Brier slates have nearly disappeared, the thickness of 200 feet, which separated the two ore deposits in the ninth level, having diminished to about 30 feet on the thirteenth level. The plan of the thirteenth level (fig. 48) seems to show that the east end of the ore deposit which terminates on the twelfth level, 250 feet east of the Burnt shaft, does not extend to the depth of the thirteenth level, its place being taken by a narrow belt of jaspilite. If upon further exploration it is found that the Curry beds actually end at this place, as the ore deposit appears to do, or if it is found that they end a little farther east, their termination will undoubtedly be discovered to be due to the little fold already referred to as exhibited on the surfaces east of shaft No. 1 and on the eighth level of shaft No. 2. If this fold continued to pitch west at the same angle below the eighth level as it does between this level and the surface its apex should occur somewhere near the position of the end of the cross cut on the thirteenth level of "C" shaft (compare also fig. 49).

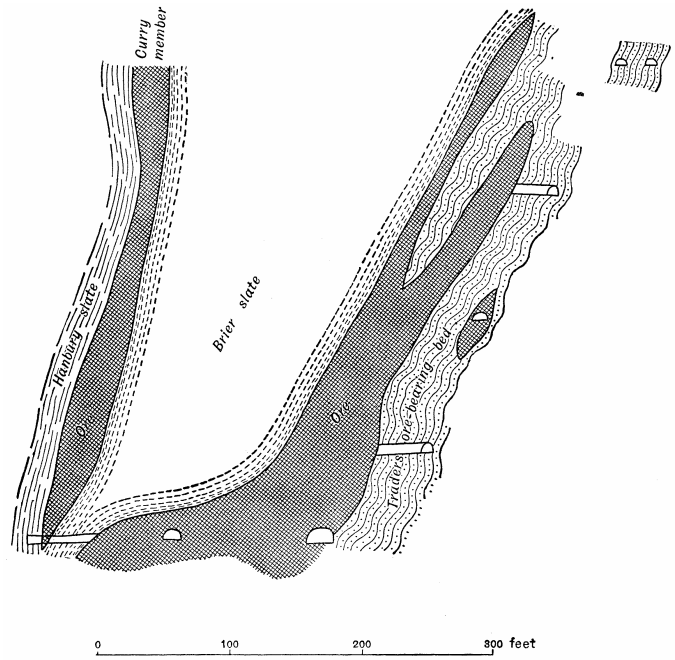


FIG. 49.—Vertical north-south cross section through West Vulcan mine, 250 feet east of the Burnt shaft. The dip is to the south.

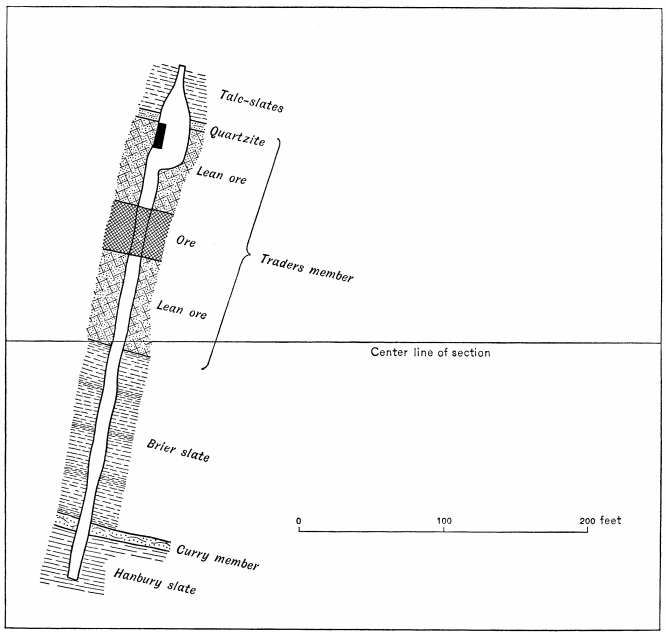


FIG. 50.—Horizontal section of West Vulcan mine at the fifteenth level.

Fig. 50 is a plan of the fifteenth level of the "C" shaft. This is a crosscut traversing the entire Vulcan formation from the talc-schists underlying the Traders member to

the Hanbury slates overlying the Curry member. The width of the formation is here 300 feet, of which 160 feet is occupied by the Traders member, 125 feet by the Brier slates, and 15 feet by the Curry beds. The narrowness of the Curry member may again be due to the presence of the fold alluded to above.

At the contact of the Curry jaspilites with the Hanbury slates at the south end of this crosscut and at the south end of the little crosscut extending south from the east end of the thirteenth level is the peculiar cherty-looking rock which has already been referred to as differing somewhat from anything else seen in the district, with the exception of an apparently similar rock found at the end of a drift from the Klondike shaft and interbedded in thin layers with the jaspilites on the dump heap of this shaft. The West Vulcan rock is evenly but thinly laminated, hard, dense, and gray, and is traversed by very narrow veins of dark-green chlorite along joint cracks and cut by wider veins of calcite or dolomite and of pyrite, or by veins composed of a mixture of the last-named mineral and quartz. Pyrite is also disseminated through the mass of the rock, in some places as minute granules so small as to be almost imperceptible to the unaided eye; in other places in larger particles so thickly crowded together as to make the rock almost a massive aggregate of pyrite granules. In the latter case the pyrite also occurs in veins the main trunks of which run parallel to the bedding, and send off minor branches that anastomose through the rock in all directions. In the specimen collected from the dump of the Klondike shaft the cherty rock appears as a layer between thin, dense ore layers. It contains very little pyrite, but in place of this mineral there are tiny veins of limonite and of hematite. In some places the chert passes into normal jasper. In this particular case the light-colored band appears to be a true chert belonging to the Curry member. From the depths at which the West Vulcan specimens were found, viz, 1,000 feet and 1,200 feet beneath the surface, it was at first thought that they might represent remnants of the original rock that gave rise to the jaspilites. Upon examination in thin section, however, the rock is found to be made up mainly of fragmental and cherty quartz and sericite, with the addition here and there of small fragments of plagioclase, rutile, and possibly minute particles of zircon. In some sections these are the only constituents, but in many others dolomite is also rather abundant in the form of small veins and nests disseminated irregularly through the mass. No crystals of this dolomite were observed in the specimens studied, nor was any trace of a nodular structure discernible. The rocks are plainly not original carbonates, nor are they representatives of original pyritiferous beds that may have served as the sources of the iron in the Vulcan formation. They are presumably dolomitic phases of the Hanbury slates that were silicified near the contact with the Curry beds by the same process that silicified these, the pyrite and much of the carbonate being subsequent infiltrations. The rock in the drift at the Klondike shaft was obtained from a depth of only 175 feet. It differs from the specimens from the West Vulcan levels in containing so much carbonate and so little secondary quartz that it may be rightfully called a cherty dolomite. In this particular instance the rock is minutely brecciated and is cut by both calcite and chert veins, so that it is difficult to determine exactly the proportions of chert and carbonate in the original rock. It is certain, however, that the rock does not represent original sideritic beds from which the iron of the ore deposits was obtained.

CENTRAL VULCAN AREA.

This area includes the east half of the southwest quarter of sec. 10 and the entire southeast quarter of the same section. It lies immediately east of the West Vulcan area and occupies the whole stretch of the iron-bearing belt between the West Vulcan and the East Vulcan mines. There are no mines at present operating in this district, nor are there any natural exposures of the iron-bearing rocks. A number of exploring pits and a few exploring shafts, besides the old open pit of the Central Vulcan mine, serve to trace the Curry belt about three-fourths of the way across the area. The Traders belt has been opened up at only two points—by a shaft indicated on the map (Pl. XXXIV) as Jones's shaft and by a crosscut from a shaft in about the center of the northeast quarter of the section. From Jones's shaft a drift extends south into the Brier slates. The width of the slate belt here is about 540 feet, as against about 270 feet north of the West Vulcan or Klondike fold, and 340 feet in the East Central tunnel, running north from the exploring shaft in the eastern portion of the area. The excessive width of the belt at Jones's shaft is ascribed to repetition of the beds by the fold discovered to the west. This folding necessitates the existence of a corresponding fold in the Traders beds east of Jones's shaft and a corresponding embayment in the margin of the dolomite a little farther east. These can not be observed because of the covering of sandstone. Their position is approximately indicated on the map by dotting the borders of the several belts. The thickness of the Traders beds across this area and the position of the southern boundary of the dolomite are, of course, unknown. The former is arbitrarily represented as having the same width as it has north of the Klondike fold.

The absence of known noteworthy ore deposits in this area is probably accounted for by the general absence of folding or brecciation. Where the Curry member is narrowest, and where, presumably, more or less brecciation exists, is the deposit of the Central Vulcan shafts. On the Traders belt the only promising exploration is Jones's shaft, and it is significant that this is near the fold in the Traders beds corresponding to the Klondike fold in the Curry beds.

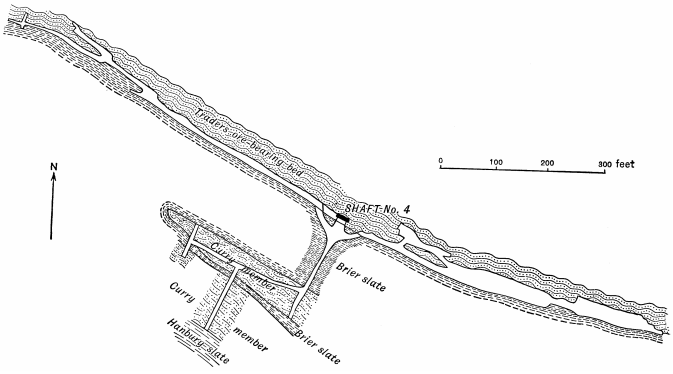
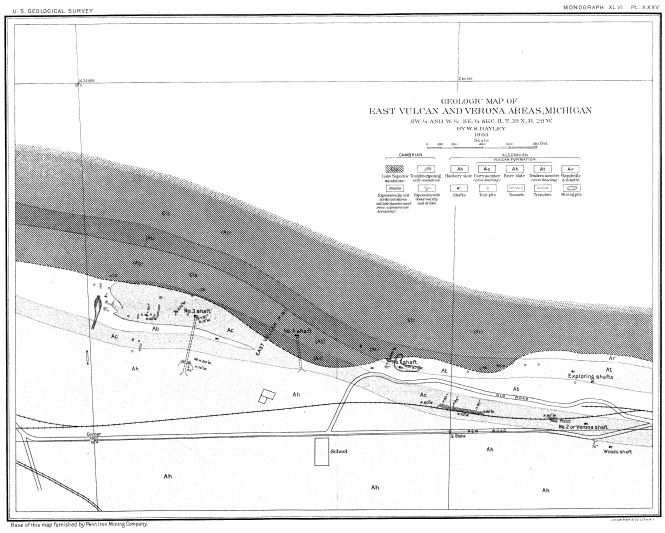


FIG. 51.—Horizontal section of East Vulcan mine at eighth level, No. 4 shaft.



[Plate XXXV. Geological map of East Vulcan and Verona areas]

EAST VULCAN MINE.

This area extends through the southwestern portion of sec. 11, T. 39 N., R. 29 W., just east of the Central Vulcan area (Pl. XXXV). In it are the Nos. 1, 3, and 4 shafts of the East Vulcan mine and east of it the one shaft of the Verona mine. The Vulcan beds occur on the side of the same ridge that extends all the way from the Curry mine, and which is bordered everywhere by the iron-bearing formation. The top of this ridge is covered with the sandstone that presents in so many areas an unconquerable obstacle to the investigation of the Huronian rocks. Fortunately, this sandstone covering overlaps the iron-bearing beds to only a slight extent, its southern boundary being nearly coincident with that of the Randville dolomite. It is usually, however, a little south of the southern limit of the dolomite; hence the exact position of this can only be indicated approximately. Just west of the west line of sec. 11 the Brier slate widens and passes into the section as a belt 500 to'600 feet in width. About a hundred yards farther east this belt divides into two belts, separated from one another by a belt of iron-bearing beds, which is interposed between the Traders belt to the north and the belt of Curry beds to the south. Between this place and the meridian of shaft No. 4 there are therefore in a section across the Vulcan formation three belts of iron-bearing beds and two of Brier slate. Farther east the middle and southern iron-bearing belts appear to coalesce in consequence of the disappearance of the southern belt of Brier slate. Beyond to the east, as far as the Sturgeon River, only two iron-bearing belts and one slate belt are known. A study of the distribution of the slates as exposed by ledges and test pits near the west line of the section shows clearly that the slates wrap around the western end of the middle ore-bearing belt and that at the turn their beds are broken and contorted into many little folds pitching east. The southern belt of Brier slates becomes thinner to the east and on the eighth level of shaft No. 4 it is only 10 or 15 feet thick (fig. 51). Thus the middle belt of the iron-bearing beds is a syncline of the Curry member, pitching east, and the southern belt of Brier slates a closely compressed fold, also pitching in the same direction. The cross section through shaft No 3 (fig. 52) shows the synclinal character of the intermediate (northern Curry) jaspilite belt very beautifully. If we assume that the end of this belt is only a short distance below the sixth level of the mine, the pitch of the fold is about 35°. On the plan of the eighth level of shaft No. 4 (fig. 53) the fold in the Curry beds again appears.

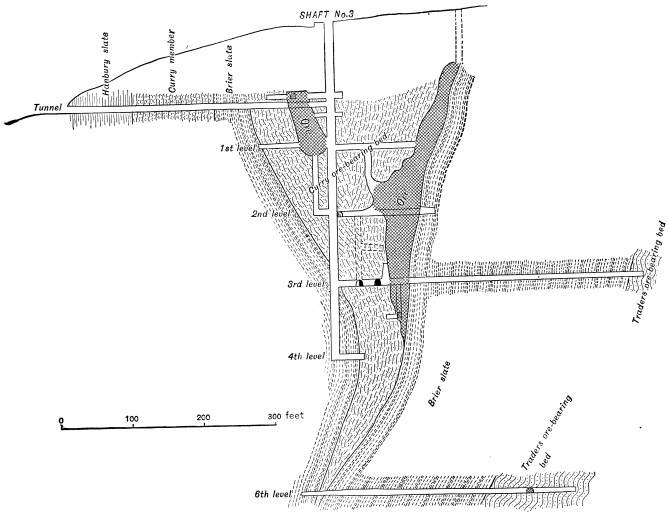


FIG. 52.—Vertical north-south cross section through shaft No. 3, East Vulcan mine. The general dip of the beds is to the south.

The principal ore deposits thus far exploited in shaft No. 3 are along the sides of the syncline in the Curry beds. That being worked from shaft No. 4 is in the Traders beds, partly on the contact of these with the overlying Brier slate (see fig. 53). The dip of the contacts is about 60° S. The only indication of the presence of the dolomite in this area is the existence of talcose slates north of the Traders jaspilites on the eighth level, shaft No. 4. The contact between the two formations projected to the surface would make the surface contact occur under the sandstone covering about 300 feet north of shaft No. 4. On the map (Pl. XXXV) the Traders belt is represented as of uniform width across the area, making the southern boundary of the dolomite parallel

with the southern boundary of the Traders beds. That this contact is sinuous can hardly be doubted. It is probable that it is deeply indented.

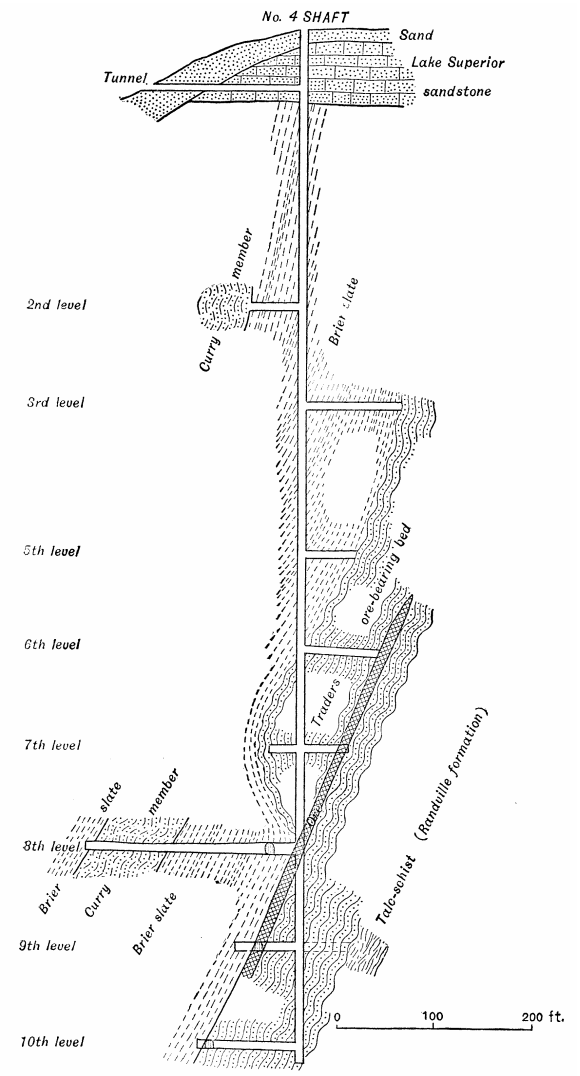
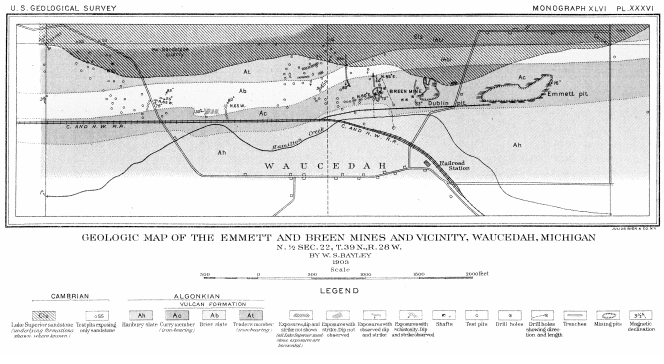


FIG. 53.—Vertical north-south cross section through shaft No. 4, East Vulcan mine. The dip of the beds is to the south.



[Plate XXXVI. Geological map of the Emmett and Breen mines and vicinity, Waucedah]

West of shaft No. 3 the exposures are abundant. The strikes and dips observed confirm the inferences outlined above with respect to the existence of a large fold in the Curry beds at this place. The Brier slate is very much contorted beyond the observed termination of the northern belt of the Curry beds, and the exposures of the latter indicate that these, too, are folded. A little exposure just east of shaft No. 3, for instance, shows a strike of N. 15° W., i. e., nearly transverse to the direction of the belt, and a dip 87° E.

East of shaft No. 3 the exposures and test pits are comparatively few. The several belts appear to continue with approximately uniform width to the center of the section (north-south quarter line).

VERONA MINE.

The Verona area is east of the East Vulcan location. It occupies the southern half of the southeast quarter of sec. 11 and the northern portion of the adjoining sec. 14. The mine shaft, which was formerly known as Southeast Vulcan, is situated near the south line of the southwest quarter of the southeast quarter of sec. 11.

Information concerning the geology of the area is scanty, since rock exposures are few and the ground has not been explored to any great extent. In the cuts alongside the railroad track west of the Verona mine the Curry jaspilites are exposed in long ledges striking N. 70° to 80° W. and dipping about vertically or very high to the north. In the Woods shaft, southeast of the Verona shaft, the contact of the Hanbury slate with the Curry beds dips 75° to 80° S. The normal dip over most of the area seems to be to the south at high angles, as it is for some distance to the west, but here and there for short distances the beds are overturned to the north.

The Traders member has been traced by test pits and an exploring shaft nearly to the east edge of the section, but very little has been learned of its structural features.

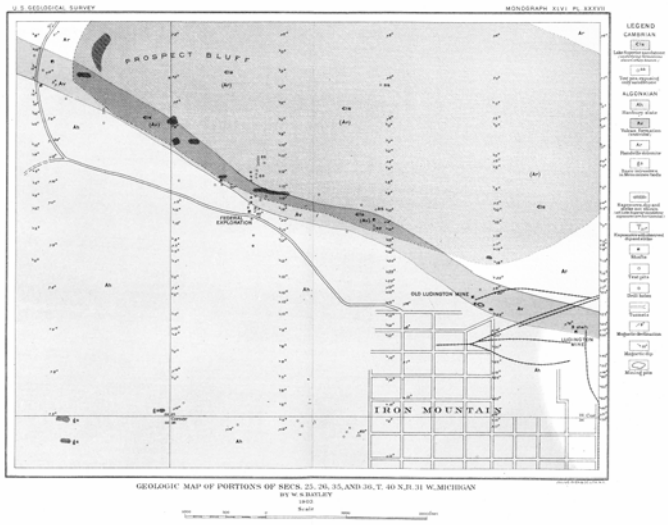
The ore deposit in the Verona mine has been only partially explored. So far as now known, it comprises an ore body in the Curry member. Drill holes put in to the south of the seventh level, near its east end, penetrated a belt of Brier slate that apparently lies between two belts of jasper, which farther west unite and form a single belt. This may indicate the presence of a fold in the iron-bearing series, but its exact nature has not yet been ascertained.

EMMETT AND BREEN MINES.

These mines are situated at the village of Waucedah, in sec. 22, T. 39 N., R. 28 W. (Pl. XXXVI). They were the first mines opened on the Menominee range, and consequently have been more fully described than any others in the district. From the descriptions, however, very little can be gleaned with reference to the occurrence of the ores. At present the difficulties met with in attempting to decipher their geology are almost insurmountable. The great open pits are full of water. Sandstone covers the ore-bearing beds in many places, resting upon a very irregular pre-Cambrian surface, and therefore in some instances reaching considerable distances beneath the present surface. Moreover, the basal layers of this sandstone are often highly

ferruginous, sometimes consisting mainly of hematite intermingled with a small portion of siliceous and other impurities. These ferruginous beds resemble very closely some of the Traders slates elsewhere, consequently it is exceedingly difficult to identify them as Cambrian. Further, the ore-bearing beds exposed in the mining pits and in their immediate vicinity contain much more fragmental material than has been encountered elsewhere. The thin sections show great numbers of round and sharp-edged quartz grains, much muscovite and other light-colored micaceous minerals, light-green earthy substances resembling serpentine, and occasional clastic grains of feldspars. The ore is in little bands between these components and in well-defined narrow layers interbedded with layers composed principally of the siliceous minerals.

To the west of the mine pits much more typical cherts and jaspilites are found, not only in the dumps of the numerous test pits scattered over the area, but also in natural ledges. By the aid of these pits the three separate belts of the Vulcan formation can be traced entirely across sec. 22, and their limits with reference to one another can be delimited with a fair degree of accuracy. On the other hand, the exact boundary of the formation with respect to the dolomite on the north and the Hanbury slate on the south can be indicated only approximately, the former because of the sandstone covering and the latter because of lack of exposures of the slates.



[Plate XXXVII. Geological map of portions of secs. 25, 26, 35, and 36, T. 40 N., R. 31 W.]

The Traders belt enters the section from the west at the northwest corner, continues east to the north-south quarter line, and then trends east of north and leaves the area between the north quarter post and the northeast corner of the section, its southern boundary passing through the corner or a few feet north of it. The belt is traced almost exclusively by test pits and shafts, but near the quarter post there is a large craggy ledge of cherts and jaspilites that suggests more strongly the Curry beds than the Traders. At the southwest corner of the ledge there is an excellent exhibition of the "bands and shots" of ore in a white or gray pellucid chert. The shots are spherical masses of hematite about the size of a small buckshot, and the bands are chains of these lying side by side in a line.

The Brier slate is shown in a number of pits and in several small ledges. The rocks exposed have the typical aspect of these slates in the greater number of instances, but in others they are strongly ferruginous and cherty. This is particularly so near the west side of the northeast quarter of the northwest quarter of the section where the rocks are contorted into numerous small folds. These folds, which pitch west at angles of about 30°, indicate the presence of a larger fold in the neighborhood which may have caused an accumulation of ore in the folded rocks. The position of this larger fold can not be mapped with our present knowledge because of the lack of sufficient exposures.

The Curry belt is not as well delimited in the western portion of the section as are the other two belts of the Vulcan formation. A few pits south of the Brier slates, however, are bottomed in an iron-bearing formation which must, from its position, be the Curry member. Near the north-south quarter line, however, and east to the east line of the section, test pits that have uncovered the Curry member are frequent, and the large open pits of the Emmett and Breen mines leave no doubt as to the existence of an iron-bearing series between the Brier and the Hanbury slates. This series of rocks dips south at about 70°. Natural exposures are to be seen at the westernmost of the Emmett pits. The jaspilites and the ores associated with them are exceedingly sandy looking, and, as has been mentioned, they contain an abundance of clastic quartz grains. Nowhere in this area are the distinctly-banded jaspilites met with, except perhaps in a few of the pits in its western portion.

SUMMARY.

The above brief description of the mines will serve to show that the ore deposits, where of any magnitude, are situated in just such positions with respect to the surrounding rocks as might have been predicted on the assumption that the accumulation of the ores is the result of the action of percolating ground waters. The larger and richer deposits are without exception in the troughs of pitching synclines. The smaller and leaner deposits are along such contacts as would naturally be followed by descending currents. Where the rocks are brecciated near the contacts the removal of silica has proceeded with greater completeness than along contacts where there has been no brecciation and the ores are consequently rich. Where brecciation is lacking the ores are leanest. Where folding, brecciation, and other marked disturbances are lacking there the ores are lacking also.

OTHER LOCALITIES OF THE VULCAN FORMATION.

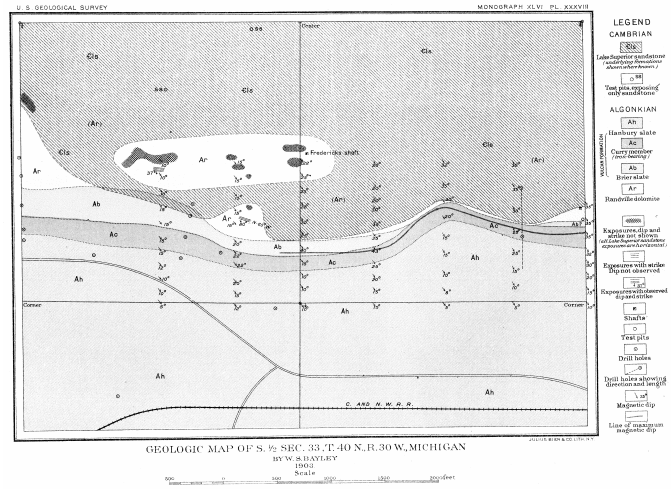
There are several other areas along the southern ore-bearing belt where the Vulcan formation is present, but from which, so far as is now known, merchantable ore deposits are absent. These emphasize the statements

made above as to the manner of occurrence of the ore bodies, since they serve to show that, in the absence of marked disturbances in the jaspilite belt, there is not much hope for the discovery of valuable deposits.

Secs. 25 and 261 T. 40 N., R. 31 W.—The westernmost point at which any member of the southern belt of the Vulcan formation has been observed is at about the center of the northwest quarter of sec. 26, T. 40 N., R. 31 W. (Pl. XXXVII). From this point a series of pits and shafts extends, with short intervals between them, all the way to the east side of sec. 25, but they cover only a narrow strip of territory running through the district, and so give very little evidence as to the conditions underground. That the Vulcan formation exists from one end of the district to the other admits of no doubt. A jaspilite belt stretches throughout the entire distance, and this is bordered on the south by a series of slates. In some places the slates are red and earthy. In other places they are mottled sericitic varieties, and in still other places they resemble some phases of the Brier slates. Some of these slates are unquestionably Hanbury. Whether others are Brier or not it is impossible to say at present. The northern margin of the jaspilite belt appears to have been reached by the most northerly of the drill holes through the sandstone in the vicinity of the Federal exploration in the western portion of sec. 25 and in drifts running north from the more northerly shaft in sec. 26. In both these places the rock bordering the jaspilite is either the Randville dolomite or the cherty quartz rock lying above this. At the old Ludington mine, near the center of the southeast quarter of sec. 25, the dump contains in abundance large fragments of coarse quartzite like that at the base of the Traders member and pieces of jaspilite that are identical in appearance with the Traders jaspilites at the Aragon mine. Moreover, the situation of the old Ludington works with respect to the present Ludington mine indicates that both mines are at the same geological horizon, i. e., the horizon of the Traders member. Passing westward, the conditions seem to be the same at the explorations in the center of sec. 25. Farther west the jaspilite belt is narrow and is bordered on the south by slates closely resembling the Brier slates. It is probable, indeed almost certain, that near the west line of sec. 25 only one jaspilite belt is present, and this along its upper contact at the Federal exploration contains an ore body 110 to 115 feet in width. The contact dips south at 85°. At several other points lean ores have been found, but nowhere else has a distinct and well-defined ore body been discovered.

Just east of the east line of the area now being discussed all three members of the Vulcan formation are known in complicated folds that have caused a repetition of the members in several belts. These have been traced westward to within a few hundred feet of the east line of sec. 25, but have there been lost because of lack of exposures and of explorations. Until these shall have been followed continuously into sec. 25 the manner and place of their disappearance can not even be conjectured and the problem of the geology of this section and the one to the west must be left unsolved.

The overlapping of the sands tone beyond the southern limit of the Randville dolomite prevents the detection of folds in this formation, if they exist, and the character of the explorations in the jaspilite belt has not been such as to develop the folds that may be present in it. It may be that folds of large size exist in the center of sec. 25, since both sharp and smooth folding on a large scale is noted in many of the jaspilite fragments on the dump of the deep shaft at this place; but, if so, there is no evidence on the surface to indicate the fact.



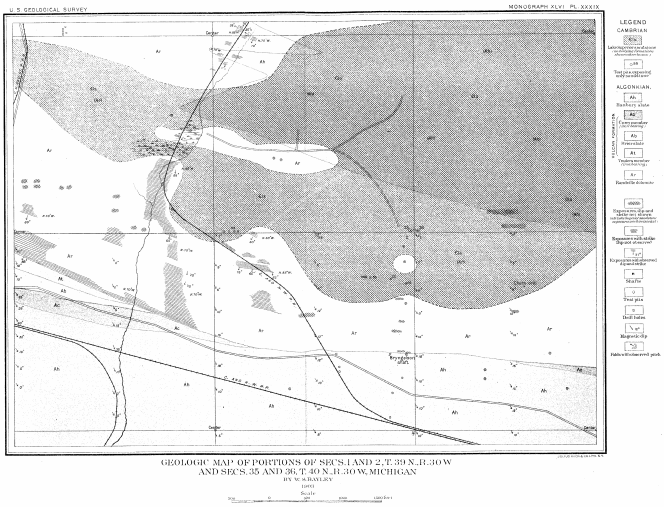
[Plate XXXVIII. Geological map of south half of sec. 33, T. 40 N., R. 30 W.]

Sec. 33, T. 40 N., R. 30 W.—This section lies between the Keel Ridge location (Pl. XXIX) and the Quinnesec and Cundy mines (Pl. XXX). The explorations along the iron-bearing belt across the section are not sufficiently numerous to give much idea as to the distribution of the underlying rocks. An iron-bearing belt enters the southwestern corner of the section and leaves the southeastern corner (Pl. XXXVIII). From the scanty information at hand it appears to lie between the Hanbury slate to the south and a quartzite or slate to the north. The former is believed to be the cherty phase of the Randville dolomite that lies above the more purely dolomitic beds, and the latter is thought to be a phase of the Brier slate. This belt apparently disappears by overlap in the center of the southeast quarter of the section and gradually thickens both to the east and the west. At this place, too, there is some evidence of the northward bending of the iron-bearing belt, which may indicate a corresponding northward embayment in the dolomitic margin and a gentle fold in the entire Vulcan formation. No ore deposits have thus far been developed within the area. This is not surprising if the iron-bearing member is the Curry member, especially if, as appears to be the case, there is no sharp folding to cause brecciation in the jaspilites or to furnish troughs for the accumulation of the ores.

North of the Vulcan beds the dolomite is exposed in a number of large exposures in the western portion of the section. It has likewise been found in drill holes and a shaft in its extreme eastern portion. Elsewhere north of the northern boundary of the Vulcan beds only

sandstone is known. At two places this has furnished some ore from the conglomerates at its base.

Secs. 1 and 2, T. 39 N., R. 30 W.—This area is east of Quinnesec and between this village and sec. 6, T. 39 N., R. 29 W., to be referred to later. There are no natural exposures of the Vulcan formation or of the Hanbury slate in the area, although exposures of the Randville dolomite are abundant, especially in sec. 2, T. 39 N., R. 30 W., and in sec. 35 lying to the north (Pl. XXXIX). A large number of explorations have, however, been made in the area and these have afforded a large number of facts from which the geological structure may be inferred. The dolomite exposures in secs. 2 and 35 have been described in another place (see p. 263 et seq.). The southern boundary of the formation in sec. 1 is determined with a fair degree of accuracy by exposures, pits, and drill holes. Its northern boundary can be established only approximately, as the usual layer of sandstone covers all the northern portion of the area underlain by this dolomite. Drill holes in the southwest quarter of the southeast quarter of sec. 35, and a test pit near the north line of sec. 1 indicate that the boundary is north of these points. Along the line between secs. 1 and 2 the dolomite belt is shown by drill holes and test pits to be continuous from the corner to the Bryngelson shaft, about 1,600 feet south of the corner. Its southern boundary is a continuous straight line without indentations of any kind which would indicate the presence of folds.



[Plate XXXIX. Geological map of portions of secs. 1 and 2, T. 39 N., R. 30 W., and secs. 35 and 36, T. 40 N., R. 30 W.]

South of the dolomite the Vulcan beds should normally occur. To the west of sec. 2 the three members of the formation have been observed, but there are no exposures or explorations in the western half of the section by which they can be traced across the line. The magnetic line which is so strong in the neighborhood of the Cundy mine enters the section from the west but gradually dies out within a quarter of a mile of its west line. Near the center of sec. 1, in the eastern portion of the area, a drill hole penetrated a few feet of lean ore lying between Hanbury slates and a narrow band of gray slates between it and the dolomite. The entire Vulcan series at this place is not 30 feet thick.

Between this drill hole and the western line of sec, 2 the explorations have shown only Hanbury slate south of the dolomite. This is often graphitic near the dolomite and is in some places traversed by a great many quartz veins. In the Bryngelson shaft and in a trench a few feet to the west the slate is in contact with the dolomite (see p. 366), so that there is no possibility of the presence of the Vulcan beds between them. The complete disappearance of the Vulcan formation after entering the area from the west and its gradual thinning as it enters the area from the east is explained as due to overlap of the Hanbury slate along a sinking shore line (see pp. 370-372).

Sec. 6, T. 39 N., R. 29 W.—This section has probably proved more disappointing to explorers than any other in the entire Menominee district. In the search for the westward extension of the Norway and Aragon ore deposits an immense amount of money has been expended in explorations, and even now, with the results of all these explorations in hand, we are nevertheless still very much in the dark as to the geology of the section. There seems, however, to be no possibility of the existence of undiscovered folds in the area, and therefore not much possibility of the presence of large ore deposits comparable with those of the Norway and Aragon mines.

The succession, beginning at the north, is: Dolomite, followed by light-colored slates that are talcose in part, and in part quartzose; coarse quartzite, like that elsewhere near the base of the Traders beds; a jaspilite belt from 250 to 450 feet in width, and, finally, a wide belt of slate (Pl. XL). The boundary between the Lower and the Upper Menominee is drawn at the top of the talcose slates. The Vulcan beds dip south at angles varying between 55° and 70°, and strike nearly east-west. The southern slate at some places is in some respects like the typical Brier slate; at other places it is the typical gray slate of the Hanbury formation. Its maximum width, as developed by drilling, is about 400 feet. South of this point the nature of the underlying rock is unknown. It is possible, of course, that the slate is Brier and that elsewhere to the south is a second jaspilite belt, and that the Hanbury slate is much farther south. On the map the slate in which the drills were put down is placed in the Hanbury formation. This would make the jaspilite belt to the north represent the Curry member, unless this member, together with all the Brier slate, is absent, and this is not considered probable. The true age of the iron-bearing beds and the slate to the south of them can not be determined until the hiatus between the Norway and Cyclops mines and the west line of sec. 5 has been explored sufficiently to enable one to trace the three members of the Vulcan formation from the mines westward into sec. 6.

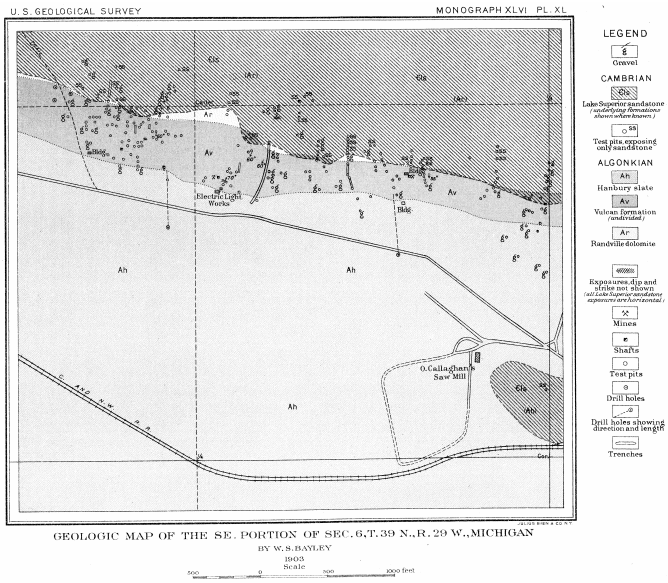
Where it enters the section from the east the jaspilite belt is about 250 feet wide. It keeps this breadth uniformly to near the center of the section, where it gradually widens

to about 400 feet or 450 feet, and beyond the center it again contracts slightly. The expansion near the center of the section is evidently due partly to folding.

In the open pit east of the shaft north of the old electric-light works the jaspilites are well exposed in sharp folds pitching west. The dip in places is 70° N. Since the dip farther north is 60° S., there may be a fold in the beds between these points. Nowhere else in the belt is there any evidence of the presence of folds, although subordinate folding within the formation no doubt exists. The normal dip of the jaspilites is about 55° to 60° S. To the north near the dolomite it becomes flatter, and on the top of the hill under the sandstone it is quite flat.

The rocks are typical jaspilites composed of alternating layers of schistose hematite and dense waxy jasper. The jasper is often in flat lenticular bands, and in some cases these bands are cherty rather than jasper like.

The slate belt between the jaspilites and the dolomite appears to be much wider than it usually is, but this great width may be due to the flat dip of the upper surface of the dolomite, corresponding to the flat dip of the overlying jaspilites.



[Plate XL. Geological map of southeast portion of sec. 6, T. 39 N., R. 29 W.]

An interesting feature of some of the deeper pits near the center of the section is the presence of an abundance of chert on their dumps. This is usually dark colored, flinty and very much brecciated, the fragments consisting very largely of a pellucid white chert. Large bowlders of the same chert are sometimes found inclosed in the basal layers of the overlying sandstone. Some of these bowlders are finely brecciated, but others consist of the dark chert traversed by veins of the white variety. The fragments in the brecciated phases are probably shattered portions of veins of this kind, and the rock is probably from a chert layer at the top of the dolomite.

Secs. 12 and 13, T. 89 N., R. 29 W.—The most easterly exposures of the Vulcan formation, with the exception of those occurring at Waucedah, are to be found on the west side of the Sturgeon River, near the north quarter post of sec. 13, T. 39 N., R. 29 W. (Pl. XLL) The greater portion of the south half of the section to the north is occupied by the Randville dolomite, the exposures of which have been described on preceding pages (pp. 271-273). North of the dolomite the country is supposed to be underlain by a westward-pitching syncline of the Hanbury slate, and northeast by an eastward-pitching syncline of the Vulcan formation (see pp. 404-407). On the south the dolomite is bordered by a belt of the Vulcan formation about 900 feet wide, and south of this is the Hanbury slate.

The Vulcan beds are exposed by trenches and test pits, near the north-south quarter line of sec. 13 and by a group of pits near the center of the northwest quarter of the northwest quarter of the section. All three members of the formation are represented in their typical development. The jaspilites in the trench strike east-west and dip vertically. The dump of the northernmost pit near the southernmost ledges of dolomite shows the usual coarse quartzite at the base of the Traders member, and the talcose slates that usually separate the Traders quartzites and jaspilites from the dolomite. This latter rock nearest the contact with the overlying Vulcan beds is brecciated, and some specimens of the breccias look very conglomeratic. Close search through the conglomeratic phases, however, revealed no foreign fragments that might indicate that the rock was water deposited.

HANBURY SLATE.

DISTRIBUTION AND TOPOGRAPHY.

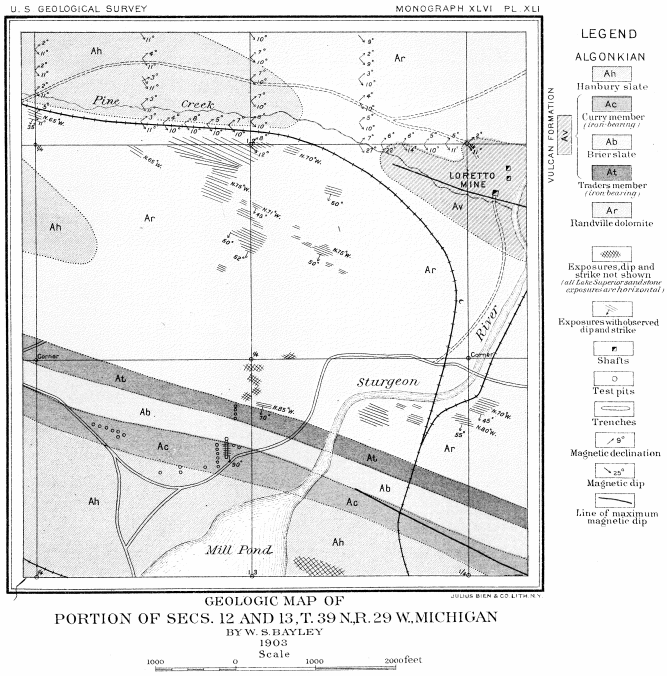
The Hanbury slate occurs mainly in three large belts constituting valleys that correspond with synclines between the older rocks. It occupies nearly all the low ground in the Menominee trough, forming a plain broken only by heaps of glacial material deposited upon it, by the protrusions of a few hillocks composed of the harder slates, or by equally resistant greenstones. Exposures in the slate areas are very rare and widely scattered. They are confined almost exclusively to the hillocks to which reference has been made and to the lower slopes of some of the stream valleys. The slates are also exposed in a number of places on the sides of cuts along the railroad right of way.

Since the main part of the Menominee trough is a westward-pitching synclinorium the slate areas are narrowest at the east and gradually widen toward the west. The northern belt is divided into two portions by the western area of Quinnesec schists. The northern part turns northwest and leaves the Menominee district at the northern limit of the area mapped, while the southern portion coalesces with the middle belt and crosses the Menominee River into Wisconsin. East of Iron Hill the two northern belts again coalesce and

extend as a single belt to the Sturgeon River. Near the longitude of Waucedah all the slates disappear to the east beneath the Paleozoic beds.

LITHOLOGY.

The formation comprises black and gray clay slates, gray calcareous slates, graphite slates, graywackes, thin beds of quartzite, occasional beds of ferruginous dolomite, and rarer bodies of ferruginous chert and iron oxide. These rocks present no unusual characteristics. The argillaceous slates are like normal slates elsewhere. The quartzites and graywackes are likewise normal. The calcareous slates are either fine-grained quartzites cemented by a calcareous or dolomitic matrix, or are normal clay slates with nests and crystals of some carbonate scattered through their masses. The dolomites and cherts are like those in the Randville and Vulcan formations.



[Plate XLI. Geological map of portions of secs. 12 and 13, T. 39 N., R. 29 W.]

The predominant rocks of the formation are the gray clay slates and the calcareous slates. The latter are more abundant in the lower portions of the formation and the former in the upper portions, but the exact vertical relations of the two rocks have not been made out, because of the scarcity of exposures and the very intricate folding to which they have been subjected.

The formation is cut by dikes of schistose greenstones, and in one or two places sheets of the same rock have been intruded between the sedimentary beds.

Clay slates.—The clay slates are mostly gray or black normal argillaceous slates, in which there is always more or less ferruginous matter. Where exposed to the weather they are light in color and have a shaly character. Muscovite or sericite then becomes prominent and their iron components are decomposed to red ocherous compounds. Where most altered the rocks are light-red sericite-slates or shales. When the slates contain small quantities of calcareous components their weathering is somewhat different. They tend to bleach to a very pale-green or white color and to become porous through the loss of their calcareous cement. The ferruginous components oxidize, forming red ocher, and this lies in an irregular pattern on the light-colored background. The result of these changes is a red and white or pale-green, mottled, friable slate, known locally as “calico slate.” A few varieties of the black slates are quartzose. These are denser and more compact than the more purely argillaceous varieties. They are not at all shaly and they possess little or no slaty cleavage. These rocks grade into the quartzites and graywackes.

Under the microscope the argillaceous varieties of the clay slates are seen to consist of small splinters and grains of quartz and an occasional grain of feldspar lying in a crystalline matrix composed of interlocking quartz, small spicules of sericite, kaolin, and chlorite, larger plates of the last-named mineral, and the usual accessories of slates, rutile crystals and needles, limonite clumps, and a few nests of calcite. In some specimens the sericite preponderates over all the other constituents; in others the chloritic component is in excess, and in yet other phases quartz is most prominent. Thus the normal slates pass on the one side into sericite-slates and on the other side into quartzite. Usually there is an interlamination of quartzose and chloritic or sericitic beds with an average thickness of not more than one-fourth inch.

The most typical sericite-slates, or perhaps more properly schists, differ from the argillaceous ones principally in the greater size of the individual sericite fibers. Because of the larger dimensions of this micaceous component the schistosity of these slates is much more pronounced than that of the gray and black argillaceous phases.

Upon exposure to weathering influences many of the argillaceous and sericitic slates, as has been stated, pass into mottled “calico” slates. The rocks are bleached in certain places by the alteration of the greenish sericite and chlorite into colorless compounds except near cracks, where the chlorite is weathered into a mass of ocher and quartz. The latter change causes red stains to spread out from the walls of all cavities into which water can penetrate, thus producing red irregularly shaped mottlings against the bleached, white background.

The graphitic varieties of the clay slates are black, very fissile, thinly laminated rocks. They appear to be limited to those portions of the formation near its contact with ferruginous beds. At any rate, they have been seen only in association with the underlying Curry member and at horizons a few hundred feet above the base of the slate formation, where cherts and ores have been developed, but they do not everywhere occur at the base of the formation. This frequent association of ore and graphitic slates suggests the possibility of a genetic relationship

between them which has been referred to in another place (see p. 354). The graphitic slates appear to grade laterally into the normal gray slates, of which they seem to be local modifications. Since they occur mainly near contacts the graphitic slates have usually been tremendously sheared into very thin folia with many repeated, complicated, and irregular contortions. When stained by ocherous deposits these slates are recognizable by the curved or convex character of the plates into which they usually split.

Examined microscopically the graphitic slates are usually very fine grained. They contain an abundance of sericite and kaolin, forming an extremely fine-grained web in which small quartz grains are embedded. The graphite coats the walls of shearing joints. It is observable under the microscope only when the sections are perpendicular to the cleavage. All specimens are schistose in parallel positions, and the calcite, limonite, and most of the crystallized quartz grains are elongated in the same direction. In many sections microscopical folds are visible which are counterparts of the folds seen in hand specimens.

Graywackes and quartzites.—The graywackes and quartzites of the Hanbury formation are normal rocks of their kind, requiring no special description. They both occur in comparatively thin beds interlaminated with slates, more frequently in the lower part of the formation than in the upper portion. The quartzites are more abundant than the graywackes, but neither are common.

In one place only within the district is the quartzite present in any considerable quantity. This is near the point where the Chicago and Northwestern Railway crosses the line between sec. 19 in T. 40 N., R. 30 W., and sec. 24, T. 40 N., R. 31 W. In the cut through which the right of way runs beautifully banded slates are exposed, striking in general N. 75° W. and dipping nearly vertically. With these are interbedded narrow bands of quartzite or graywacke. The slates are distinctly ripple marked, and, together with the quartzites, are compressed into little folds pitching steeply (45° or more) to the west. The slates are green and cherty and the quartzite is gray or white and novaculitic. To the east the quartzose layers pass into cherty and ferruginous bands. The chert bands wedge out and then occur in flat lenticules surrounded by slate. Farther east the ledge disappears, but the ground is strewn with great fragments and bowlders of a fairly coarse-grained calcareous quartzite cut by a few quartz veins.

This quartzite is light gray in color and its weathered surface is pitted with little holes marking the places from which some constituent, probably calcite, has been removed. West of the railroad some few hundred steps the quartzite is exposed in place on the side of a little knob overlooking a swamp. Here it appears to have a thickness of at least 50 feet.

Although no rocks other than those described occur in the near neighborhood, which might serve to determine the relations of these, the petrographical character of the slates is so distinctly like that of the Hanbury slates elsewhere that no doubt is felt as to the stratigraphical position of the beds. They are more cherty than is usually the case, but, as will be shown later, they contain no greater proportion of cherty material than is met with at several other places in the slate area. The occurrence is particularly interesting for the great thickness of the quartzite bed.

Under the microscope the quartzite differs from the quartzite of the Sturgeon formation in containing many large and small fragments of plagioclase, orthoclase, and microcline. Moreover, its quartz grains lack the distinct clastic appearance of those in the Sturgeon quartzites. The grains seem, to be corroded, and neighboring grains therefore appear to interlock by irregular sutures. Calcite or dolomite is also present in the rock, partly as little nests between the quartz grains and partly as a sparse cement. It may be due to the presence of this component that the quartz grains have the corroded outlines.

Calcareous slates and dolomites.—By the addition of calcareous material the argillaceous slates pass into the calcareous slates. These sometimes contain as much as 50 per cent of calcite or dolomite as a cement. With an increase in the carbonate the slates lose their slaty character, become more massive, and finally pass into beds of limestone or dolomite measuring from a few inches to 20 feet in thickness. On weathered surfaces both the dolomite and the calcareous slates are often coated with a skin of brown ocherous limonite, which in the case of some of the massive dolomites reaches a thickness of an inch or more. Much of the limonite is pseudomorphous after siderite. These facts show that the dolomites are sideritic, and that the siderite has partly decomposed, producing limonite.

When fresh the calcareous slates are lighter colored than the corresponding argillaceous phases, their color being usually some shade of gray. They lack the silvery luster of the sericitic varieties and their schistosity. Where their weathered surfaces are not incrusted with limonite they are pitted with little pores from which the carbonate has been dissolved.

The calcareous slates may be divided into two classes: (1) Those into which carbonate-bearing solutions infiltrated, depositing nests of calcite and dolomite, and (2) those in which these carbonates and siderite appear as original components in the form of small grains and tiny rhombohedral crystals or groups of crystals. The first class includes those slates, cut by calcite and dolomite veins, which are saturated with carbonate material. This occurs either in elongated nests arranged in lines along the cleavage planes or as a matrix in which the sericitic, quartzose, and chloritic components of the rock are embedded. In the second class the carbonate appears to be the embedded material. The matrix surrounding the carbonate is a fine-grained aggregate, with the composition and structure of the argillaceous slates. As in the first variety, the carbonate is arranged in lines that are parallel to the cleavage.

The calcareous slates grade into dolomites which vary in color through many shades of gray and pink. The majority are dark-gray, impure varieties, very different from the dolomite of the Randville formation, while a few beds consist of pink varieties identical in appearance with many specimens of the Randville dolomite. In many cases the dolomites are closely associated with cherts and sometimes with thin beds of limonite or other ferruginous compounds. Their lithological features will be referred to at greater length in the discussion of occurrences.

Cherts and ferruginous oxides.—The ferruginous cherts and iron oxides are not known to be present in the Hanbury slate in large quantity. Indeed, they are usually only locally developed in association with the sideritic dolomites and calcareous slates where these have been severely crushed or folded. The source of the iron oxides is clearly iron-bearing carbonate in the calcareous slates and the dolomites.

The cherts are white or yellow massive rocks with a finely granular texture. They occur as thin seams and veins traversing the slates and dolomites, and as thin beds interlaminated with equally thin beds or seams of hard siliceous and ocherous slates and with thicker beds of dolomite.

Wherever the cherts occur there is usually found also a greater or less quantity of some iron oxide. Sometimes this appears as small veins of pure hematite cutting through the cherts, sometimes as coatings of hematite on the walls of cracks traversing the slates, sometimes as small vugs inclosed in shattered cherts, sometimes as druses covering the walls of the cavities in an extremely porous chert, sometimes in distinct bands interlaminated with bands of graywacke or quartzite, and sometimes in the form of a mixture of oxides and hydroxides impregnating slaty material. In short, the iron oxides occur in all forms characteristic of deposits precipitated from percolating waters. The slates impregnated with ferruginous matter are naturally dark red or black. Where but slightly ferruginous they still plainly exhibit their true character. When, however, the proportion of the iron oxides is large, but few traces of the original slate remain, and the rock resembles a slaty ocher or a compact siliceous ore.

At several places, more particularly at one place in the slate area near the south quarter post of sec. 21, T. 39 N., R. 28 W., the banding of the material obtained from a deep shaft appears on the weathered surfaces to be as even and as well defined as the banding of the ores and ferruginous quartzose slates of the Curry member. Close inspection of the hand specimens, however, especially where made on fresh fracture surfaces, shows that the resemblance to the Curry rock is illusory. The banded rock is mainly a graywacke interlaminated here and there with layers of slate. A set of cracks cuts the graywacke parallel to its bedding planes, and along these the percolating waters found ready passage. An earthy hematite was deposited in the cracks and in the rock mass adjacent to them, thus producing bands of ore material separated by belts of the graywacke, in which there was little deposition of ore.

Large deposits of hematite, such as characterize the Hanbury formation west of the Menominee River, in the Florence, Crystal Falls, and Iron River districts, are not known in the Menominee district; but ore bodies sufficiently large to warrant exploration have been discovered at several widely separated localities. These localities will be referred to more particularly in subsequent pages and the character of the cherts and ores in each will be briefly described.

Igneous rocks and their contact deposits.—In several places the slaty series is intruded by greenstones mainly in the form of dikes. The igneous rocks in their present condition are much altered diabases or basalts composed of uralitized augite or hornblende, decomposed plagioclase, and a considerable quantity of quartz that is probably entirely secondary.

The slates in contact with the igneous rocks are in many instances metamorphosed to a slight extent. Actinolite has developed in them as single long, slender, needles penetrating all the other components and as radial groups of needles. A few large plates of dark-green chlorite also occur in some of the metamorphosed phases and a little altered feldspar is present in very irregularly shaped masses forming a sort of matrix by which all the other constituents are surrounded. This feldspar, which is now partly changed to kaolin or saussurite and is reddened by ferruginous dust particles, must have been infused into the sedimentary rock from the neighboring intrusive. In most cases the quartz of the original slates has also suffered considerable change. Its fragmental character has largely disappeared. Its contours are rounded, its peripheries corroded, and neighboring grains interlock. The fine débris in the matrix has entirely recrystallized. In some specimens calcite is present in small quantity; in others it occurs in large quantity. In both cases it is apparently an alteration product of the feldspar.

FOLDING AND SECONDARY STRUCTURES.

The major folding of the Hanbury slate corresponds with that of the underlying formations. Along a north-south cross section there are three major synclines with east-west axes, the major anticlines having been eroded save at the ends of the central dolomite belt and at the east end of the western area of Quinnesec schist. At these places the slates should present plunging anticlines. The exposures necessary to confirm this inference are lacking. The north-south major folds corresponding to the broad north-south folds of the Randville dolomite are not easily recognizable. The slate belts, however, widen to the west and wrap around both ends of the central dolomite area and around the east end of the western Quinnesec schist area. There must be anticlinal arches over the dolomite and the schists with a syncline between, and there must also exist a second syncline between the eastern end of the central dolomite belt and the Loretto mine. The slates must likewise pass over the