GEOLOGICAL SURVEY CIRCULAR 120

September 1951

GEOLOGY OF THE NORTHERN PART OF THE IRON RIVER DISTRICT IRON COUNTY, MICHIGAN

By

H. L. James and C. E. Dutton

PREPARED IN COOPERATION WITH THE GEOLOGICAL SURVEY DIVISION
MICHIGAN DEPARTMENT OF CONSERVATION

UNITED STATES DEPARTMENT OF THE INTERIOR
Oscar L. Chapman, Secretary
GEOLOGICAL SURVEY
W. E. Wrather, Director

Washington, D. C.

Free on application to the Geological Survey, Washington 25, D. C.

CONTENTS

ILLUSTRATIONS

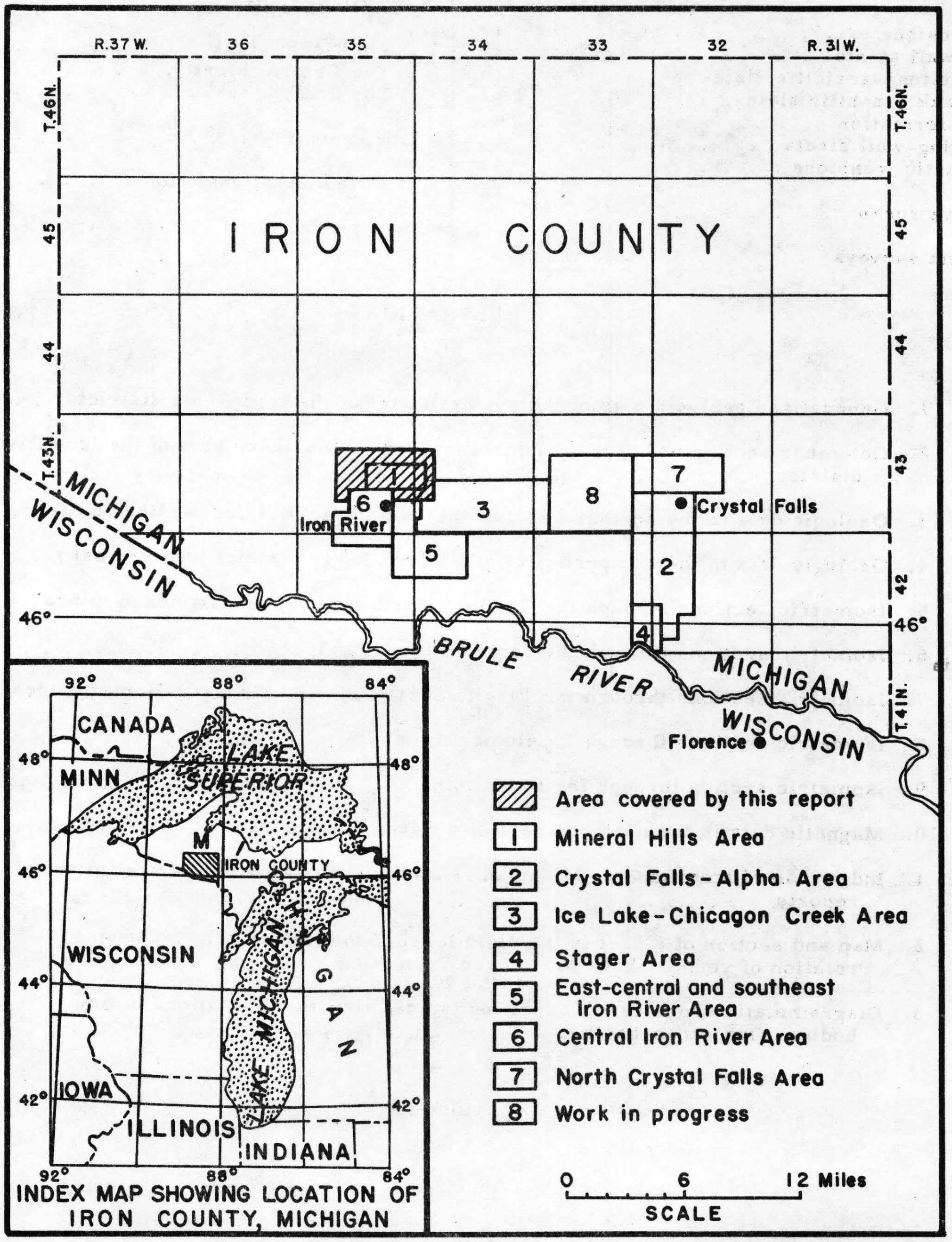


Figure 1.--Index map of Iron County, Michigan, showing areas covered by preliminary reports.

GEOLOGY OF THE NORTHERN PART OF THE IRON RIVER DISTRICT IRON COUNTY, MICHIGAN

INTRODUCTION

The northern part of the Iron River district, the area of this report, is about 5 miles from east to west and 2 1/2 miles from north to south. It extends mainly west and north of the town of Iron River and is part of the Iron River-Crystal Falls district of southern Iron County, Michigan (fig. 1). It is known locally as Mineral Hills, the name of the community centered around a group of mining locations within the area.

Iron ore is mined from parts of fourteen 40-acre tracts in an area about 2 1/2 miles long and 1 mile wide, and ore has been produced from eleven additional tracts. It is hoisted through seven shafts that are operated by four mining companies. Production began in 1907, and through 1949 the total production had been slightly more than 36,000,000 tons. The present annual production from the area is a little less than two million tons--about one half the output from the entire Iron River district, according to the annual reports of the Lake Superior Iron Ore Association, Cleveland.

The geologic work in the Iron River-Crystal Falls district has been a continuing cooperative investigation by the Geological Survey Division of the Michigan Department of Conservation, and the U. S. Geological Survey. This report is one of a series of preliminary publications (Dutton, and others, 1945; Dutton, 1949; James, and others, 1947; James and Wier, 1948; Pettijohn, 1947, 1948) whose purpose is to report progress in the work and to make the information available as soon as possible. The reports are entirely preliminary in nature and do not include discussion of theoretical considerations, the results of microscopic study of the rocks and ores, nor an appraisal of the pertinent literature.

The present report is based largely on intermittent compilation and study since the first brief report on this part of the Iron River area that was issued in 1945. Most of the mine workings added since 1945 were mapped, other parts of some mines were remapped, and all available drill core was examined during the investigation. Magnetic surveys were made in some parts of the area, but in general the character of the data did not warrant extensive traversing.

The work was possible only through the wholehearted cooperation of the mining companies, because they permitted access to the mines, to the core houses, and to much file information. The mining companies made prints of hundreds of maps and drill-hole data upon request. Acknowledgment is made for this assistance and many other courtesies extended by officials of Pickands, Mather and Co., M. A. Hanna Co., Cleveland-Cliffs Iron Co., Mineral Mining Co. Jones and Laughlin Ore Co., Inland Steel Co., and the former Davidson Ore Co. Information on some of the older explorations was furnished by A. D. McPherson.

The cooperation of various members of the Michigan Geological Survey in the work is especially acknowledged. The discussions and continued interest of F. G. Pardee have been particularly helpful.

GENERAL GEOLOGY

The Iron River district is the western end of a triangular-shaped synclinorium that has apices at Iron River, Mich., Crystal Falls, Mich., and Florence, Wis. (See index map, fig. 1.) Greenstone, composed chiefly of chloritized ellipsoidal lavas, agglomerates, and tuffs, bounds the basin on the north and south sides and forms several masses on the east side. Tight, complex folding of the strata is general throughout the synclinorium, and especially complicated patterns of tight folds and faults exist in the vicinity of Iron River.

An extensive and generally thick mantle of glacial deposits covers the bedrock in most places. The thickness of the glacial materials in the mapped area is locally as much as 330 ft and is commonly 100 to 200 ft. Bedrock is exposed only in four small outcrops, one in the northern part of sec. 14, another in the northern part of sec. 16, and two in the NW1/4 sec. 26. In some places the geology is virtually unknown because of the general absence of outcrops and the paucity of drill holes. Even where information from drill holes and underground workings is relatively abundant, many uncertainties as to the geologic pattern exist.

The strata in the area are similar to those elsewhere in the district; they are a complexly folded series of pre-Cambrian slates, graywacke, oxidized and unoxidized iron-formation, and locally iron ore. The age of the strata is generally considered to be upper Huronian, although a middle Huronian age is possible. The greenstone on which the sedimentary beds rest is exposed at only one place in the area and at a few places north of the area.

Diabase dikes are the only intrusives known in the Iron River district; most have been profoundly altered. They are of probable Keweenawan (late pre-Cambrian) age.

The general geology of the area and a generalized structure section are shown on plate 1. Geologic boundaries are also shown on larger-scale maps (pls. 3 and 4) on which drill holes and representative mine levels are shown. The details of structures within the area of the mines are shown by a series of isometric cross sections (pls. 5, 6, 7, 8, and 9).

STRATIGRAPHY

Separation of the strata into distinct stratigraphic units is beset by many difficulties. Chief among these are the similarities of the strata above and below the iron-formation, and the complex structure. Interbedding of various lithologic units is common but is frequently difficult to distinguish from infolding. Because of the complex folding, thicknesses are especially difficult to determine--commonly the drilled thickness of a member is several times the stratigraphic thickness. These uncertainties lead to wide divergence of opinion, not only with respect to thicknesses but with respect to the stratigraphic divisions themselves.

The cooperative program in the Iron River-Crystal Falls district began with the mapping of some of the mines within the area of this report. Some of the concepts presented in the first preliminary report (Dutton, and others, 1945) have remained valid; but restudy of this area, plus much additional information from other parts of the district, have required revision of others.

The basement rock consists of greenstone, and it is overlain by a series of sedimentary rocks that can be divided into three major units: the footwall strata, the iron-formation, and the hanging-wall strata.

The general outline of the stratigraphy of the area is shown on plate 2 (columnar section and stratigraphic chart for the northern part of the Iron River district), and some of the more pertinent facts concerning the rocks are presented in the following paragraphs.

Greenstone

The greenstone that forms the basement on which the Huronian sedimentary rocks rest is, so far as known, exposed in the northern part of the Iron River district only in the SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 16. Rock belonging to this sequence is exposed also in the NE$\frac{1}{4}$ sec. 12, T. 43 N., R. 35 W., about three-fourths of a mile north of the mapped area. At this latter locality it is a massive, chloritized basic volcanic rock showing pillow structures. Elsewhere the greenstone consists of altered tuffs, agglomerates, and massive flow rocks.

A number of holes have been drilled in the northwest part of the mapped area, but none of the core could be located for examination. Some of the holes encountered material that was logged as "greenstone," but most of the rock was recorded as slate. If the classification is correct, possibly the bedrock in this part of the area consists of interbedded greenstone and slate, but information is not adequate enough to be certain.

Footwall strata

The footwall strata are defined as the series of rocks lying stratigraphically below the iron-formation and above the greenstone. The contact with the greenstone has not been seen. In this area the footwall strata have been divided into two major units; a lower siltstone sericitic slate sequence, and an upper graphitic slate sequence. The total thickness of the footwall strata is not known, but it appears to be a minimum of several hundred feet.

Siltstone-sericitic slate

Massive, well-banded, gray siltstone, with some interbedded sericitic, dark-gray slate, forms the bulk of the footwall strata, Slaty cleavage is well developed in the slates and is locally present in the siltstones. Fine banding is general in the siltstone, and graded bedding is occasionally seen. The siltstone almost invariably shows numerous very small faults with displacements on the order of a few tenths of an inch. In many places this minor faulting grades into a pseudoconglomeratic structure that is due to minor faulting of some layers, accompanied by rotation and rounding of the fragments. Generally, the pseudoconglomerate is massive, without indication of shearing; and it appears that the structure is due to disturbance prior to lithification of the rock. Essentially, the rock is to be classified as contemporaneous breccia, the product of subaqueous slump of unconsolidated material.

Black graphitic slate

Above the siltstone and sericitic slate is a black, graphitic, highly pyritic slate that underlies the iron-formation throughout the Iron River-Crystal Falls district. The unit within this area consists of three members that have an average total thickness of about 25 ft. From oldest to youngest they are: graphitic slate breccia, laminated graphitic slate, and chert breccia. Pyrite is very abundant in these graphitic rocks, especially in the slate breccia and the laminated slate, where it forms 30 to 40 percent of the rock. Because of its exceedingly fine grain, however, the pyrite is rarely visible to the unaided eye.

The basal member of the graphitic slate is a breccia (the "speckled gray" of field terminology), which is a marker bed throughout the Iron River district. This rock consists of numerous small angular fragments of graphitic slate in a dense graphitic matrix. The fragments rarely exceed an inch in diameter. The rock is massive, in contrast to the laminated character of the overlying slate. Locally, the graphitic slate breccia grades downward into the pseudoconglomerate of the underlying siltstone sericitic slate, but more typically it is separated from the underlying strata by interbedded gray and graphitic slate. The thickness of the breccia is as much as 25 ft in some places and averages about 10 ft.

The middle member of the graphitic slate is a thin-bedded to laminated rock in which pyrite-rich layers alternate with layers that contain less pyrite. The bands are typically one-eighth to one-half inch thick. In a few places, notably in the James mine, several layers of chert 1 in. to 2 in. thick occur in this member. The total thickness of the laminated graphitic slate is generally about 10 ft.

A chert breccia separates the laminated graphitic slate from the iron-formation in most parts of the mapped area. Where unoxidized this rock is massive and dark colored, with abundant platy fragments of chert. The chert fragments are as much as several inches in length and are oriented at random. Where chert fragments are scarce the rock superficially resembles the basal graphitic slate breccia. The chert breccia differs from the other two members of the footwall graphitic slate sequence in that it contains an appreciable content of iron carbonate, as shown in the following table. The specimens are from the James mine, 7th level, and were analyzed by the Pickands, Mather and Co. laboratory.

	Total Fe	S	Pyrite content (calculated)	Carbonate content (calculated)
Chert breccia	22.80	6.68	12.5	35.3
Laminated slate	19.40	19.17	35.8	5.6
Slate breccia	19.50	17.02	31.9	9.5

The chert breccia has an average thickness of about 5 ft.; locally it is absent. Because of its high content of iron carbonate, the rock is susceptible to deep oxidization in many places and may be included with the overlying iron-formation.

Iron-formation

The iron-formation of the northern part of the Iron River district consists of a cherty, lower unit and a slaty, upper unit.

The cherty unit is about 100 ft thick and is the host rock for the ore deposits. Where unoxidized it consists chiefly of interbedded dark chert and gray siderite in about equal proportions, with minor partings of sideritic or graphitic slate. The layers range in thickness from less than one-tenth in. to 4 in. Where oxidized the rock consists of bedded white to gray chert and iron oxide (either yellow limonite or reddish hematite). This rock, by diminution in the amount of chert, grades into ore. An excellent section of the cherty unit in its unoxidized state is exposed on the fifth and sixth levels of the James mine, in the shaft area.

The slaty unit of the iron-formation, where unoxidized, typically consists of alternating thin layers of impure carbonate, graphitic pyritic slate, and chert. Locally, the rock consists chiefly of either carbonate or graphitic slate. The chert is less abundant that in the underlying cherty unit and commonly occurs as small nodules or as layers that are irregular in thickness. Bedding-plane surfaces adjacent to the layers of irregular chert have a wavy or lumpy appearance, the swellings being over nodules or lenses of chert. The carbonate layers are gray to dark gray and many are silty; some approach sideritic graywacke in composition. Where graphitic slate is the dominant constituent the rock closely resembles the footwall laminated graphitic slate. The thickness of the individual layers in the slaty unit is most commonly between one-tenth and one-half inch, but in the eastern part of the area (as in the east part of the Spies mine) the layers are several inches thick. Throughout much of the Mineral Hills area the slaty unit is completely oxidized to a reddish slate, with some layers of buff, gray, or green slate.

Despite widespread oxidation, the slaty unit rarely is converted to ore; commonly, the base of the slaty unit forms the upper contact of the ore bodies that occur in the underlying cherty unit. As a result, this contact between the two units of the iron-formation can be rather accurately located in most of the mines. The contact of the upper unit of the iron-formation with the overlying graywacke, on the other hand, is not encountered as often although in a stratigraphic sense it is a more important boundary. On the maps and sections that accompany this report, the upper unit of the iron-formation is grouped with the stratigraphically distinct graywackes and breccias of the hanging-wall strata.

As mentioned above, parts of the slaty, upper unit consist chiefly of bedded impure carbonate; and in places this rock is thick enough to warrant consideration as an iron ore. The limb of iron-formation that lies immediately south of the Central Mineral Hills fault zone is unoxidized for much of its length (see pls. 5 and 6, cross sections D-D', E-E', and F-F'), and drilling has disclosed carbonate-rich zones of possible economic importance.

Breccia consisting of chert and siderite fragments in a sideritic or graphitic matrix is closely associated with the slaty, upper unit in many places. At least locally, the breccia is interlayered with bedded iron-formation.

The thickness of the slaty, upper unit is variable, chiefly because portions of the bed were removed by erosion prior to deposition of the overlying hanging-wall strata. In most places the unit has a thickness of 100 to 200 ft.

Both units of the iron-formation are characterized by complex internal folding, which appears to have been facilitated by the thin banding of the rocks.

The hanging-wall strata

Above the iron-formation is a series of rocks referred to as the hanging-wall strata. This sequence consists of breccia, slate, and graywacke. In other parts of the Iron River-Crystal Falls district, hanging-wall strata are overlain by a magnetic ironstone (see col. 2); but so far as known at present, this latter rock does not occur within the northern part of the Iron River district.

The contact of the hanging-wall strata with the iron-formation is an unconformity that in many places is marked by chert breccia. This breccia, where unoxidized, is a massive rock that consists of angular chert and siderite fragments in a slate or graywacke matrix. As might be expected, there is a considerable range in thickness. In places the breccia is absent, and coarse graywacke directly overlies the iron-formation; elsewhere the breccia may be 50 to 100 ft thick. An occurrence of breccia in the Homer mine is shown on the accompanying sketch (fig. 2). At the ninth level shaft station of the Wauseca mine a 6-ft bed of coarse graywacke lies between the iron-formation and an overlying bed of chert breccia.

In the western half of the area some drill holes pass directly from massive graywacke into iron-formation. Others intersect a zone consisting mostly of chert between the graywacke and the iron-formation. This chert may be a chert rubble at the base of the graywacke, rather than bedded chert; but the evidence is inconclusive.

The bulk of the hanging-wall strata above the breccia consists of massive graywacke interbedded with minor gray slate. The graywacke in the eastern part of the area is somewhat different from that in the western part. In the eastern part the graywacke is dark gray, fine to medium grained, with occasional fragments of chert or slate. Where unoxidized the rock has an iron content typically about 15 percent, the iron being in the form of siderite or iron-rich chlorite. The associated slates,are dark gray and sideritic. In general, they are well banded and only slightly sericitic. In the western part of the area the graywacke is light-colored medium to coarse grained, and contains an abundance of clastic feldspar grains. In the fresh rock these feldspar grains are colorless or pink; in the altered rocks they are white or buff, owing to kaolinization. The iron content of the rock is low, generally under 10 percent and often as low as 4 percent. The associated slates are light gray and massive. Commonly they are sericitic. Like the graywacke, their iron content is low.

The change from nonfeldspathic, iron-rich graywacke to coarse-grained, feldspathic, iron-poor graywacke appears to be a progressive one. It probably reflects proximity to the source area of the sediments--that is, the coarser, feldspathic sands were deposited close to the exposed land surface whereas the finer-grained, nonfeldspathic type was deposited farther offshore. It is to be noted that cross bedding, never observed in the nonfeldspathic graywacke, has been seen in drill core from the western part of the area.

The thickness of the hanging-wall graywacke and slate has not been determined with any degree of accuracy. Drill holes in many parts of the area have passed through more than a thousand feet of the rock, but the amount of repetition by folding or faulting is not known. Certainly, however, this unit is at least several hundred feet thick.

Magnetic ironstone

The magnetic ironstone, a widespread stratigraphic unit is the Iron River-Crystal Falls district, is not known to occur within this mapped area. However, a fairly pronounced magnetic anomaly in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 13 may reflect its presence; and a brief description is therefore given below.

The ironstone is a laminated flinty rock composed of finely intergrown siderite, iron-rich chlorite, chert, and magnetite. The darker layers are rich in chlorite and magnetite, and the lighter layers are rich in siderite and chert. This unit is distinguished from the main iron-formation by finer banding and by its magnetic properties. In other parts of the district the magnetic ironstone is separated from the hanging-wall graywacke by massive gray slate and by magnetite-bearing graywacke.

INTRUSIVE ROCKS

Dikes are fairly numerous in the area. Most have been thoroughly altered to chlorite and kaolinite. The rock of the altered dikes is typically massive, light gray to greenish, and commonly difficult to distinguish from some varieties of graywacke and slate. Identification of some dike rock is not definite except under the microscope, where relict textures are generally visible despite the complete alteration to chlorite and kaolinite. Most of the dikes appear to have been originally diabasic in composition.

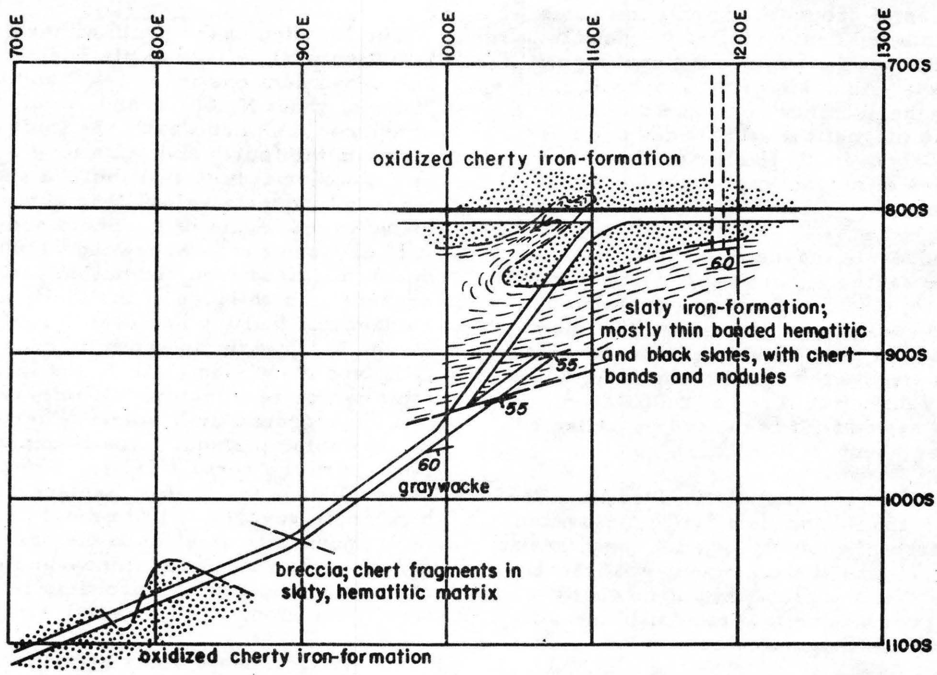
A fresh diabase dike is crossed by the "650" level of the Forbes mine. The rock is a dark gray and fine to medium grained. Glistening laths of feldspar are visible to the unaided eye. This dike is magnetic and is polarized in a direction opposing the present magnetic field of the earth. As a result, it is marked by a negative magnetic anomaly. By means of magnetic surveys and drill-hole information, the dike can be traced for about a mile and a half in a general easterly course. The dip is 60^{0}-80^{0} S.

The dike in secs. 11, 14, and 15 is marked by a low to moderate positive magnetic anomaly (see pl. 10), and its map pattern is inferred chiefly from the magnetic data. The rock, as seen in the core from a recent drill hole in the NE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 14, is a medium-grained partly chloritized diabase.

Most of the dikes mapped thus far are in or adjacent to the major fault zones. Thicknesses range from 4 in. to 200 ft.

MAGNETIC SURVEYS

No systematic magnetic survey was made of the entire northern part of the Iron River dis-



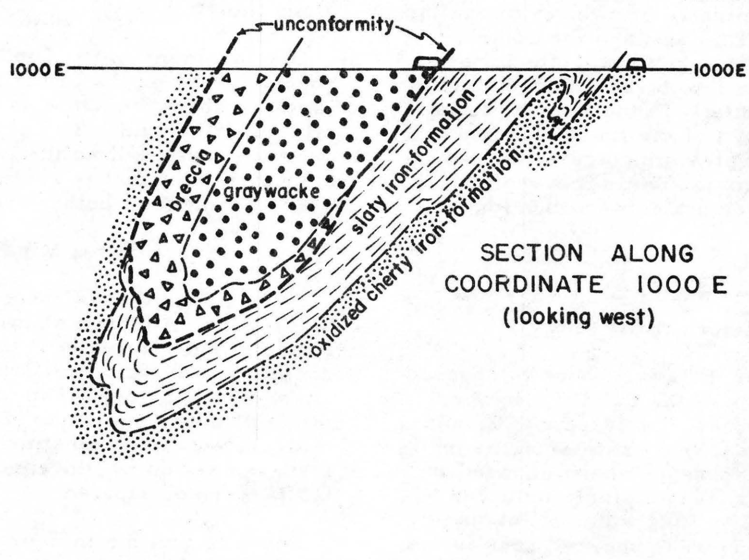


Figure 2. --Map and section of a part of the ninth level of the Homer mine, showing relation of younger beds to the iron-formation.

trict. The magnetic values along the few traverses were determined by vertical magnetometers, of Askania or Ruska make; the results, together with results of some surveys by the mining companies, are shown on plate 10. The values are adjusted to a zero base station that is located in sec. 28, T. 43 N., R. 34 W., and has been used for other U. S. Geological Survey reports on the district.

So far as known, the magnetic ironstone, which has been traced by magnetic methods through much of the Iron River-Crystal Falls district, is not present within the mapped area. The iron-formation itself is nonmagnetic. Except in areas of pronounced and continuous anomalies, detailed contouring of the data is difficult because of the numerous "spot highs" and "spot lows." Analysis of the magnetic profiles over these highly localized anomalies shows that the magnetic disturbances are not caused by bedrock; in all likelihood they are due to boulders of magnetic greenstone in the glacial drift.

A low to moderate magnetic anomaly is present in the southern part of sec. 11, the northern part of sec. 14, and the eastern part of sec. 15. As mentioned earlier in this report, the anomaly is caused by a slightly altered diabase dike. A pronounced negative magnetic anomaly trends in an easterly direction through the SE$\frac{1}{4}$ sec. 14 and the S$\frac{1}{2}$ sec. 13. It is caused by a dike of fresh diabase, about 30 ft thick.

A positive magnetic anomaly is present in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 13. An inclined drill hole passes beneath the area of anomaly; it cuts nonmagnetic graywacke and slate of the hanging-wall strata. It is possible that a shallow fold of magnetic ironstone is present and that the drill hole was too deep to cut the magnetic rock.

STRUCTURE

The structure of the northern part of the Iron River district is dominated by two major faults: the North Mineral Hills fault and the South Mineral Hills fault. As shown on plate 1, these faults divide the area into three structural units. Mining is confined chiefly to the Central block although the south part of the Bates mine and the east part of the Spies mine are within the South block. Other major faults may well be present within the North block and the South block.

Faults

North Mineral Hills fault

The North Mineral Hills fault zone is crossed at one or more levels of the Cardiff, Homer, Davidson No. 1, Forbes, Davidson No. 2, and Davidson No. 3 mines. See cross sections on plates 5 and 6. On the west, where exposed in the Cardiff workings, it is a single fault and shows as a zone, 10 to 50 ft wide, of intense shearing and crushing. The sheared rock is cut by irregular quartz veins. The fault dips steeply to the south. In the Forbes and Davidson No. 1 mines, two or three distinct faults can be mapped within a zone about 200 ft wide. One or more chloritized basic dikes lie within the fault zone in most places. In general the dikes follow the fault zone but locally (as in the Homer mine) they diverge.

The North Mineral Hills fault has an average dip of about 60°S. It is a reverse fault, the south side having been thrust over the north side. The amount of displacement is difficult to determine exactly, but it is about 2,000 ft. Movement seems to have been practically parallel to the dip. The fault truncates the fold structures at a low angle.

South Mineral Hills fault

The location of the South Mineral Hills fault is not so well defined as its northern analogue. See cross sections on plates 7 and 8. It appears to trend about N. 60° E and, in general, dips steeply to the northwest. The fault was encountered on the fourth and sixth levels of the Spies mine, where it is a well-defined shear zone marked by quartz veins. It is exposed in parts of the lower levels of the Sherwood mine. Where it is crossed by the Sherwood "1200" level, deeply oxidized iron-formation and ore are present on both sides of the fault, and the direct evidence of faulting has been largely obliterated. To the southwest, as shown in cross sections L-L' and M-M', on plate 7, the location of the fault can be reasonably well inferred by surface and underground drill holes. Wherever evidence is available, the south side is depressed with respect to the north side; so, like the North Mineral Hills fault, this displacement is a high angle reverse fault in most places. The fault appears to steepen to the east--the dip is at least 80° in the Spies mine--and the Bates mine fault zone, which probably is its eastward extension, is about vertical.

Chloritized basic dikes are numerous in and adjacent to the South Mineral Hills fault. Some of the dikes are no more than 4 in. thick, and most seem to continue for only short distances along the strike.

Displacement on the South Mineral Hills fault appears to be on the order of 1,500 to 2,000 ft, which is about the same as that on the North Mineral Hills fault. The direction of throw, however, is reversed; so the two faults define a structural unit that is raised with respect to the areas adjacent on both north and south.

Central Mineral Hills fault

A fault zone trends about N. 80° W. from the Spies mine. Although shown on plates 1 and 4 as a single fault, actually it is a rather irregular zone in which individual faults can be traced for short distances only. Dips vary, but in general the fault zone appears to be about vertical. It is interpreted as an adjustment fault along which stresses set up by movement on the two major faults were dissipated.

According to the interpretation made by W. E. Seppanen, chief engineer for the Pickands, Mather and Co. in the district, a steeply dipping fault marks the boundary between oxidized iron-formation and unoxidized iron-formation in the south part of the Davidson and James mines. This interpretation seems reasonable and is shown on isometric sections D-D' (pl. 5) and E-E' (pl. 6) of this report. The inferred fault would be part of the Central Mineral Hills fault system.

Other faults

An east-trending structural break somewhat similar to the Central Mineral Hills fault is present in the Wauseca and South Homer mines. It is not sufficiently well defined to show on the maps and sections of this report but locally appears to have considerable displacement.

The Bates mine fault zone (pls. 4 and 9) is an east-trending structure that was encountered in many levels of the now abandoned Bates mine. The fault zone is nearly vertical and is everywhere marked by intense shearing and quartz veining. Apparently the south side of the northern fault shown on plate 9 was downthrown at least 1,000 ft, and thus its direction and general magnitude of displacement is similar to the Central and the South Mineral Hills faults. The displacement on the southern fault has not been determined satisfactorily, but the areal pattern on the 14th and 16th levels indicates the probability that the south side is downthrown as in the northern fault. If this type of displacement is present, the fault extends vertically from the sixth level and passes along the south side of the truncated anticline. The alternative but probably less likely interpretation of relative displacement would require that the upward extension of the fault from the sixth level be inclined northward and pass along the north side of the anticline. Determination of the amount of displacement is questionable in either case because the fault is generally parallel to the stratification.

An east-trending fault seems reasonably well established by the drilling data in the SE$\frac{1}{4}$ sec. 23. Drill hole No. 8 (550 ft south and 323 ft east of the center of the SE$\frac{1}{4}$ sec. 23) and drill hole No. 9 (545 ft south and 473 ft east of the same point) both entered rock of the footwall strata at the bedrock surface and then passed through a zone of intense shearing into rock of either the hanging-wall strata or the uppermost part of the iron-formation. The fault dips steeply to the north, and the south side is downthrown. The displacement seems to be about 1,000 ft.

The North block

The structure of the North block (see cross section on pl. 1) is very inadequately known. Iron-formation is reported at bedrock surface in the SE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 15, in the NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 14, and near the center of sec. 13, as indicated by drill holes (pl. 4). These occurrences may define an anticlinal belt of iron-formation lying 1,000 to 2,000 ft north of the North Mineral Hills fault; in at least one locality (SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 13), rocks that almost certainly belong to the hanging-wall strata are present north of the reported iron-formation.

Drill holes in the northern part of sec. 14 encountered siltstone pseudoconglomerate of the footwall strata. Unless the structure is complicated by other faults, a belt of iron-formation should lie south of this area of known footwall strata--that is, in the south part of the N$\frac{1}{2}$ sec. 14. (See cross section on pl. 1.)

The Central block

Most of the mine workings in the area are confined to the Central block, which is bounded by major faults on both the north and south (cross section on pl. 1). Details of the structure of this area are shown by means of isometric cross sections on plates 5, 6, 7, and 8.

The structures within the block consist chiefly of folds that trend nearly east. Overturning to the north is general. The major structures are referred to by the following names for convenience of description: the North trough; the Spies anticline and its western analogue, the Cardiff anticline; the Central syncline; the Shaft anticline; the South trough; and the South Homer trough. Each of these structures is complex--that is, each is modified by other folds of lesser magnitude. Cross folds, some of which are tightly compressed, are common and greatly complicate the structural pattern.

The dominant structure is the Central syncline, a deep fold that locally places the iron-formation at depths of more than half a mile. However, the subsidiary synclines that flank it on both the north and south have contained most of the ore.

The North trough, which consists of two or more folds in most places, has been one of the most productive structures in the Iron River district. Details of this structure are shown on plates 5 and 6. The trough contained most of the ore bodies of the Cardiff, North Homer, Davidson, Forbes, and James mines, from which approximately 23,000,000 tons of ore has been mined. The trough is separated from the Central syncline by the Spies anticline and the Cardiff anticline. These latter two structures appear to be correlative in general although some doubt exists because of intervening cross folds. In general the North trough is a relatively shallow structure, which accounts for the thorough oxidation; the maximum depth of the iron-formation, for much of the length of the structure, is less than 1,000 ft. To the east the trough widens and deepens to form the Spies-Barnett Basin in the north part of sec. 24 and the south part of sec. 13 (cross section G-G' on pl. 6). To the west the trough is gradually cut off by the North Mineral Hills fault, which truncates it at a low angle.

The South trough, from which most of the ore of the Virgil, Sherwood, and Wauseca mines has been taken, is separated from the Central syncline by the Shaft anticline. The trough reaches its greatest depths in the Sherwood mine and in the south part of the Homer mine, where the keel of the fold of iron-formation lies 1,500 to 2,000 ft below the surface. In the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 23 is another downfold, the South Homer trough, in which lie the ore bodies of the south part of the Homer mine.

Information is not adequate to define the folds of the Central block much beyond the west edge of sec. 23. Several drill holes have been sunk recently in sec. 22, but the data are not available for publication at the present time. Several drill holes have been sunk in sec. 21, but the core could not be located. From the available descriptions the rock appears to belong mostly to the hanging-wall strata and to the upper slaty unit of the iron-formation. One hole cut 45 ft of ore.

The South block

The South block is a heterogeneous structural unit. It is bounded on the north by the South Mineral Hills fault but appears to lack a natural south boundary. On the west, in the W$\frac{1}{2}$ sec. 26 and the E$\frac{1}{2}$ sec. 27, hanging-wall graywackes make up most of the bedrock surface. Near the center of sec. 26 iron-formation has been drilled in structures that are apparently anticlinal. Recent drilling in the southeast part of sec. 23 indicates a complex structural pattern, but the details remain obscure. The fault shown on the map is marked by a zone of intense shearing and by numerous dikes. The south side of the fault is downthrown with respect to the north side, and the displacement appears to be on the order of 1,000 ft.

The structure in the area of the east Spies mine workings (NE$\frac{1}{4}$SW$\frac{1}{4}$ sec. 24, and NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 19) is reasonably well known. The folds trend in a northerly direction, and underground drill holes disclose three anticlinal blocks of footwall strata that probably reach bedrock surface.

The complex structure of the Bates mine has not been entirely deciphered. A pair of nearly vertical faults (the Bates mine fault zone) and accompanying narrow folds, as shown on plate 9, are the major elements and have a westerly trend--at right angles to the trend of structures in the adjacent east Spies mine. South of the fault is a basin-like area containing tightly folded strata.

ORE DEPOSITS

The ore deposits are almost entirely confined to the cherty, lower unit of the iron-formation; and in many places the entire thickness of this unit has been converted to ore. In most parts of the area the ore consists of soft reddish hematite. However, the ore of the James mine, and to some extent that of the Davidson and Sherwood mines, is composed of yellow "limonite" (goethite), part of which is soft and part of which is hard and crystalline. No rational explanation has been devised to account for the variation in character of the ore, as the hematitic and limonitic types occur in similar structural and stratigraphic positions. All of the ore is of a high-phosphorous grade. The sulfur content of the shipped ore is generally high (0.07 to 0.18 percent). Most of the sulfur occurs as white or pink gypsum, which increases in amount near the bottoms of some of the synclines. Parts of some ore bodies are unminable because of their high sulfur content.

The ore commonly retains the banded structure of the original iron-formation though locally it has a massive or obscurely fragmental appearance. No diminution in thickness of the iron-formation is noted where it is altered to ore, but the porosity of the rock has been greatly increased. This is indicated by the fact that the ore in the ground is calculated at 12 cu ft to the ton whereas nonporous material of this composition would have a value of about 8 cu ft to the ton. As a result of its high porosity and permeability, the iron-formation is always an aquifer; and mine drainage is a major problem. Some aspects of the water problem have been presented in a recent publication (Stuart, and others, 1948).

The structural control of the ore is obvious in most places. The ore commonly, but by no means always, lies directly on the footwall of underlying graphitic slate along the keel of a syncline. In this structural position much or all of the cherty, lower unit of the iron-formation may be converted to ore, and ore may be present on minor anticlinal structures within the larger synclines. The ore bodies are more irregular and generally smaller on the limbs of ore-bearing structures. The ore, if present, occurs on the structural footwall; therefore, on the overturned limb of an overturned fold the ore body will occur in the stratigraphically upper part of the cherty, lower unit. Typical structural positions of ore bodies are shown diagrammatically in figure 3. In some cross sections an ore body may appear to lack structural control. This is usually an apparent lack only, as examination of the maps will reveal that the controlling structure is a cross fold and that the structural footwall of the ore is subparallel to, and outside of, the plane of section. Faults appear to be of minor importance as structural controls of ore.

DISTRIBUTION OF OXIDATION

Inasmuch as the ore deposits are localized within those parts of the iron-formation that have been oxidized, the distribution of oxidation is a matter of prime importance in the search for ore. The oxidation referred to here is the alteration related to the epoch of ore formation and is not the surficial oxidation that has occurred since glaciation of the area. The depth of oxidation varies greatly from place to place. Locally the iron-formation is unoxidized at bedrock surfaces; elsewhere the same unit is oxidized to depths of at least 1,500 ft.

Except in the E$\frac{1}{2}$ sec. 19, the NW$\frac{1}{4}$ sec. 26, and the SE$\frac{1}{4}$ sec. 13, the cherty, lower unit of the iron-formation is oxidized at bedrock surface at all places where it has been explored in the northern part of the Iron River district. The slaty, upper unit of the iron-formation is thoroughly oxidized locally, as in the North trough, the South trough, the South Homer trough, and the Bates mine area; but in general the oxidation is much less extensive. In most places the oxidation fades out in irregular fashion from the lower ore-bearing unit toward the slaty, upper unit; but in some places, as in the east part of the Spies mine, the oxidation boundary between the two is abrupt.

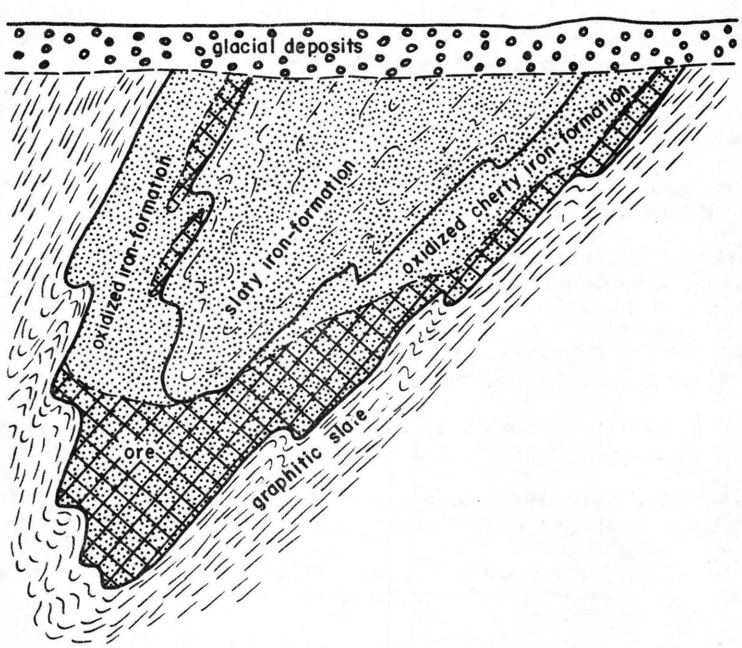


Figure 3.--Diagrammatic cross section showing typical structural relations of ore bodies. Ore cross-hatched.

The amount of the iron-formation that is unoxidized is notably greater in the lower levels of the mines than at the surface. The iron-formation encountered in the mine workings north of the North Mineral Hills fault is almost entirely unoxidized. The faulted north flank of the Central syncline in the James mine (see cross section F-F', pl. 6) is entirely unoxidized although this same limb yielded ore at higher levels a short distance to the west (see section E-E', pl. 6).

The east end of the Central syncline (in the SE$\frac{1}{4}$NW$\frac{1}{4}$ sec. 24) is thoroughly oxidized; this oxidation extends downward along the structure at least as far as cross section I-I' on plate 7, but it is likely that the deeper parts are unoxidized. The iron-formation on the Shaft anticline is oxidized, at least in part, through sec. 23. Oxidation on the North trough decreases as the structure deepens to form the Spies-Barnett Basin in the N$\frac{1}{2}$NW$\frac{1}{4}$ sec. 24 and the S$\frac{1}{2}$SW$\frac{1}{4}$ sec. 13; so that near the west edge of sec. 24, as shown on the small north-trending section attached to cross section G-G' on plate 6, even the lower part of the iron-formation is unoxidized.

The iron-formation cut by drill holes in the easternmost part of the mapped area (E$\frac{1}{2}$ sec. 19) is chiefly unoxidized.

Information is scarce in the western part of the mapped area, but holes in the NW$\frac{1}{4}$SE$\frac{1}{4}$ sec. 21 indicate that the iron-formation is oxidized. Drill hole No. 4, 640 ft south and 510 ft east of the center of sec. 21, cut 45 ft of ore.

In the southernmost part of the mapped area--that is, in secs. 26 and 27--oxidation appears to be irregularly distributed. Drill holes in the NE$\frac{1}{4}$SE$\frac{1}{4}$ sec. 27 cut oxidized iron-formation and ore after passing through a few hundred feet of younger graywacke. In the SW$\frac{1}{4}$NW$\frac{1}{4}$ sec. 26 most of the iron-formation cut is unoxidized. In the SW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 26, however, the iron-formation is oxidized, and several drill holes cut short sections of ore.

Oxidation appears to be extensive in the W$\frac{1}{2}$ sec. 13, except in the southernmost part. Much of the younger graywacke that makes up most of the bedrock surface is oxidized, and presumably oxidation extends into the adjacent or underlying iron-formation.

In sec. 14, north of the main belt of iron-formation, one drill hole near the center of the SE$\frac{1}{4}$ cut oxidized iron-formation and ore.

In sec. 15 a number of holes in the SE$\frac{1}{4}$SE$\frac{1}{4}$ cut oxidized iron-formation at depth.

As mentioned in the discussion of the structure of the North block, a belt of iron-formation should lie south of the drill holes in the N$\frac{1}{2}$ sec. 14; but no evidence is available as to the possible extent of oxidation.

REFERENCES CITED

Dutton, C. E., Park, C. F., Jr., and Balsley, J. R., Jr., 1945, General character and succession of tentative divisions in the stratigraphy of Mineral Hills district, Iron River, Iron County, Michigan: U. S. Geol. Survey Preliminary Rept., pp. 1-4.

Dutton, C. E., 1949, Geology of the central part of the Iron River district, Iron County, Michigan: U. S. Geol. Survey Circ. 43, pp. 1-9.

Good, S. E., and Pettijohn, F. J., 1949, Magnetic survey and geology of the Stager area, Iron County, Michigan: U. S. Geol. Survey Circ. 55, pp. 1-4.

James, H. L., Clark, L. D., and Smith, L. E., 1947, Magnetic survey and geology of the Ice Lake-Chicagon Creek area, Iron County, Michigan: U. S. Geol. Survey Strategic Min. Inves. Preliminary Rept. 3-213, pp. 1-11.

James, H. L., and Wier, K. L., 1948, Magnetic survey and geology of the eastern and southeastern parts of the Iron River district, Iron County, Michigan: U. S. Geol. Survey Circ. 26, pp. 1-18.

Pettijohn, F. J., 1947, Geology of the Crystal Falls-Alpha iron-bearing district, Iron County, Michigan: U. S. Geol. Survey Strategic Min. Inves. Preliminary Map 3-181.

---------------- 1948, Magnetic and geologic data of parts of the Crystal Falls-Alpha iron district, Iron County, Michigan, Michigan Dept. Cons., Geol. Survey Div., pls. 1-9.

Stuart, W. T., Theis, C. V., and Stanley, G. M., 1948, Ground-water problems of the Iron River district: Michigan Geol. Survey Div. Tech. Rept. no. 2.

INT.-DUP. SEC., WASH., D.C. 5005