rence of graphitic matter is, however, not confined to the slates. The Vulcan formation is often so highly charged with carbonaceous matter that it becomes very dark in color or even black. Mr. Connibear, of the Cleveland Cliffs Iron Co., states that he has encountered, in drilling, rocks having all of the appearances of graphitic black slate but which contain by analysis from 20% to 25% of iron. There is no doubt that much of the black slate of this district is heavily charged with iron in the form of oxide and carbonate although pyrite is the most conspicuous iron bearing mineral.

While in the Dober mine iron ore and ferruginous chert grade laterally and vertically into black slate and black chert, in many places the ore lies with sharp contact on black slate the bedding in the two rocks being parallel. South and east of the Dober workings are interbedded black, gray, and green slates carrying thin bands of jasper and cherty iron carbonate.

Sections through the Dober mine, drawn by Mr. D. A. Hellberg, are given in fig. 10 through courtesy of the Oliver Mining company.

The Isabella workings are northeast of the Dober. The Vulcan formation in the Isabella is separated on the fifth or 500-foot level from the Vulcan in the Dober by from 250 to 300 feet of "black rock" and black slate which, as in the Dober, seems to completely enclose the ferruginous chert and ore on this level. Gradational phases between ferruginous chert and black graphitic slate and chert are shown here as in the Dober workings. Formerly the Isabella was worked as an open pit. A "chimney" of ore was worked from the surface downward to a depth of several hundred feet but drilling shows that this body seems not to be connected with the ore in the lower levels now worked from the Dober shafts. The rocks exposed in the walls of the open pit are mainly lean iron formation. Gray slates occur on the southeast side and these are succeeded by graphitic black slate which crosses the pit from northeast to southwest. The ore body seems to have lain on the black and gray slate with steep pitch to the northwest and was overlain by ferruginous chert.

The Chatam Mine.—The Chatam mine is operated by the Brule Mining company. It is northwest of the Isabella on the N. E. ¼ of the S. E. ¼ of Section 35, T. 43 N., R. 35 W. The property is crossed from north to south by Iron river and is being developed through two shafts, No. 1 west of the river, and No. 2 east of it.

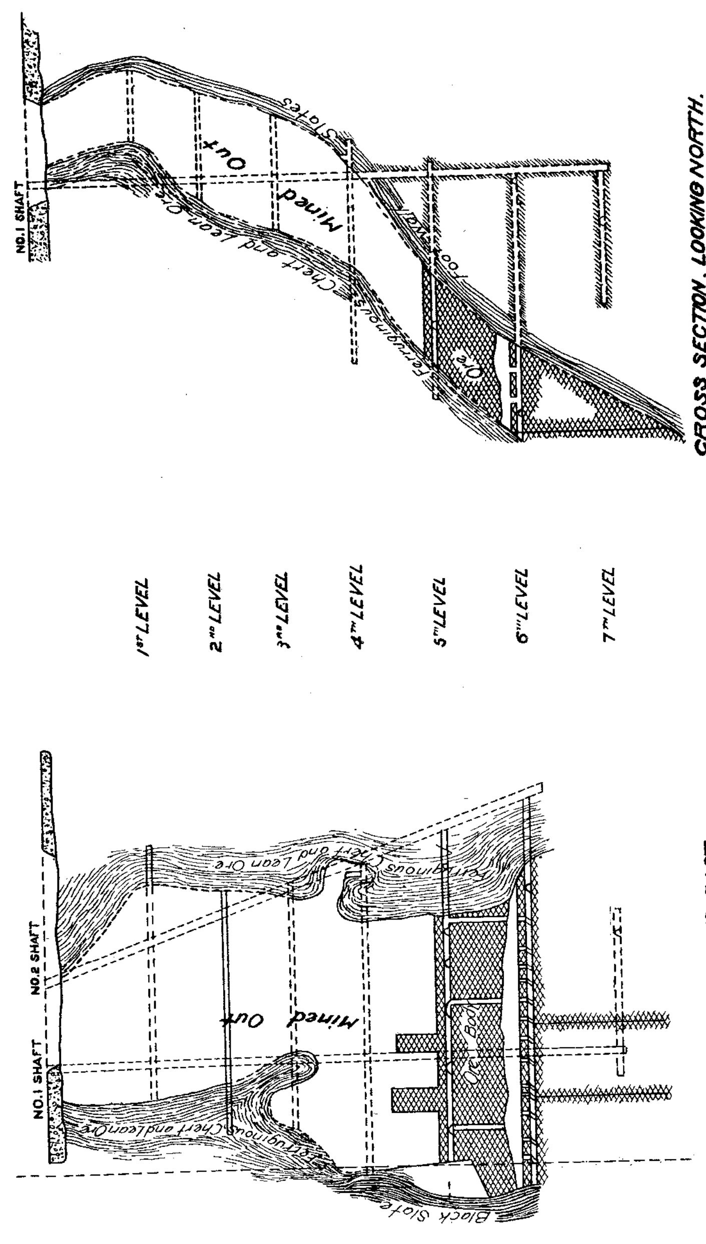


Fig. 10

SECTIONS THROUGH DOBER MINE.

OLIVER IRON MINING CO.

SCALE 0 100 200 300 400 FEET

1909

In the workings of shaft No. 1, which has reached a depth of 400 feet, the Vulcan formation trends north and south and dips steeply east. At the time of the writer's visit two bodies of ore were being stoped, one about 300 feet south of the shaft and the other between the shaft and the north boundary of this property. The pitch of both ore bodies is in the direction of dip of the iron formation and both extend from the fourth level to the surface. The ore grades laterally along the strike of bedding and across it into lean ore and ferruginous chert.

In the workings of shaft No. 2 the general dip of the Vulcan formation is steeply west and strike about N. and S. Ore bodies occur in the northern and southern ends of the workings, one about 200 feet north of the shaft, reaching surface under the highway and the other at the south pitching apparently south or southwest. The relations between ore and adjacent rocks are the same here as in the workings of No. 1 shaft.

The Hiawatha Mine.—South of the Chatam mine a belt of iron formation swings westward with steep north dip through the property of the Hiawatha mine. In this mine the Vulcan is overlain on the north or hanging wall side by black graphitic slate and black chert but the foot wall rocks are not exposed, the south cross cuts being in iron formation often but slightly altered. On the surface in a drainage ditch on the south side of the small ravine just south of the shaft are exposed an interbedded series of dark graywacke, black slate, and ferruginous slate and chert (see p. 98-99). These rocks underlie the iron formation opened up in the Hiawatha workings. The structure of the Hiawatha belt is by a number of engineers interpreted as a closely compressed syncline pitching westward toward the main "Iron river trough." The writer, after a study of the mine workings and mine plats, through the courtesy of the Munro Iron Mining company, is not able to either affirm or deny the correctness of this interpretation. There is absolutely no evidence of a synclinal structure to be adduced from the *facts* of structure in the Hiawatha mine. The north or hanging wall is fairly well defined, the south or foot wall is not penetrated by the mine workings. The underlying rocks exposed at the surface are not lithologically closely similar to the black slate and chert of the hanging wall but they *may* nevertheless be stratigraphically equivalent. Until some evidence to the contrary

is found the Hiawatha belt must be interpreted as a northward dipping monocline as indicated by *known* facts of structure.

The occurrence of ore in the Hiawatha mine is similar to that in Chatam No. 1. The longer dimensions of the ore bodies are generally in the plane of bedding of the iron formation. In some

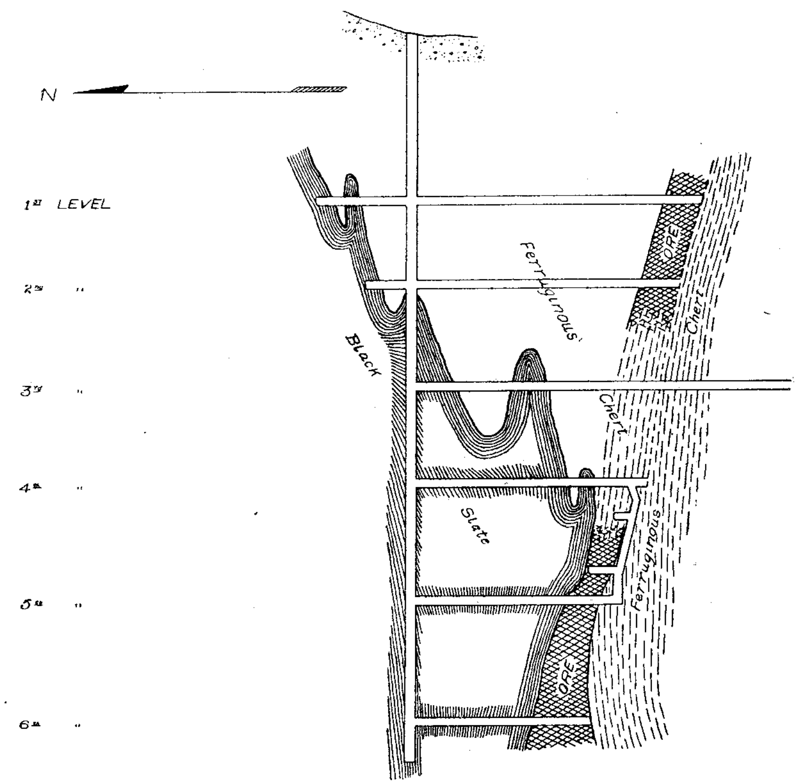


FIG. 11

SECTION THROUGH MAIN CROSS-CUTS OF HIAWATHA MINE.
1909 SCALE FEET MUNRO IRON MINING CO.

places they lie against the black slate and chert hanging wall, in others they are overlain and underlain by lean ore and ferruginous chert and pass by gradation in the plane of bedding into these rocks. In some places the ore is underlain within a few feet by iron formation only slightly altered. While the iron formation is generally contorted by minor folding, the ore bodies do not seem to have close relation to folds but must be considered as irregular concentrations in a steeply dipping belt of iron formation. A cross section through the Hiawatha mine is shown in figure 11 through the courtesy of the Munro Iron Mining company.

The Riverton Mine.—North of the Chatam is the Riverton mine on the N. E. 1/4 of the N. E. 1/4 of Section 36, T. 43 N., R. 35 W. The Riverton mine is the oldest in the district and marks the site of the first discovery of iron ore by Harvey Mellen in 1854. It was formerly worked as an open pit to the second level. The mine is not in operation at the present time. The following notes are the result of a study of the rocks exposed in the open pits and of mine plats furnished through the courtesy of the Oliver Mining Company.

The general trend of the Vulcan formation is north and south, the dip steeply west. It is underlain on the east by chloritic-biotitic-quartz slates and schists, in places more or less ferruginous. These constitute the "green rock" appearing in the mine plats. With the exception that the term "green rock" has been changed to chloritic-quartz schist figures 12 and 13 are reproductions of drawings furnished by the Oliver Mining company. The strike of the magnetitic-chloritic-sideritic slates exposed on the top of Stambaugh hill would carry them under the iron formation of the Riverton mine. With the exception of magnetite these rocks are mineralogically similar to the "green rock" of the Iron River mine and are doubtless equivalent to it.

Two separate, main ore bodies occurred in the Riverton mine. The lowermost lay on the foot wall of chloritic-quartz slate and seems to have been completely separated from the upper one by an intervening belt of black slate. It was bottomed on the fifth level in ferruginous chert and "jasper." The upper body was underlain and overlain by black slate and, like the former, seems to have bottomed in ferruginous chert and jasper. Both ore bodies had a western pitch in direction of dip of iron formation. These relations are clearly shown in figures 12 and 13.

From the Riverton mine the Vulcan formation extends northward into the workings of the Miller exploration on the S. W. 1/4 of the S. W. 1/4 of Section 25, T. 43 N., R. 35 W. The formation is here said to bear ore. The property is undeveloped and the workings are now filled with water.

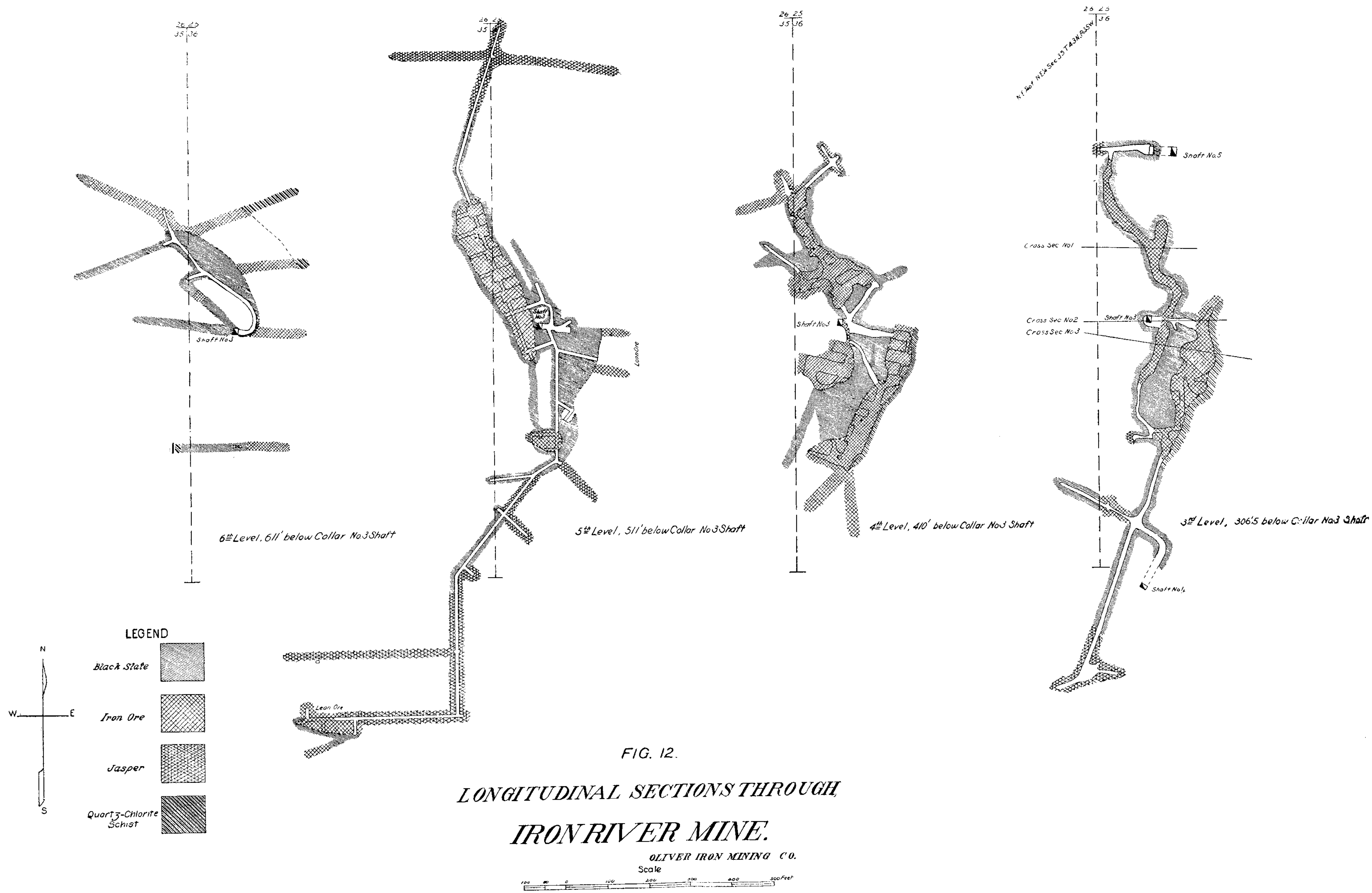


FIG. 12.

LONGITUDINAL SECTIONS THROUGH

IRON RIVER MINE.

OLIVER IRON MINING CO.

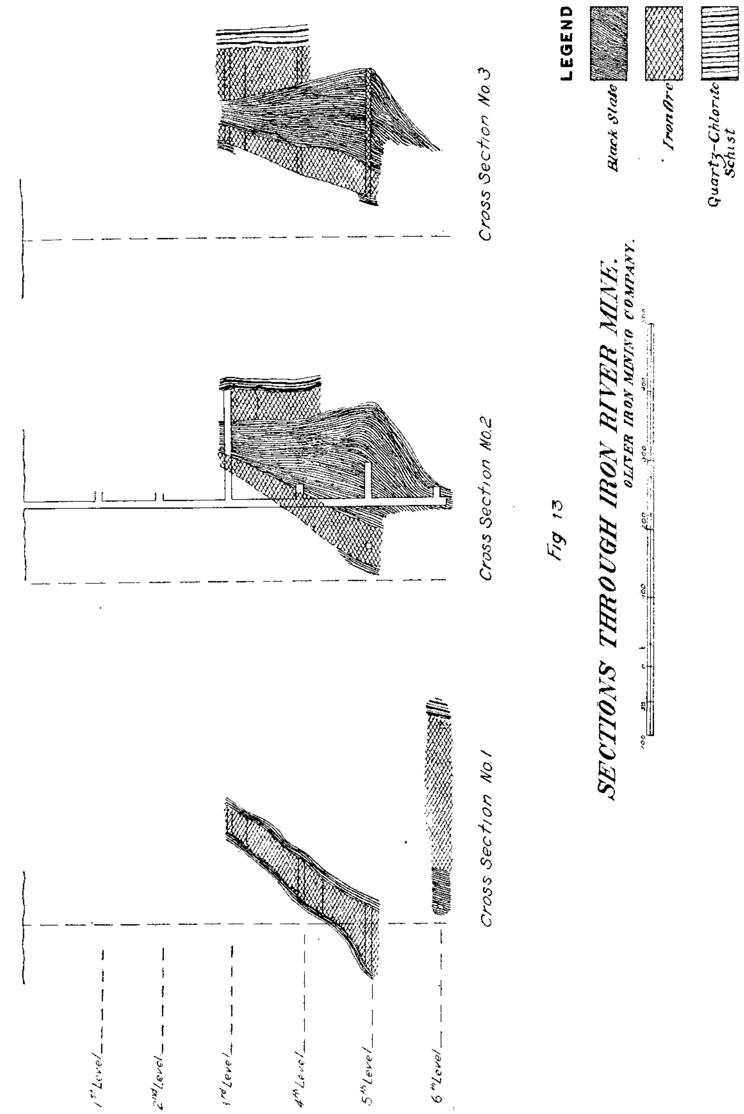


Fig 13

SECTIONS THROUGH IRON RIVER MINE.
OLIVER IRON MINING COMPANY.

The Sheridan Mine.—The Sheridan mine lies west of the Miller exploration. It was an early producer but has not been operated since 1896. Considerable exploratory work has been recently done which, with surface exposures, gives a fairly good idea of the succession. The trend of the rock seems to be a little west of north. On the west side of the property is a belt of black slate which is succeeded eastward by a variable thickness of cherty iron carbonate grading farther eastward into ferruginous chert which is in turn followed by another belt of black slate. Brecciated jasper and chert succeed the second black slate belt and in this material is sunk the open pit of the old Sheridan mine. Still farther east is a third belt of black and gray slate which extends southward into the Riverton property. With this succession of rocks on a single 40-acre tract the impossibility of separating slate and iron formation in mapping is again well illustrated.

Beta and Nanaimo Mines.—The Beta and Nanaimo mines are among the earliest producers. They are not now in operation and the workings are inaccessible. Beyond the fact that the Vulcan formation is steeply dipping here as elsewhere and trends in a general northwesterly direction the writer has no information regarding the structure in the Vulcan formation in these mines.

James Mine.—The James mine is in the N. ½ of the N. E. ¼ of Section 23, T. 43 N., R. 35 W., about 1½ miles north of Iron River. The Vulcan formation is well opened up on four levels to a depth of 400 feet. On the third level the workings extend from 80 feet east to 1,380 feet west of the shaft. The main drift on this level follows the strike of the iron formation slightly west of north. The rocks are folded and contorted in a bewildering manner. Perhaps a majority of the folds have a westward pitch. The general structure is a monocline dipping from vertical to steeply north or south. Cross cuts to the north and south penetrate black slate in both directions. In general the ore bodies in this mine occur in pockets and lenses of varying dimensions, grading into ferruginous chert, as in the Zimmerman, Hiawatha, Baker and Chatam mines, but the larger ones lie on walls of black slate. None of the ore bodies thus far mined are known to reach the surface. Evidence of gradation along the bedding of iron formation with black slate and black chert is plentiful here as in the Dober, Isabella and other mines and presents a great obstacle to accurate structural mapping. When these rocks are encountered in cross cuts work is usually suspended.

Perhaps a close detailed study of the mine would show that the ore bodies are more or less closely related to the westward pitching folds. This seems to be true in at least one notable instance. From a drift a few hundred feet west of the shaft on the 400-foot

level a north cross cut penetrated 145 feet of ore lying on a steeply northward dipping black slate wall, and grading northward into ferruginous chert and ore which at 120 feet north of the ore body is cut off by a northward dipping wall of black slate. The total width of the iron formation in this cross cut is 260 feet, which gives a thickness of 250 feet normal to the bedding. The ore body follows the south slate wall upward to the third level and passes over a wedge of black slate as shown in a sub level about 40 feet above with a total width of 230 feet and descending on the south side of the slate wedge with a thickness of 116 feet on the third level. In the sublevel where the crest of the black slate wedge is encountered the banding in the ore shows a perfect anticlinal fold pitching west. A cross cut on the third level 200 feet west of this place and 400 feet lower does not cut the black slate. The relations are shown in section in figure 14 drawn by Mr. A. J. Myers of the Pewabic Mining Co.

South of the James mine about three-eights of a mile is the Konwinski exploration in which is proven by drill holes and two exploratory shafts a belt of iron formation at least nearly half a mile long with strike slightly north of west parallel to the James belt. So far as known the rock occupying the interval between the James and the Konwinski belts is mainly black slate. According to the mine captain, pumping from the western Konwinski shaft does not affect the water level in the shaft about 800 feet slightly S. W. and this is taken by him as evidence that the two shafts are separated by an impervious slate belt.

The James belt is opened on the west by the Gleason exploration in the N. E. ¼ of the N. W. ¼ of Section 23 and drilling for a distance of some one-half to three-fourths miles farther west is reported to have proven the extension of the James belt thus far in this direction.

The Spies exploration of the Verona Mining company between 600 and 700 feet slightly southeast of the James shaft is in ore bearing Vulcan formation and eastward on the strike of the Gleason-James-Spies belt in the N. W. ¼ of Section 19, T. 43 N., R. 34 W., many drill holes of the Hall exploration of the Florence Mining Co. penetrate ferruginous chert and ore. From known facts of general structure it seems probable that the Hall exploration is on about the horizon of the Chicagon exploration, but it by no means follows that these explorations are connected by a continuous belt of iron formation since it is not improbable that the Vulcan formation is discontinuous, being replaced along the horizon by slates and possibly to some extent by greenstone.

THE NORTHERN AREA.

MORRISON CREEK BELT.

A narrow band of ferruginous chert and sideritic slate disclosed in the dumps of numerous test pits follows the sixteenth line forming the north boundary of the south half of the S. W. ¼ of Section 24, T. 44 N., R. 35 W. A few outcrops of sideritic slates occur on the banks of Morrison creek in an east-west line with the pits. The dip is vertical or slightly northward. The iron formation at Morrison creek is closely associated with black carbonaceous slate with which it is underlain and probably interbedded. Adjacent to the iron formation on the north, and stratigraphically above it, is sericitic schist, a metamorphosed equivalent of the graywacke exposed to the east and north in numerous outcrops. Southward the slate seems to be underlain by volcanic greenstone which outcrops for about a mile along the line between townships 34 and 35, R. 44 N.

THE ATKINSON BELT.

Southwest of Atkinson Vulcan formation occurs in a double belt separated by a belt of volcanic greenstone-breccia. (See figure 15.) The dip of the greenstone and associated iron formation and slate here seems to be uniformly northwest at an angle of about 55°.

It will be interesting to consider in some detail the Atkinson section since the interbedded relations of the various rocks in the Michigamme slate are here best exhibited. The southernmost rock is mainly black slate carrying considerable but varying amounts of carbonaceous matter, in places becoming cherty and ferruginous, especially toward the top of the horizon, where it gives place to a thin iron formation, according to plats of the McColman exploration furnished by the Verona Mining Co., about 80 feet thick. The Vulcan formation at this horizon has not been followed beyond the workings of the McColman exploration. The iron formation, as shown by an examination of the rocks on the dump of the McColman shaft, includes hard, limonitic iron ore, ferruginous chert and brownish and gray banded sideritic slate. The slaty phases are sericitic, chloritic, and biotitic, and in one case abundant titanite was found. The ore occurs in lenses in the slaty phases of the formation. From an inspection of the Verona Mining Co. plats it appears that the highly sericitic-biotitic-chloritic slates are abundant just under the overlying greenstone.

The greenstone belt extends from the N. E. corner of Section 18, T. 44 N., R. 35 W., northward into the S. W. ¼ of the N. E. ¼ of Section 9 of the same township and doubtless further in both directions where exposures are lacking. Its thickness seems to vary from 700 or 800 feet up to possibly 1,400 or 1,500 feet at the northeast end. In places this rock is very schistose, but generally its original agglomeratic structure is plainly observable. Brecciation is common but resulting structures can usually be discriminated from its original agglomeratic structure, the fractures of the former cutting indifferently across the latter. The rock is extremely altered. Weathered surfaces have the green colors of chlorite and epidote and show abundance of secondary calcite and dolomite filling fracture planes.

The greenstone is overlain by a belt of ferruginous slates and cherts becoming more siliceous in the upper horizons. Near the underlying greenstone black carbonaceous slates are found but these seem to be less prominent in the higher horizons which are composed dominantly of very lean ferruginous granular chert. Only one natural exposure is known, but numerous pits and a few drill holes disclose the character of the formation. This belt is less than a quarter of a mile wide. North of it sericitic slates are found and these in turn grade northward into micaceous schists and graywackes which are the dominant rocks in the northern part of the Iron River district.

While little is known of the extent of the Vulcan beds in the Atkinson district it should be noted that southwest, on the strike of these beds, in the S. E. ¼ of Section 14, T. 44 N., R. 36 W., lean, ferruginous, white, granular, cherty beds of the character of similar ones at Atkinson are associated with black slate and overlain by micaceous graywacke. Similar, white, granular chert occurs on the strike of the Atkinson horizon in the bed of Paint river in the S. W. ¼ of the N. E. ¼ of Section 1, T. 44 N., R. 35 W. While

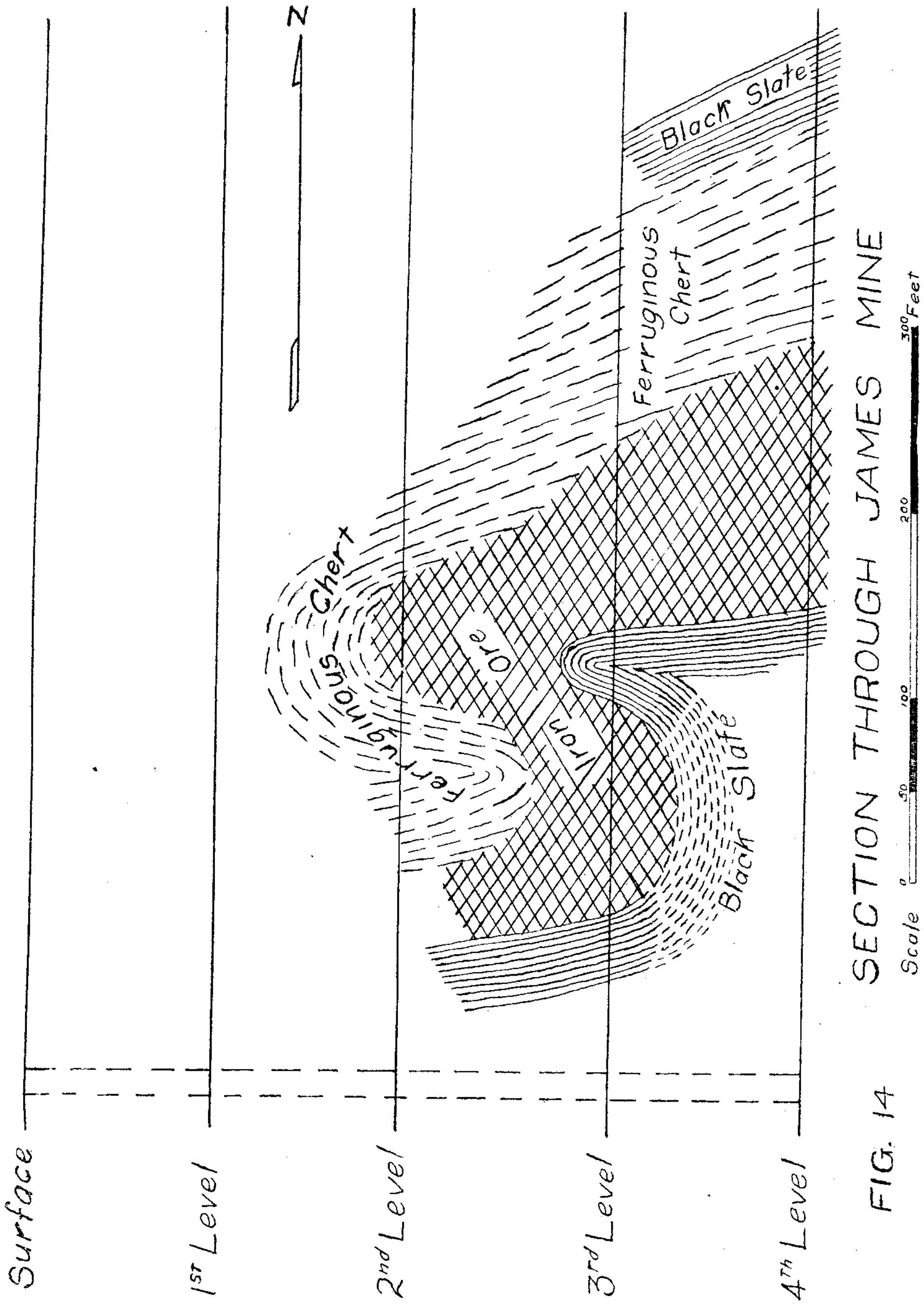
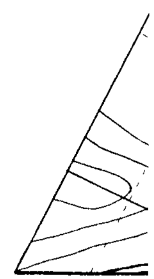


FIG. 14

SECTION THROUGH JAMES MINE



these two occurrences seem to be at about the horizon of the Atkinson beds, it should not be inferred that iron formation is continuous from one locality to the other along this indicated belt. The probabilities are that the reverse is true.

SLATES AND GRAYWACKES OF THE MICHIGAMME SERIES.

Slates and graywackes and their metamorphosed equivalents form the bulk of the Michigamme series in which the Vulcan iron formation occurs. In the northern part of the district graywacke and graywacke-slate and their metamorphosed equivalents are the dominant rocks. They are well exposed in the valley of Paint river from which they have received the name Paint Slates. The rocks associated with the Vulcan formation in the central or ore producing part of the district are, on the whole, finer grained and comprise a variety of phases including the black carbonaceous slate, closely associated in occurrence with the Vulcan formation, and gradational phases to graywacke and iron formation.

A study of these slates throws some light on the conditions of deposition of the iron bearing rocks and also explains some of the difficulties encountered by the prospector and the geologist in correlating stratigraphic horizons of one area with horizons in adjacent areas.

CHARACTER OF THE MICHIGAMME (HANBURY) SLATES ASSOCIATED WITH THE VULCAN FORMATION.

(1). *Black Slate.*—The term *black slate* in local usage covers all slaty rocks of black or very dark color. Carbonaceous matter, responsible for the dark colors, is the characteristic constituent and varies from a small amount, which may be present in any of the slates, to perhaps 10% of the weight of the rock. The typical black slates are soft, coal black, pyritic, and contain perhaps between 5% and 10% of carbon. A specimen from the south or hanging wall on the third level of the James mine, called "graphite" by the miners, was selected for analysis because of its apparently high content of carbon. At the point where the specimen was taken the transition from ferruginous chert to black slate is abrupt and the sample for analysis was broken from the wall of a drift only a few inches from the contact.

ANALYSIS OF BLACK SLATE FROM THE JAMES MINE.[1]

SiO_2	66.63
Al_2O_3	2.48
Fe_2O_3	7.80
FeO	1.58
CaO	.25
MgO	.29
S	7.06
C	8.64
CO_2	.83
H_2O	3.80
Total	99.36

Compared with the composition of typical slates and shales this rock is markedly deficient in alumina and the alkalies, the percentage of these constituents corresponding to 66.63% of silica in typical mud slates and shales being about balanced in this rock by the carbon and sulphur content. The carbon occurs mainly in uncombined amorphous condition, the sulphur in combination with iron to form pyrite or marcasite, the latter minerals being invariably present in abundance in the black slates.

When exposed to the air in waste piles the iron sulphide rapidly oxidizes, the iron to hematite and the sulphur to sulphur dioxide. Burning waste piles are a common sight in the Iron River district. The reaction which may be written:

$$2FeS + 11O = Fe_2O_3 + 4SO_2$$

takes place with liberation of heat which operates to raise the temperature of the pile, thus increasing the rapidity of the reaction. As the temperature of the pile continues to rise combustion ensues and at this point the carbon burns to form carbon dioxide gas. When combustion occurs, the quantity of sulphur gas escaping into the air causes a disagreeable suffocating odor in the vicinity of the burning pile. In the presence of moisture an aqueous solution of sulphur dioxide is formed, which by absorption of oxygen from the air and also by combination with water forms sulphuric acid with evolution of heat thus further raising the temperature of the pile and accelerating chemical action. Thus is explained the familiar

[1]Analysis by Prof. A. J. Clark, Michigan Agricultural College.

fact of observation that burning takes place most rapidly in wet weather and is especially active immediately following a rain when the waste piles are saturated with water. The sulphuric acid unites with the bases present in the rocks to form soluble sulphates which are brought to the drying surfaces of the rock fragments by capillarity and left on evaporation as a white efflorescent coating which washes off in rainy weather to appear again in dry weather when evaporation is active. A white efflorescent coating is frequently found on drill cores of black slate which have been stored for some time in doors and also on exposures in open workings.

The black slates are closely associated in occurrence with the Vulcan formation, being frequently interbedded with it, occurring in discontinuous lenses within it, and often forming walls on which or between which ore bodies are found. It has been stated that carbonaceous matter, the essential constituent of black slate, is widely disseminated in the Vulcan formation. The "hard siliceous black slate" described in drill records and often exposed in mine workings is really highly carbonaceous iron formation. To the drill men the occurrence of black slate or "graphite" is an indication of the proximity of "ore formation." In the most generally accepted theories of the origin of the Lake Superior iron formations which have been published up to this time, the occurrence of carbonaceous matter in the iron formations and in associated carbonaceous slates has been interpreted as evidence of the presence of organic matter, mainly plants, in the waters in which deposition occurred and the organic matter is believed to have been instrumental in the formation of iron carbonate. That the presence of associated carbonaceous matter (whether of organic or inorganic origin) has some causal relation to the occurrence of iron carbonate is generally accepted by students of Lake Superior geology. Whatever the explanation may be, the characteristic close relation in occurrence of black slate and iron formation is not entirely a matter of chance association.

Associated and frequently interbedded with the Vulcan formation are slates of various kinds whose characters and relations to the Vulcan formation can be described in detail only by reference to specific occurrences. This is the author's excuse for introducing here a few type descriptions.

(2). *Chloritic, biotitic, quartz slate.*—On the Barrass exploration of the Verona Mining company, in a drill hole 400 feet W. and 1,120 feet S. of the N. W. corner of the N. E. corner of Section 36, T. 43 N., R. 35 W., slaty rocks described in drill records as "granular cherty green and gray slate" are interbedded with chert and ferruginous slate. The hole, pointed east at an angle of 70°, penetrated:

0- 85	feet	overburden.
85- 92	"	chert and ferruginous slate.
92-105	"	granular green and gray slate.
105-120	"	ferruginous chert and slate.
120-131	"	granular green and gray slate.

The *"granular green and gray slate"* proves, on microscopical examination, to be a chloritic, biotitic, quartz slate, carrying a few scattered grains of iron carbonate. About 50% of the rock is quartz in small irregular grains which are embedded in chlorite and biotite, while opaque and semi-opaque blotches of material having no definite optical properties are rather abundant.

(3). *Chloritic, sericitic, quartzose and feldspathic, carbonate slates.* At the pumping station in No. 2 shaft on the fourth level of the Dober mine is a dense massive greenish colored rock, locally referred to as "green rock." Under the microscope a thin section presents a mesh of chlorite and sericite in which are embedded numerous grains of carbonate and quartz, the latter in small irregular detrital grains, and rarely a small fragment of plagioclase feldspar. Brownish, semi-opaque material having no definite optical properties is scattered in blotches through the slide.

The position of this rock with reference to the Vulcan formation is not clear. It probably underlies on the southeast the ferruginous chert and ore of the Dober mine with which it is in contact.

(4). *Sericitic-biotitic schists.*—Sericitic, biotitic schists are exposed in a series of outcrops in the N. W. ¼ of the N. E. ¼ of Section 12, T. 42 N., R. 35 W., northwest of the Youngs mine. The strike of the schistosity is N. 60° to 70° west, and dip, on the whole, highly inclined northeastward. Cleavage surfaces exhibit the silvery luster of sericite when not stained with iron oxide. Microscopic examination reveals a mass of very small flakes of sericite, biotite and chlorite in which minute grains of quartz are sparingly disseminated. Ferric oxide is rather abundant. It is mainly

secondary to pyrite as shown by its pseudomorphs after the latter.

The strike of these slates would carry them under the Vulcan formation in the Youngs mine. To the north they are overlain by black slates and the Vulcan formation shown in explorations on the Fogarty property and in outcrop on the Iron River in the S. ½ of the S. ½ of Section 1, T. 42 N., R. 35 W. In a ravine leading from the Youngs mine eastward to Iron River these schists occur in alternate bands with chert characteristic of the Vulcan formation.

(5). *Chloritic-biotitic-quartz schists.*—These rocks with variable characteristics form in large measure the footwall of the old Riverton pit. On the plats and cross sections of the Riverton mine[2] they are called "green rock." A specimen taken from an outcrop south of the Riverton pit on the road leading up Stambaugh hill presents under the microscope a completely interlocking mosiac of quartz, mainly coarsely crystalline, some individuals being greatly elongated in the plane of schistosity. Chlorite and biotite are intimately mixed and intergrown and enclose many areas of finely crystalline silica. Biotite and chlorite are also associated along fracture planes and form stringers separating the crystal individuals in the quartz mosaic. Pyrite is sparingly present, but in most cases it has oxidized to hematite. The rock is completely recrystalline and is properly termed chloritic, biotitic, quartz schist.

(6). *Hematitic, chloritic, quartz slates* at south end of Riverton pit. In mineral composition (5) is related to a massive, mottled, greenish and reddish rock, occurring on the strike of (5) in the south end of the old Riverton open pit. A specimen studied in thin section showed numerous rounded to subangular quartz grains associated with areas of very finely crystalline quartz aggregates in a matrix composed of abundant chlorite and hematite with a small quantity of biotite and an occasional minute crystal of zircon. In the greater part of the section quartz, chlorite, hematite and biotite are intermixed in confused manner, each of these minerals being in places enclosed in combinations of the other three. In many instances finely crystalline quartz, hematite, and chlorite are associated in oval areas of faint outlines resembling altered forms of greenalite granules. Hematite is in some cases arranged concentrically about rounded aggregates of finely crystalline silica and in others about single individuals of limpid quartz.

[2]Furnished through the courtesy of the Oliver Mining Co.

Similar rocks occur in a ravine at the S. W. corner of the S. W. ¼ of the N. W. ¼ of Section 36, T. 43 N., R. 35 W., apparently lying between the magnetitic-chloritic-sideritic slates of Stambaugh hill and ferruginous chert and ore shown in pits about 112 to 130 paces west. Their stratigraphic position here is apparently the same as in the former locality at the Riverton pit.

(7). *Sideritic graywacke.*—On the Hiawatha mine location, (S. W. ¼ of the S. E. ¼ of 35-43-35) in a drainage ditch following the north side of the ravine which extends in a northeasterly direction across the property, the interbedded relations of the Vulcan formation to slates and graywackes of varying characteristics are well exhibited. At a point about 300 paces south and 60 paces west of the center of the S. E. ¼ of the section massive, dense, black, fine grained graywacke is exposed, striking about N. 50° W., bedding about vertical. As the trench is followed westward, at about 120 paces the graywacke gives way to soft, dark, carbonaceous and somewhat ferruginous slate, which in turn is succeeded by siliceous black slate carrying dark cherty bands exposed in the dump of a test pit about 100 paces farther on. At the end of the trench about 120 paces S. 20° W. of the latter locality leanly ferruginous chert is interbedded with rocks having the outward appearance of graywacke and black and brown somewhat ferruginous slates. At points in the trench where the rocks are not exposed fragments which have been thrown out on the embankment indicate that gradational phases between the various types described are present.

The dense, black graywacke exposed at the east end of the pit is of especial interest because it represents a halfway stage between the Vulcan formation, which in its pure phases shows no traces of fragmental origin, to typical graywacke, a wholly fragmental rock.

Microscopic examination shows that the rock is composed of the minerals quartz, chlorite, carbonate, biotite, plagioclase, orthoclase, sericite, pyrite, and opaque to semi-opaque material not differentiated, probably carbonaceous.

Quartz occurs in (1) angular, detrital grains, (2) as recrystallized silica enclosing both chlorite and carbonate, (3) and in rounded to oblong areas of finely crystalline aggregates associated with chlorite and hematite.

Hematite is especially associated with chlorite, penetrating it in needle-like crystals and frequently enclosed in it.

Carbonate is abundant in granules and rhombic sections scattered through the slide. Some of the carbonate rhombs show zonal arrangement of coloring, green on the interior, becoming yellowish and then brownish as the periphery is approached, a phenomenon of incipient alteration rather than of zonal growth of the crystal, although in slides examined the common alteration of carbonate to hematite was not noticed.

Biotite, commonly associated with meshes of chlorite and also in fracture planes cutting quartz grains is plentiful, and sericite is very sparingly present in minute flakes.

Detrital grains of orthoclase and plagioclase feldspar are scattered through the rock in abundance. A few show incipient cloudy alteration, but most of them are fresh and clear.

Opaque, black and brown material, probably carbonaceous, is scattered widely through the rock, but seems to be especially associated with the carbonate.

From the description given in the preceding paragraphs it is evident that this rock partakes of the nature both of an ordinary graywacke and of the cherty iron carbonate of the Vulcan formation and must be considered as one of the many gradational phases between the Vulcan formation and associated clastic rocks. Mr. H. L. Botsford reports that similar rocks are found in association with ferruginous chert in the Chicagon mine.

(8). *Sideritic-magnetitic graywacke.*—Southeast of the Chicagon mine in the S. W. ¼ of the N. E. ¼ of Section 36, T. 42 N., R. 34 W., are outcrops of dark magnetic sideritic graywacke, strike N. 40° W., dip 60° southwest. In texture and composition this rock is analogous to the sideritic graywacke on the Hiawatha mine location, with the exceptions that magnetite is abundant and epidote, not observed in the Hiawatha rocks, is sparingly present. Associated with them are chloritic-sideritic-magnetitic slates, exactly similar to those on Stambaugh hill. (See pp. 56-59.)

Other slates differing in unimportant particulars from some one of the eight varieties described above might be added to the list but little would be gained in so doing. Enough has been said to establish the fact, already emphasized, that the various phases of the Michigamme slates associated with the Vulcan formation are in endless variety of gradational relations to the latter and to each other. Such relations are due to changing conditions of deposition both in time and from place to place on the bed of the sea in which the Michigamme series accumulated, a discussion of which is given in a later chapter.

MICHIGAMME SLATES IN THE NORTHERN PART OF THE DISTRICT. (PAINT SLATES.)

The Paint slates are exposed in the valley of the Paint River, and in the valleys of tributary creeks. They are mainly quartzose and feldspathic sedimentary rocks exhibiting the general characters of graywacke and arkose. They vary in texture from conglomeratic to fine grained and in structure from massive thick bedded rocks to micaceous schists. Bedding is well marked on many exposures in the northeastern part of the district but westward it is generally obscured or obliterated by recrystallization and development of micaceous minerals resulting in schistose structures. From the structural standpoint there is no evidence to explain why the rocks should in this direction exhibit a higher degree of metamorphism, because the development of schistosity seems not to be accompanied by more intense folding. The explanation seems to lie in original finer textures, which would enable the rocks to more readily recrystalize under the same conditions of metamorphism. The structure of the Paint slates has already been described.

The mineral composition of six typical graywackes of the Paint slate formation is shown in the table below.

MINERAL COMPOSITION OF SIX THIN SECTIONS OF TYPICAL GRAYWACKES OF THE PAINT SLATE FORMATION.

No. *	Quartz.	Plagio-clase.	Ortho-clase.	Chlorite.	Sericite.	Biotite.	Epidote.	Zoisite.	Carbonate.	Sphene.	Zircon.	Ferrite.
1....	x	x	x	x	x	x	x	......	......	......	......	x
2....	x	x	x	x	x	x	x	......	......	......	......	......
3....	x	x	x	x	x	x	x	......	x	......	......	......
4....	x	x	x	x	x	x	x	x	......	......	......	......
5....	x	x	x	x	x	x	......	......	x	x	......	......
6....	x	x	x	x	x	x	......	......	x	x	x	......

*1. From outcrop 750 paces E. and 175 paces N. of the S. E. corner of section 24, T. 44, N., R. 34, W.
2. From outcrop 500 paces E. and 300 paces N. of the S. W. corner of section 24, T. 44, N., R. 34, W.
3. From outcrop near location of 2.
4. From outcrop 850 paces S. of N. E. corner of section 18, T. 44, N., R. 35, W.
5. From outcrop near center of section 29, T. 44, N., R. 35, W.
6. From outcrop 250 paces E. of center of section 19, T. 44, N., R. 34, W.

These specimens from widely separated outcrops extending from the eastern to the western side of the area have markedly similar mineral compositions. Quartz, plagioclase, orthoclase, chlorite, sericite, biotite, and epidote are the characteristic minerals, while zoisite, carbonate, sphene, zircon, and ferrite are accessory. Quartz is more abundant than feldspar and, of the latter mineral, plagioclase predominates over orthoclase. Chlorite, sericite, and biotite are abundant in all specimens, the two latter increasing in importance in the more schistose varieties. These minerals, being of finer grain, form a ground mass in which the clastic particles of quartz and feldspar are embedded. They also occur together with carbonate and quartz in areas of altered feldspar, usually plagioclase. Epidote is plentiful in (1), (2), (3), and (4). It occurs in scattered grains and clusters of grains, usually altered to chlorite on the periphery in a few cases the alteration being complete. When zoisite occurs it is in zonal intergrowth with epidote but this mineral is rare.

The Paint slates carry lenses of Vulcan iron formation with associated carbonaceous slates, as at Morrison creek and Atkinson. They are also interbedded at various horizons with greenstone agglomerates and tuffs.

BASIC INTRUSIVES AND EXTRUSIVES IN THE UPPER HURONIAN GROUP.

Igneous rocks of basaltic type are abundant in the upper Huronian group. The distribution of those now known is indicated on the accompanying map of the Iron River district (Plate 1). There is much difficulty in determining the general distribution of these rocks because the relations to the slates are so intricate that it is never safe to conclude that adjacent exposures are, or are not, separated by slate.

The rocks are principally of extrusive type and have surface textures, especially the ellipsoidal and agglomeratic textures, so characteristic of the Hemlock formation and of the volcanics associated with the upper Huronian of the Crystal Falls district. Some of these extrusives are distinctly contemporaneous with the slates. Southwest of Atkinson agglomeratic and tuffaceous phases of the greenstone are interbedded with slate and iron formation of the upper Huronian group. (Fig. 15.) In the southern part of the district, Section 23, T. 42 N., R. 34 W., ellipsoidal and tuffaceous greenstone occurs north of the Upper Huronian slates in a northward dipping series. From the lack of contact metamorphism and the abundance of tuffaceous phases and effusives they were probably nearly all deposited contemporaneously with the sediments. It follows that the deposition was probably subaqueous. Definite evidence of relations is lacking for many greenstones, especially those not adjacent to slates or some of those which have been developed by mining operations and explorations.

Greenstones in the southern part of the district.—A belt of isolated outcrops of volcanic greenstone, following the trend of the Saunders formation south of it, extends across the southern part of the district. These rocks seem to lie in a stratigraphic horizon between the main part of the Michigamme series above and the Saunders formation below. They occupy the same stratigraphic position with reference to overlying slates and underlying dolomite as do the Hemlock greenstones of the northern Crystal Falls district. However, it is well to avoid the use of the term Hemlock here since it has been used by Clements with a stratigraphic significance, i. e., in designation of volcanic greenstones of *Lower Huronian* age occurring between the Michigamme (Hanbury) series above, and the Randville dolomite below. It is probable, as shown above, (p. 50) that some of the greenstones mapped by Clements as Hemlock are of Upper Huronian age and since in the Iron River district volcanic greenstones occur at various horizons in the Michigamme series, as do the Clarksburg volcanics of the Marquette district, the term Clarksburg is more preferable than Hemlock. It is important to bear in mind that the essential facts of occurrence of the Huronian volcanics are the same in the Crystal Falls, Iron River, and Gogebic districts and probably also in the Menominee district. In the Crystal Falls district volcanic activity began after the close of Randville time, continued through Middle Huronian time[3] into Michigamme time. In the Gogebic district the volcanics are contemporaneous with the Upper Huronian of the eastern end of the district. In the Menominee district contemporaneous volcanics are not *certainly* known, but it is possible if not probable, that the western green schists well exposed at the lower and the upper Twin Falls on the Menominee

[3]A Middle Huronian series has not yet been recognized in the Crystal Falls district, but if present it probably lies below the Michigamme (Hanbury) series and above the Randville formation. This horizon seems to be occupied, at least in part, by the Hemlock volcanics.

River and east and west of this locality, referred by Bayley to the Keewatin (Quinnesec schists), are of Upper Huronian age. There is no evidence favoring the one hypothesis more strongly than the other, but westward in the Florence district of Wisconsin, on the strike of these rocks, are similar greenstones which are certainly interbedded with the Michigamme (Upper Huronian) series. In the Iron River district volcanic activity was recurrent at intervals and was possibly continuous from Saunders time (Lower Huronian) well on into Michigamme time (Upper Huronian).[4]

It is, therefore, clear that the Iron River district is part of a region in which volcanism was more or less active during Upper Huronian time. It is improbable that volcanic activity began simultaneously or closed simultaneously everywhere in this wide area. Periods of activity in one district may correspond to periods of quiescence in another and in a single small area, as in the Iron River district, there were alternate periods of activity and quiescence. In the light of these facts the task of closely correlating the volcanics of one district with those of another is obviously one of extreme difficulty if not impossible.

PARTICULAR OCCURRENCES OF GREENSTONES IN THE SOUTHERN PART OF THE DISTRICT.

Section 24, T. 42 N., R. 34 W.: Ellipsoidal and tuffaceous greenstone occurs north of Brule river, extending from the west line three-fourths of a mile slightly northwest through the center of the section. A few outcrops occur on the south side of Brule river and greenstone also occurs in a shaft at the old Jumbo exploration. (See fig. 3 and pp. 65-66.) In the outcrops on the north side of the river, principally north of the C. & N. W. Ry., the ellipsoidal structure is well developed. The ellipsoids are, on most surfaces, distinct and vary in size up to a foot in longest diameter. On weathered surfaces the ellipsoids are a light green in contrast to the yellowish color of the matrix surrounding them. Except in a single outcrop the rock is very schistose (strike slightly N. W., dip vertical) and exceedingly fine grained. The only minerals identified without the use of a microscope are chlorite and iron pyrite. A particularly noticeable character is the large amount

[4]Since this paragraph was written Mr. W. O. Hotchkiss, State Geologist of Wisconsin, has shown by work in the Florence district that the Quinnesec schists of the Menominee district are probably not older than Upper Huronian. (Personal communication.)

of dolomite developed irregularly throughout the rock and especially in cracks and cleavage planes.

On the south bank of Brule river the greenstone is massive on the whole and fine grained showing faint traces of ellipsoidal structure in only one place. In other places it looks like a schistose amygdaloid especially at the south end of the exposures. At the north end it is more massive though it is spotted. Where highly weathered and decomposed the rock has a reddish color and in one place (285 paces S. and 400 paces W. of the center of the section) a tunnel has been driven some 15 feet into the rock, evidently in search of iron ore. The exposure, which is some 250 paces long, is separated by a thin bed of slate striking E.-W. and dipping 70°-90° S. The contact with the greenstone is rather sharply defined. The contact planes dip south, about 85° on the north side and 45° on the south side. At the water's edge the slate bed is about six feet thick narrowing upward to not more than four feet. (Plate 7.) The slate is dark, exceedingly hard and brittle and cut by innumerable fine seams of quartz and pyrite. Under the microscope it appears to be an exceedingly fine grained chloritic quartz slate. About 85% of the rock is chlorite. Sericite is sparingly present in minute flakes and occasionally a spangle of biotite. Pyrite is abundant but much of it has oxidized to hematite. Secondary quartz occurs in stringers and veinlets filling minute fractures, and in original disseminated fine grains.

The greenstones seem to be interbedded on the south with the slates and Vulcan formation of the Jumbo belt. The north boundary follows the magnetic line which runs just north of the outcrops slightly west of north into section 21 (see map, Plate 1) where it dies out.

Section 21, T. 42 N., R. 34 W.—About two miles slightly N. W. of the exposures in section 23 is an isolated exposure of greenstone agglomerate. The outcrop occurs about 400 paces S. and 275 paces E. of the N. W. corner of Section 21 at the west base of a prominent hill. The rock forms a jagged mass of angular fragments of light colored greenstone in an amygdaloidal schistose matrix. It is highly decomposed, secondary dolomite being more abundantly developed here than in the ellipsoidal greenstones in section 23. (Plate 8.) The magnetic line, which crosses the east line of the section at about 650 paces south of the N. E. corner, if extended would pass just north of this outcrop.

Section 18, T. 42 N., R. 34 W. The Wild Cat Shaft.—Westward, the next occurrence of greenstone is at the Wild Cat Shaft about 1,570 feet south and 50 feet east of the center of the section. The shaft is filled with water. The rocks which have been thrown out on the dump include highly decomposed greenstone and cherty and chloritic carbonate rocks of the Vulcan formation. The disposition of the rocks in the dump indicates that the greenstone was encountered beneath the slates but further than this the structural relations between the two formations are not known. The greenstone is of medium grain and may be either extrusive or intrusive.

The slates are gray, green, and yellowish in color, well banded and laminated, and are cut by innumerable fine intersecting fractures. In composition they vary from cherty iron carbonate, carrying some chlorite, to highly chloritic, biotitic and hematitic varieties. The content of siderite never reaches above 35% of the volume of the rock. There are a few pieces of hard siliceous hematite on the dump showing that locally alteration to iron ore has been accomplished.

On the basis of relations shown at the Wildcat shaft the boundary between the slate-iron formation series on the north and the greenstone-slate series on the south has been extended westward from the N. W. ¼ of the N. W. ¼ of Section 21 through a point a short distance south of the shaft.

Section 13, T. 42 N., R. 35 W.—In a low ridge extending east from the road running diagonally across the N. E. ¼ of the N. W. ¼ of the section to within 80 paces of Iron River are numerous exposures of greenstone. The ridge is flanked on the north by low ground which is strewn at the base of the ridge with angular blocks of slate, some of them of large size. The slate is nowhere exposed in place and its relations to the adjacent greenstone cannot be observed. However, it is certain that the slate is in contact with the greenstone near the base of the ridge, because the slate fragments show by their large size, angularity and abundance that they have not been carried far by either ice or water.

At the west end of the exposures the greenstone is dark colored, massive, dense and fine grained, similar to that in the Jumbo shaft except that it is less decomposed. Toward the east the rock becomes lighter in color and the surfaces exhibit the peculiar pock marked appearance of variolitic greenstone. The spherules vary up to a half inch in diameter and are evidently more resistant than the matrix surrounding them as they project above it in mammillary protuberances. The spherules differ in color from the matrix. They are light gray while the matrix is light green. (Plate 9 B.)

An occurrence of variolitic basalt in the Upper Huronian volcanics has been described by Clements[5] from T. 44 N., R. 33 W., Section 4, 375 paces south and 900 paces west of the S. E. corner. This occurrence is "in close proximity to the remnant of a basalt stream which shows well marked flowage structure," but "the relations of the two rocks are not determinable from the exposures." The Iron River occurrence is a short distance (150 paces) southeast of a large exposure showing well developed agglomeratic structure. The fragments are well rounded, vary up to a foot in diameter and are embedded in a matrix of material differing from them only in being finer grained. (Plate 9 A.) The rounded character of the fragments makes the term *eruptive pseudo-conglomerate* applicable to this rock, rather than *eruptive breccia.* This structure has been described by Clements[6] as it occurs in the Hemlock volcanics of the Crystal Falls district. The exact method of formation of the eruptive pseudo-conglomerates and breccias is not known but the brecciated and pseudo-conglomeratic structures are especially characteristic of surface lavas. In discussing the origin of these structures, Clements says: "In one case in which both fragments and matrix are amygdaloidal it appears probable that the occurrence represents a true flow breccia in which the broken surface of a lava flow had been recemented by a later flow of the same kind of rock, or that it represents a very possible case in which lava welled up through and flowed over portions of its own crust, cementing the fragments. In one instance, in which both the fragments and matrix were microscopically non-amygdaloidal, it is probable that they were formed under considerable pressure, and that this was a case in which lava was forced up through a previously consolidated mass of rock of like character, and in its passage carried with it various fragments, forming an eruptive *'reibungs breccia'* or *friction breccia.*"

[5]Clements, J. Morgan. U. S. Geological Survey, Monograph 36, pp. 108-111.
[6]Ibid. p. 136.

Whatever the exact manner of formation of the pseudo-conglomeratic and variolitic structures may have been, their occurrence is pretty good evidence of the extrusive character of the greenstones in which they are found.

The slates at the north base of the greenstone ridge are especially interesting in the light of the extrusive origin of the greenstone. These rocks are really unique and are dissimilar to all others thus far found in this district. Weathered surfaces are gray, green, purple and yellowish and show very distinct banding and fine lamination. The banding is especially noticeable on some specimens where it is accentuated by the more resistant character of some of the bands which causes them to stand out above the softer ones producing a ribbed appearance. In some of the specimens the prominent bands seem to be of feldspathic composition. They are grayish white to pink, contrasting strongly with the separating green bands of chloritic composition. Other bands are marked by large numbers of whitish gray grains of decomposed material which vary in diameter up to 1-16 of an inch. There are also fine dense laminæ of dark cherty material, seldom as much as 1-8 inch in diameter. Occasionally the rock presents a very finely pitted surface produced by the weathering out of some mineral, producing minute cavities in the weathered surface. The shapes of the cavities are usually irregular but some appear to be molds of either cubes or rhomboids near cubes in form. The pitted laminæ are of chloritic composition.

Under the microscope these rocks exhibit an exceedingly fine mesh of intergrowths of chlorite and sericite, the former being greatly preponderant. The chlorite is in many places discolored by hematitic alteration. Scattered through the rock are areas of brownish semi-opaque material which does not extinguish on rotation between crossed nicols.

Narrow bands of siliceous material, made mainly of extremely irregular quartz individuals with interlocking texture, cut the thin sections. Rarely there are nicely rounded quartz grains in these bands. The quartz is usually dirty with inclusions in which sericite has been identified. There are also many areas of quartz, sericite, and chlorite having outlines suggestive of feldspar of which they may be altered products.

The appearance of these rocks, microscopically and macroscopically, and their close field association with basic extrusive greenstone strongly suggests a genetic relation to the latter. If the basic lavas represented by the greenstones had welled upward and poured out on the bottom of a water body in which sedimentation was taking place it is easy to imagine that detritus from the lavas would enter into the composition of adjacent sediments. Such has *possibly,* and I have little hesitation in saying *probably,* taken place here. The microscopic appearance of these slaty rocks suggests at once, especially if combined with examination in the field, "greenstone material." Other instances are known where basic eruptive breccias actually grade along the strike into sediments which seem to differ from them slightly, if any, in composition, and gradational relations are such that it is impossible to separate them by any line that might be drawn.

The relations between slate and greenstone are not more satisfactorily indicated here than at the Wildcat shaft (p. 105) but on the supposition that the slates are younger than the greenstone, and since explorations in adjacent territory to the north and northeast have not indicated the presence of greenstone, the north boundary of the latter (which carries interbedded slate) has been extended northwestward from the Wildcat shaft, passing just north of the exposures.

T. 42 N., R. 34 W., Section 29.—Near the southeast corner of the N. E. ¼ of the N. W. ¼ of the section, extending southwestward about 250 paces are numerous exposures of greenstone. They are of especial interest because they exhibit well developed flowage structures not observed elsewhere in the district. A notable feature of the rock is its porphyritic character irregularly developed in small local areas and especially in those showing flowage lines. The porphyritic mineral is plagioclase feldspar. This feature is exceptionally well shown on weathered surfaces where the grayish white color of the porphyritic feldspar is in contact with the green ground mass of the rock. Most of the feldspars are twinned after the Calsbad law. The ellipsoidal structure is also present in some places but is only weakly developed. A few areas showing distinct ellipsoids are surrounded by others in which are indistinct ellipsoidal outlines and these grade away into the dense fine grained green rock showing neither ellipsoidal nor flow structure.

T. 42 N., R. 34 W., Section 19.—On the east side of Brule river in the vicinity of the south one-quarter post of the section, greenstone occurs in a number of exposures. It is of the common, dense, fine-grained, pyritic variety grading into hard, flinty and slaty phases of purplish gray color which bear resemblance to the slates interbedded with greenstone on Brule river (described on p. 104).

T. 42 N., R. 35 W., Section 24.—Interesting exposures occur in the S. E. ¼ of the N. E. ¼ of the section just north of the E.-W. quarter line, forming an overhanging ledge in which several varieties of rocks occur. Greenstone of the dense, fine-grained, green variety is associated with hard, brittle, purplish rocks similar to those in the locality on Brule river just described. Gradation from the green to the purplish color may be observed in hand specimen. With the dense green and purplish varieties are others which show distinct lamination, the origin of which is not clear. Some phases show narrow siliceous bands alternating with finely laminated yellowish-green bands, strongly suggestive of sedimentary origin, while other phases show very irregular interbanding of pink and purple colors, and in one case this phase was found in contact with the dense fine-grained green variety, the contact plane being sharp and showing truncation of the bands or laminæ. That the banded and laminated structures are not secondary but original seems reasonably clear. They resemble more closely stratification produced by deposition of sediments in air or water rather than the fluxion structure of lava, schistosity, or banding produced by metamorphism but their exact manner of formation has not been determined.

North of this greenstone exposure, along the N.-S. line between the N. E. ¼ of the N. E. ¼ and the N. W. ¼ of the N. E. ¼, holes drilled by the Pewabic Mining Company are reported to have penetrated slate with the northernmost hole in quartzite and dolomite. Samples from the drill holes were not seen.

T. 42 N., R. 35 W., Sections 14 and 16.—In section 16 are a number of greenstone exposures beginning about 200 paces north of the S. ¼ corner and extending north about 200 paces, beyond which at about 50 paces is a test pit showing greenstone on the dump. This greenstone is dark, fine grained and magnetic. Dip needle readings are as high as 25° on the southernmost outcrop, decrease northward and become normal or 0° at about 150 paces north of the pit. Other greenstone exposures occur about 100 paces slightly S. E. of the W. 1/4 post of Section 16 and also at 650 paces north and 285 paces west of the S. E. corner of Section 12, T. 42 N., R. 36 W.

Summary.—The greenstones of the southern part of the district are of basaltic composition. They exhibit the general characteristics of extrusive lavas and tuffs in their general fineness of grain, ellipsoidal, agglomeratic, and fluxion structures. They are interbedded, at least to some extent, with sedimentary rocks, from which the inference may be drawn that they were at least in part contemporaneously and subaqueously deposited with the associated sediments.

GREENSTONE IN THE NORTHERN PART OF THE DISTRICT.

The northern greenstones do not differ in any essential respects from those in the southern part of the district and for that reason descriptions of particular occurrences will be omitted. So far as known the outcrops appear on the map. (Plate I.)

Field relations indicate that the northern greenstones, mainly extrusives, occur at various stratigraphic horizons in the Paint slate. The Atkinson section has already been described (p. 90-93 and fig. 15). Another instructive occurrence is in the N. W. 1/4 of Section 29, T. 44 N., R. 35 W. Greenstone occurs in a ridge extending from a point on the C. & N. W. R. R. track about 750 paces south of the N. W. corner, northwestward for about a half mile. Passing along the crest of the ridge the ordinary phases of coarse greenstone agglomerate and tuff are found. These are replaced by rocks of finer grain and marked schistosity, which in turn are replaced by mica schists showing almost perfect cleavage. The latter are a very common phase of the Paint slate formation. Evidently the greenstone is replaced along the strike by slate through a series of gradational phases.

It is exceedingly difficult to distinguish in the field between some phases of the Paint slate and schistose greenstone just as it is sometimes difficult to find the line of contact between granite and recomposed granite (arkose) when these are associated. Both are of the same, or near the same, composition, and texture alone is often the deciding factor in distinguishing between them. But if the original textures in both rocks have been obliterated by the formation of a common schistose structure the task of distinguishing between them, in some instances, becomes almost impossible.

If the greenstones originated under subaqueous conditions in the water body in which the Paint slates were being deposited it is certain that quantities of detritus from the greenstone would intermingle with adjacent sediments, and such would certainly be true if the greenstones were pyroclastic, as many of them are. It is probable that volcanism in Michigamme time was active both in sea and on land as it is now in certain volcanic regions of the globe.

It has been said that the northern greenstones, like the southern, are mainly extrusive. Medium grained phases occur in the S. E. 1/4 of Section 17, and near the W. 1/4 corner of Section 19, T. 43 N., R. 35 W., and in the N. W. 1/4 of Section 1, T. 43 N., R. 34 W. The coarser grained phases may be intrusive but this cannot be proven because of total absence of exposures showing relations with surrounding rocks.

It may be well to recall here that the greenstone exposures in the eastern part of the district just south of the Paint river seem to be continuous with others in an area in the Crystal Falls district mapped by Clements[7] as Hemlock volcanics (Lower Huronian). The westward extension of this belt is indicated in the outcrops in Section 25, T. 44 N., R. 35 W., and in Sections 12, 16, 17, 19, 6, and 7, T. 43 N., R. 35 W. These outcrops are separated by drift-covered areas and it is of course impossible to ascertain whether they are connected to form a practically continuous mass or whether they are isolated occurrences in the Michigamme series. If the latter is the case they cannot be proven Hemlock in age while if the former is true the age of the mass can be shown to be more probably Michigamme. If these rocks are Lower Huronian they must underlie the Michigamme series, in which case their exposure here is doubtless due to erosion of an anticline. Such was the opinion of Clements and the eastward continuation of this mass almost to Crystal Falls was mapped as an anticline. If such anticline exists and is continuous across the Iron River district, the sedimentary section on opposite limbs of the anticline should be the same. Though information is meagre this seems not to be the case, for the Paint slates on the north, as a whole, do not

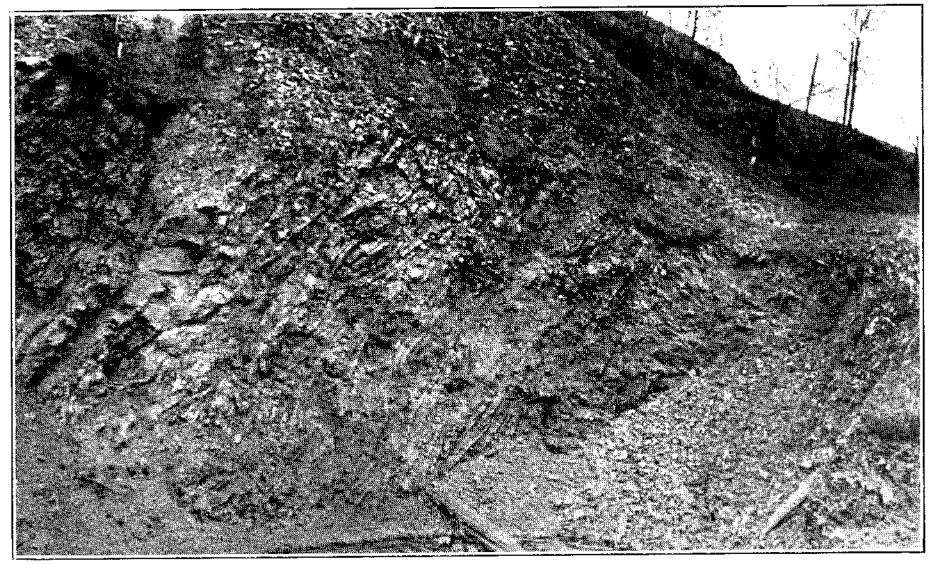
[7]Monograph 36, U. S. G. S. See geological map accompanying.

closely resemble the Michigamme of the producing part of the district. Yet in view of the rapidly varying conditions of sedimentation from place to place in the Michigamme sea this argument loses some of its force. Equivalent formations in closely adjacent areas are not necessarily lithologically the same or even similar. However, north of the belt in question interbedded Michigamme slate and greenstone occurs, notably near Atkinson, and this, with the general structure of the district and absence of contrary evidence, leads me to believe that such are the relations between the greenstone and Michigamme slate in the belt in question.

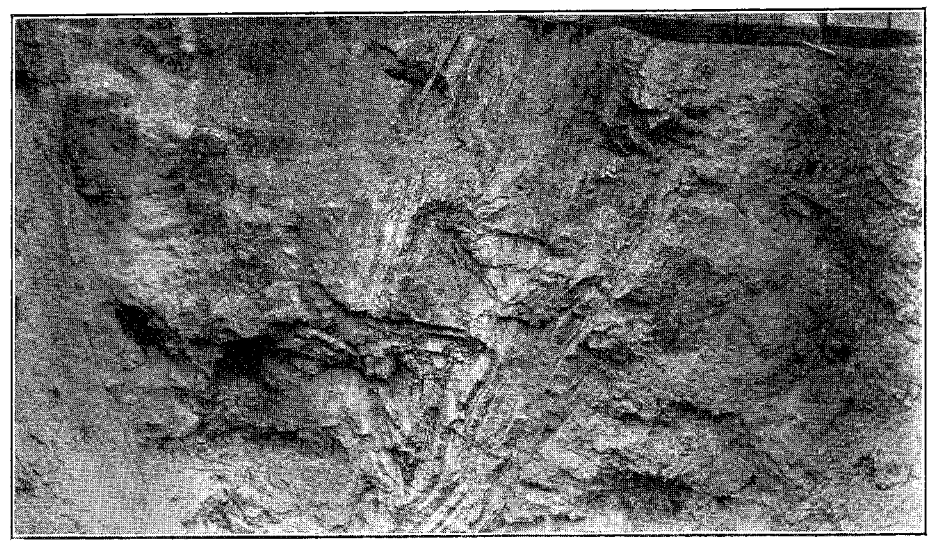
RELATIONS OF THE UPPER HURONIAN GROUP TO THE SAUNDERS (LOWER HURONIAN) FORMATION.

No direct evidence of the relations of the Upper Huronian group to the underlying Saunders formation is yet available. Certain slates conformable with the Saunders formation in Sheridan hill *may* be Upper Huronian slates and *may* therefore indicate the conformable relations between the Upper Huronian slates and the Saunders formation. The fact that the rocks of the Saunders type form a continuous belt between the Upper Huronian slates and the Archean shore to the south is evidence of nearly conformable relations. In the Florence district there are quartzites, presumably forming the conformable base of the Upper Huronian group, and in the Crystal Falls, Menominee, Felch and Calumet districts succession from underlying quartzite and dolomite to the Upper Huronian show familiar relations.

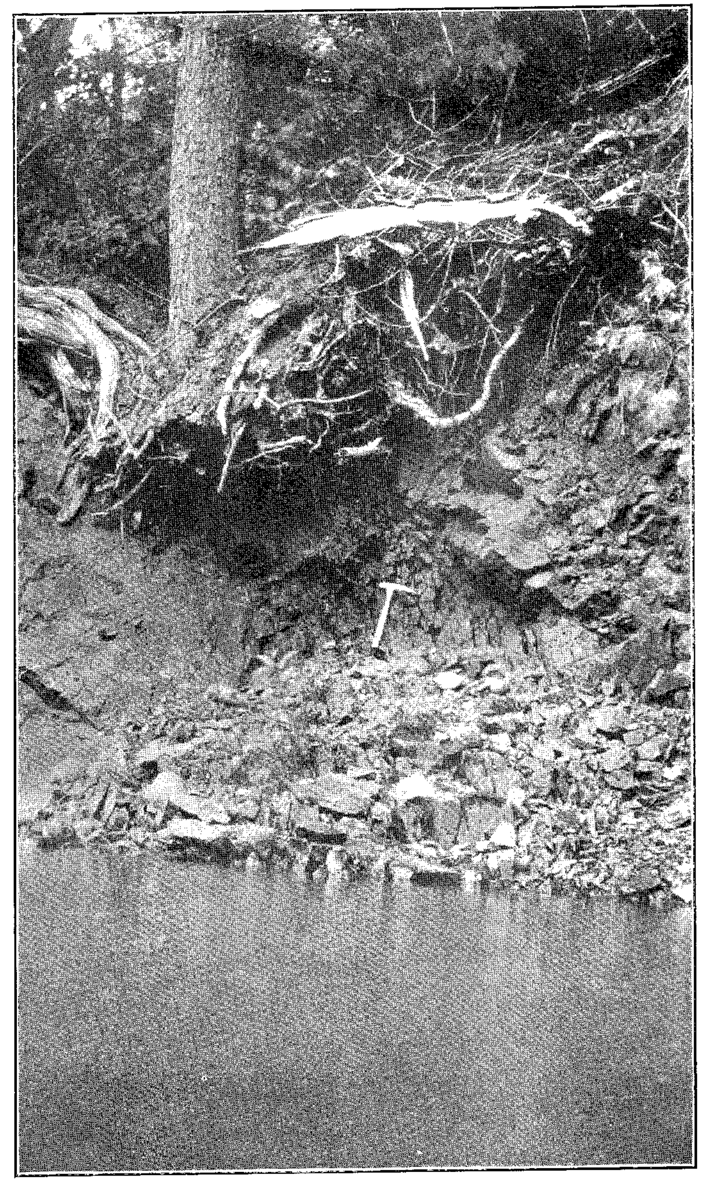
By reference to the map (Plate I) it will be seen that the north boundary of the Saunders formation would have to form a curve, convex southward with west end in the southwest ¼ of Section 19 and the east end at the exposure at Saunders dam, T. 42 N., R. 34 W., in order to exclude the greenstones in Section 29 and near the south ¼ corner of Section 19. According to the notes of Professor W. S. Bayley (1901), cherty dolomite was encountered in a well 600 paces north and 50 feet west of the S. W. corner of Section 24, T. 42 N., R. 35 W., by James Burgess, a driller employed by the Pewabic Mining company. If this information is authentic it furnishes additional evidence that the greenstones in Sections 19 and 29, T. 42 N., R. 34 W., are interbedded with the Saunders formation.



(A) VULCAN FORMATION IN THE SOUTH END OF RIVERTON PIT. THE BANDING OF THE FERRUGINOUS CHERT IS WELL SHOWN.



(B) VULCAN FORMATION IN SOUTH END OF ISABELLA PIT.

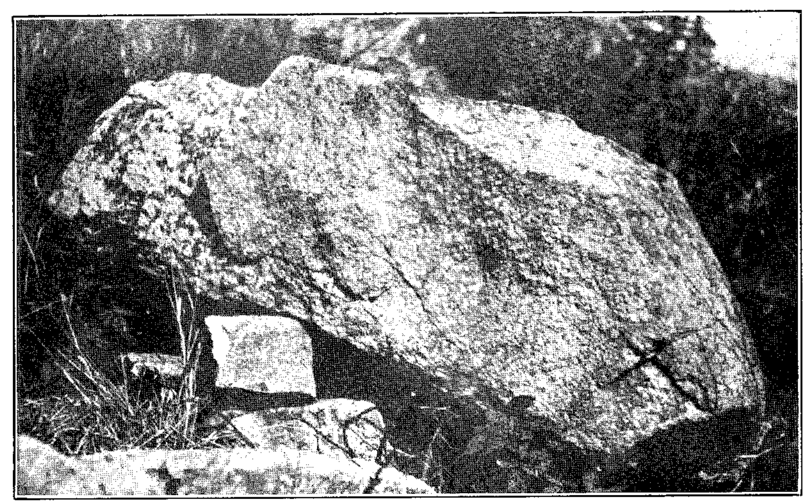


SLATE INTERBEDDED WITH VOLCANIC GREENSTONE ON BRULE RIVER, ABOUT TWO MILES EAST OF SAUNDERS.

(A) WEATHERED EXPOSURE OF VOLCANIC GREENSTONE BRECCIA IN SECTION 21, T. 42 N., R. 34 W., NEAR SAUNDERS. NOTE THE GREAT ABUNDANCE OF CALCITE AND DOLOMITE SHOWN IN WHITE.

(B) A NEAR VIEW OF A PORTION OF THE EXPOSURE SHOWN IN (A).

(A) ERUPTIVE GREENSTONE PSEUDO-CONGLOMERATE IN SECTION 13, T. 42 N., R. 35 W.



(B) WEATHERED SURFACE OF GREENSTONE FLOW. SAME LOCALITY AS (A).

ORDOVICIAN. SHERIDAN FORMATION.

Remnants of a flat lying Palaeozoic member occur in the southern part of the district on Sheridan hill and vicinity and southwestward in the S. W. 1/4 of Section 27, T. 42 N., R. 35 W. and in the northern part of Section 24, T. 44 N., R. 35 W.

The base of the member on Sheridan hill is a conglomerate made up almost entirely of material from the underlying Saunders formation. Angular fragments of chert up to a couple of inches in diameter lie in a matrix of the same composition, on the whole, but finer grained. The rock is cemented mainly with iron oxide and calcium carbonate. The thickness of the conglomerate is unknown but is not great. The conglomerate has not been found in natural exposure but occurs abundantly on the dumps of pits which have been sunk through it into the Saunders formation.

The conglomerate is probably basal to a coarse, quartz sandstone of buff or red color, and generally very friable texture. The cement is mainly iron oxide. Under a slight tap of the hammer the rock falls apart into its constituent sand grains. The thickness of this member is not known but it probably varies up to perhaps 35 or 40 feet. Like the conglomerate, the sandstone is known only in pits. It may be seen to best advantage about 550 paces west and a few paces south of the N. E. corner of Section 20, T. 42 N., R. 35 W. in the dump of a large pit. Some of the layers here carry abundant small chert fragments derived from the Saunders formation which is exposed in this vicinity.

In the S. E. corner of Section 24, T. 44 N., R. 35 W. a film of red sandstone is found mantling black slate. Here the rock carries considerable iron oxide, probably derived from the Vulcan member occurring about a quarter of a mile north of it.

The conglomerate and sandstone of these areas have the lithological characters of the lowermost Cambrian beds in the Menominee district and were formerly correlated as Cambrian. Fortunately, recent fossil discoveries in flaggy limestone beds in the S. E. 1/4 of the S. W. 1/4 of Section 27, T. 42 N., 35 W., have fixed within narrow limits the age of these formations. In this area there is one natural exposure on the east side of the Brule river and several pits all showing non-magnesian, dove or buff colored, flaggy limestone of the same general characters. The rock seems to be flat lying, although the beds in the outcrop on the Brule river, where observations were made and where most of the fossils were found, have been disturbed by slump following undercutting by the river. From the position of this outcrop in reference to an exposure of the Saunders formation on the west side of the river about 500 paces south, it seems that these rocks are not far above the eroded surface of the Saunders formation. It is not known that they are underlain by the conglomerates and sandstone of Sheridan hill. The beds are practically undisturbed in both areas, but the lowermost known occurrence of the conglomerate on Sheridan hill is about 150 feet higher and the uppermost known beds of sandstone are about 300 feet higher than the limestone outcrops on the Brule river in section 27. It seems from this that the conglomerate and sandstone on Sheridan hill is stratigraphically higher than the limestone of section 27. Doubtless the conglomerate originally formed a more or less continuous mantle at the base of the Palaeozoic member, but owing to the rugged character of the pre-Ordovician surface over which the sea advanced there was probably a considerable time interval between the submergence of the lower areas and the tops of the hills. Consequently the relative age of the basal member formed at any given point is a function of its altitude at that place. The occurrence of sandstone on Sheridan hill at an altitude of about 1,760 feet makes it certain that the entire district was almost, if not entirely, covered by a Palaeozoic sea.

The lowest exposure of the Palaeozoic beds is the limestone member on Section 27, T. 42 N., R. 35 W. This member is correlated by Mr. E. O. Ulrich on paleontologic grounds with the Lowville of New York and the Plattville limestone of Wisconsin, i. e., Middle Ordovician. The following is Mr. Ulrich's report to Dr. T. W. Stanton:

"I beg leave to report as follows on the fossils collected in the Iron River district, Michigan, by R. C. Allen, and forwarded to the Survey for examination and report by Dr. C. K. Leith, November 18, 1909.

"This discovery of fossils in Northern Michigan is of great interest, since it adds an important link in proving the former connection of the early Mohawkian limestone of Minnesota and Western Ontario across northern Wisconsin. In discussing the Lowville formation in my paper on revision of Palaeozoic systems, I state my conviction that this and perhaps other Mohawkian formations must have originally extended from New York through Ontario, northern Michigan and northern Wisconsin to Minnesota and Iowa. This direct westerly connection was indicated by the great similarity in fauna and lithology noted in comparing the Lowville limestone in New York and the more typical part of the Plattville limestone in Minnesota, Iowa, southern Wisconsin, and northwestern Illinois. I objected to communication via southeastern Wisconsin because there the beds supposed to correspond in age to the Lowville are dolomites instead of pure limestone, with no indication of transition in lithic characters northward. Hitherto the northern connection could not be established farther west from New York than Escanaba, Michigan. This Iron River occurrence, which is of the same fine-grained, non-magnesian, dove limestone everywhere characterizing the Lowville, and lies well up on the old 'Wisconsin Peninsula,' therefore may justly be regarded as tending to establish a view hitherto based only on inference.

"The following twenty species are more or less confidently identified. All are older than the Trenton limestone and younger than the latest (Pamelia limestones) Stones River.

Fossils from Iron River, Michigan.

? *Corematocladus densus.*
Tetradium cellulosum (1 fragment of tube of only).
Rhinidictya cf. *nicholsoni* and *mutabilis-minor,* (fragment).
R. cf. *major,* (fragment).
Escharopora angularis.
? *Homotrypa arbuscula.*
Rafinesquina minnesotensis.
Strophomena incurvata (Lowville var.).
Zygospira recurvirostris (Lowville var.).
Ctenodonta sp. undet. (near *C. levata*).
Leperditia fabulites.
Leperditella tumida.
L. germana.
Bythocypris granti var.
Eurychilinia reticulata.
E. subradiata.
E. n. sp.
Isotelus cf. *ovatus.*
Pterygometopus sp. undet. (*pygidium*).

"The fossils of the above list indicate an horizon at the extreme top of the Plattville limestone in the Lead district. Compared with the New York section the age of the bed corresponds to the uppermost beds of the Lowville as described by Cushing, or to the cherty bed at the base of the Black River limestone as defined by the same author."

CHAPTER V.

CONDITIONS OF DEPOSITION OF THE MICHIGAMME SERIES.

The foregoing study of the rocks of the Michigamme series throws considerable light on the physiographic and climatic conditions of their deposition. That the sediments were laid down in water of varying shallow depths under unstable and fluctuating conditions of supply of materials is evidenced by the variability in texture and composition of individual strata, their discontinuity, cross bedding, ripple marks, frequent repetition at different horizons of rocks of identical character, and the presence of intraformational conglomerates. In the earlier studied iron ranges, viz. the Animikee, Vermilion, Mesabi, Penokee-Gogebic, Marquette and Menominee, the Upper Huronian succession is in general from the base upward, conglomerate and quartzite, iron formation, slate, representing a uniform progression of a cycle of changes in conditions of sedimentation which gave rise to a type succession for the series in these districts. In the Iron River district and also in the Florence-Crystal Falls district this order of succession breaks down completely and in place of it there is presented a series of dovetailed lenses of various dimensions of slates, graywackes, arkoses, and iron formation, usually separated by indefinite gradational zones but often showing abrupt transitions. Conditions of sedimentation were therefore not uniform in time or place. Considering the series as a whole the sediments are poorly sorted; apparently the detritus was contributed to the water faster than wave and current action could sort it. If the materials had been gained at the expense of bordering shore rocks through wave erosion they would have been more perfectly sorted. It is likely that the main source of the detritus was inland from whence it was conveyed to the sea by streams and built into a delta. Under this hypothesis the rapid variations in grain, discontinuity of beds, etc., are the result of fluctuations in transporting power of the streams combined with progressive aggradation of the bed of the sea. In times