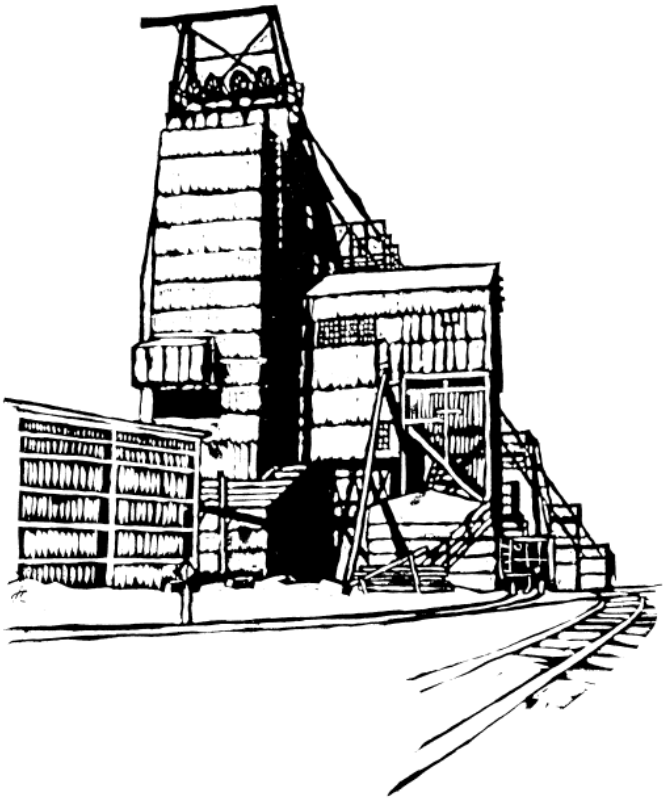

Front cover illustration:

The Bristol-Youngstown Iron mine in Crystal Falls. Opened in 1889, it operated continuously until 1934. Inland Steel Co. re-opened the mine in 1948 and operated it until closing again, perhaps for good, in 1969. Ore shipments totalled 14.8 million tons - over 70 percent of total for the entire area.
(Artwork by Jim Campbell)

STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY DIVISION

Report of Investigation 8
GEOLOGY AND MAGNETIC DATA FOR THE NORTHERN CRYSTAL FALLS AREA, MICHIGAN

By
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Contents

PREFACE 1

ABSTRACT 2

INTRODUCTION 3
- *Location* 3
- *Topography* 3
- *Ore Shipments* 3

GEOLOGY 4
- *Stratigraphic Units* 4
  - Badwater Greenstone 4
  - Dunn Creek Slate 4
  - Riverton Iron-formation 4
  - Hiawatha Graywacke 5
  - Stambaugh Formation 5
  - Fortune Lakes Slate 5
- *Igneous Rocks* 5
- *Structure* 5

PAINT RIVER AREA 6
- *Stratigraphy* 6
  - Dunn Creek Slate 6
  - Riverton Iron-formation 6
  - Hiawatha Graywacke 7
  - Stambaugh Formation 9
  - Fortune Lakes Slate 9
- *Intrusive Igneous Rocks* 9
- *Structure* 9
- *Magnetic anomalies* 10
- *Mines* 11
  - Lamont (Monitor) 11
  - Paint River 11
  - Fairbanks (Lincoln) 12
  - Lot 3 (Crystal Falls) 12
- *Explorations Town* 12
  - 43 North, Range 32 West 12
    - Section 20 12
- *Conclusions* 12

RAVENNA-BRISTOL AREA 13
- *Stratigraphy* 13
- *Structure* 13
- *Magnetic Anomalies* 13
- *Mines* 13
  - Ravenna and Ravenna-Prickett 13
  - Bristol (Claire) 15
  - Youngstown 16

GREAT WESTERN-HILLTOP AREA 16
- *Stratigraphy* 16
- *Structure* 17
- *Magnetic Anomalies* 17
- *Mines* 18
  - Great Western (Iron Star) 18
  - Crystal Falls 18
  - Hilltop 19
- *Explorations* 19
  - Town 43 North, Range 32 West 19
    - Section 22 19
    - Section 21 20

REFERENCES CITED 21

Illustrations

Figures

Figure 1. *Location and index maps* 2

Figure 2. *Structural map of iron-formation outcrop at Paint River dam.* 8

Figure 3. *Map of Ravenna-Prickett pit.* 14

Figure 4. *Plan of 12th level and cross section of Bristol mine*.....15

Figure 5. *Sketch showing mined ore bodies at 7th, 9th, 14th levels, Great Western mine.* 18

Figure 6. *Sketch showing mined ore bodies at 4th, 6th, 8th levels, Crystal Falls mine*.....19

Tables

Table1. *Stratigraphic column of the northern Crystal Falls area.* 3

Table 2. *Stratigraphic description of beds exposed in the Paint River outcrop area.* 7

PREFACE

The purpose of this report, sixth in a series of eight reports being published by the State of Michigan, is to promulgate detailed information on explorations, mines and magnetic surveys not included in U.S. Geological Survey Professional Paper 570, but invaluable for future development.

This report is a product of field investigations of the Iron River-Crystal Falls District carried out by the U.S. Geological Survey in cooperation with the Geological Survey Division of the Michigan Department of Natural Resources during the period 1943-55. Some results were published as preliminary reports during the course of the field study. The broader conclusions on the geology and ore deposits of the district appear in Professional Paper 570 published in 1968 by the U.S. Geological Survey.

The mining companies active in the district aided substantially by providing maps and records and permitting access to mine workings and drill core collections. The author gratefully acknowledges the friendly cooperation of officials and employees of The Cleveland-Cliffs Iron Co., M. A. Hanna Co., Pickands Mather & Co., Republic Steel Corp., Mineral Mining Co., Inland Steel Co., North Range Mining Co., Jones & Laughlin Steel Corp., and Pittsburgh Coke and Iron Co.

The advice, encouragement, and stimulating interest of various members of the Geological Survey Division, Michigan Department of Natural Resources is gratefully acknowledged.

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July 1967

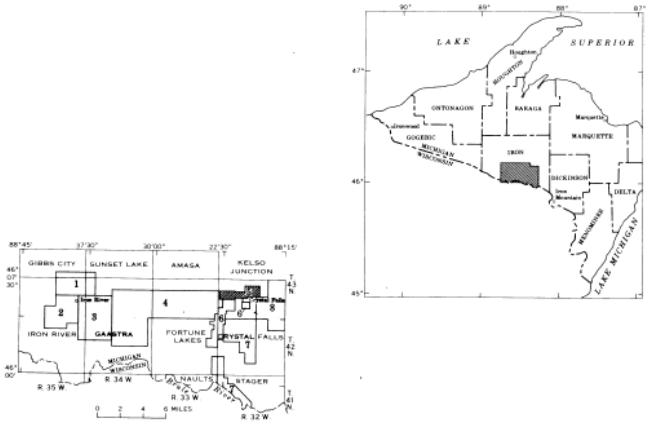

Figure 1. Location and index maps

Left: Index to work responsibility and topographic quadrangles in the Iron River-Crystal Falls District.

1. Northern Iron River Area--James, Dutton, Wier
2. Central Iron River Area--Dutton
3. Southeastern Iron River Area--James and Wier
4. Area between Iron River and Crystal Falls--James, Pettijohn, and Clark
5. Shading delineates area of this report, Northern Crystal Falls Area--Pettijohn
6. Southern Crystal Falls Area--Pettijohn
7. Alpha-Brule River and Panola Plains Areas--Pettijohn, Gair, Wier and Prinz
8. Northeastern Crystal Falls Area--Wier

Right: Shading delineates Iron River-Crystal Falls District

ABSTRACT

The Northern Crystal Falls area consists of several square miles within a 3 1/2-mile strip north of the town of Crystal Falls. Folded and upturned strata of the Animikie Series (from oldest to youngest, Dunn Creek Slate, Riverton Iron-formation, Hiawatha Graywacke, Stambaugh Formation, and Fortune Lakes Slate) occur as belts trending roughly east. Intrusive rocks are minor pegmatitic quartz veins and small bodies of metadiabase and metagabbro. Structurally, the strata lie along the northeastern apex of the Iron River-Crystal Falls synclinorium and mainly within the northern part of a large complex southwest-plunging syncline, the southern part of which has been cut off by major east-trending right lateral faults. Most of the larger ore bodies are related to synclines and are confined to the lower part of the Riverton Iron-formation. Outcrops, mine workings, exploration information, magnetic data, and test pits are shown on detailed geologic maps. Brief histories and descriptions of mines and explorations are given. From 2882 through 1968 almost 21 million tons of iron ore have been shipped from nine mines in the area.

INTRODUCTION

This report is one of the series of eight reports supplementing U.S. Geological Survey Professional Paper 570, "Geology and Ore Deposits of the Iron River-Crystal Falls District, Iron County, Michigan" (James, Dutton, Pettijohn, and Wier, 1968). This series presents data on the geology, mines, explorations, and magnetic surveys, and includes 23 detailed maps covering practically all areas of known iron-formation. The areas covered by the individual reports are outlined on fig. 1.

Information on early mining history was taken from the annual reports of the Commissioner of Mineral Statistics of the State of Michigan and from the annual reports, 1912 to 1929, of the State Geological Survey. Additional mine history and production data were taken from "Lake Superior Iron Ores" (Lake Superior Iron Ore Assoc., 1938, 1952) and from "General Statistics Covering Costs and Production of Michigan Iron Mines" (Michigan Geological Survey, 1951-68). Some of the results of the U.S. Geological Survey work in the northern Crystal Falls area appeared as a preliminary report by the author (Pettijohn, 1952).

Location

The northern Crystal Falls area is about one mile north and south, by 3½ miles east and west. Located just north of the town of Crystal Falls, the map area is more or less bisected east and west by the southeast-flowing Paint River. Report data are organized and presented in accordance with the following geographic units: Paint River (plate 3), Ravenna-Bristol (plate 1), Great Western-Hilltop (plate 1). The basic data for the area are shown on the three plates in the pocket.

Topography

Topographic relief is generally low. The lowest point, along the Paint River near the common corner of secs. 20, 21, 28, and 29, T43N, R32W, is a little less than 1,300 feet above sea level. The highest point, in the city of Crystal Falls, is a little more than 1,540 feet. On the other hand, the relief in the bedrock surface is somewhat higher--a little over 400 feet.

A highland extends from the Paint River to the southwest corner of the mapped area. East of the Paint River the high ground is broken into large but more or less isolated hills at the golf course and the Crystal Falls mine.

Superimposed on the east-west bedrock alignment of the area is the Paint River which cuts southeast roughly bisecting the area and its physiographic divisions. Briar Hill Creek, flowing east along the northern boundary of the map, is the principal tributary.

A thin layer of drift covers most of the area. Absent in the rocky uplands, it attains a considerable thickness in the lowlands--in the Runkle Lake area exceeding 250 feet. In many places it makes bedrock geologic interpretation uncertain.

Ore Shipments

Nine mines have at one time or another shipped ore from the northern Crystal Falls area. Of these, three have shipped more than one million tons. All are now inactive except the Bristol, which was reopened in 1949 and was still in operation at the time of investigation (1963), but closed in 1969. Shipments from the northern Crystal Falls area through 1969 totaled almost 21 million tons of ore.

Although ore was discovered early at the Paint River Falls or Rapids ("Crystal Falls"), little mining was done prior to completion of the Chicago and North Western Railway in 1882. Some ore was shipped every year from 1882 to 1934. When the Bristol closed in 1934, production from the area ceased until the reopening of the Bristol in 1949, except for the years 1940-43, when the Ravenna-Prickett mine was in operation.

Unit			Lithology	Thickness
Paint River Group	Fortune Lakes Slate		Mainly gray slates; some graywacke	1,500'
	Stambaugh Formation		Magnetic slate	75-100'
	Hiawatha Graywacke		Graywacke and chert breccia	10-75'
	Riverton Iron-formation		Interbedded chert and siderite; locally oxidized to banded chert and hematite; locally rich in silicates, locally magnetic	500-800'
	Dunn Creek Slate	Wauseca Pyritic Member	Laminated, pyritic, graphitic slate and slate breccia	30-50'
		Lower part	Mainly gray slate; some graywacke and siltstone	800-900'
Baraga Group	Badwater Greenstone		Fine-grained, massive, greenish-gray altered lavas, in part ellipsoidal, with a little agglomerate and tuff	

Table1. Stratigraphic column of the northern Crystal Falls area.

GEOLOGY

The data and interpretations of geology of the mines in the northern Crystal Falls area are based on studies of outcrops, test pits, and magnetic surveys, supplemented by exploratory drilling and underground workings information available from the various mining companies. Unfortunately, almost no geologic records were made of the oldest properties. The size, shape, and space relations of ore bodies, therefore, have been deduced from the sections and plans of the mine workings alone.

Stratigraphic Units

The bedrock strata can be grouped into four principal units occurring as east-trending belts. In order of age, from oldest to youngest and from north to south, these are: (1) Badwater Greenstone, (2) Dunn Creek Slate ("footwall"), (3) Riverton Iron-formation, and (4) the "hanging-wall" sequence, consisting of the Hiawatha Graywacke, the Stambaugh Formation, and the Fortune Lakes Slate (table 1).

Badwater Greenstone

The most numerous outcrops are found near the Paint River in sec. 17, T43N, R32W, just north of the map area.

The greenstones are mainly altered basaltic lavas and associated pyroclastic deposits. Most are fine-grained and massive. Less common, but by no means rare, are greenstones marked by ellipsoidal or pillow structures. Also present are agglomerates and tuffs. The latter are generally sheared, exhibiting a schistose structure. A sheared tuff in the SE¼ sec. 17 produces a strong magnetic anomaly.

The contact of the greenstones with the overlying sediments is not exposed. The boundary probably follows rather closely the limits of the greenstone outcrop area because the greenstone, where present, is prone to crop out whereas the softer overlying slates do not. The slates underlie the swampy drift-filled valley of Briar Hill Creek and its topographic extension east of the Paint River.

Observations of pillow structures in the greenstone at several scattered places show the nearly vertical flows to have their tops on the south side. Therefore, the beds decrease in age from north to south. The apparent absence of reversals of top direction indicates the greenstones are a conformable series of great thickness.

Dunn Creek Slate

Overlying the greenstone to the south is a series of beds, the Dunn Creek Slate, commonly termed the footwall slates because they are below and subjacent to the iron-bearing formation. They are almost wholly gray and black slates.

The uppermost footwall stratum, known as the Wauseca Pyritic Member, is a fissile, black, graphitic and pyritic slate known to underlie the iron-formation elsewhere in the district. Debris from this member appears on most of the mine dumps of this area and was also found in several test pits near the E¼ cor. sec. 21, T43N, R32W. Associated with the laminated graphitic slate is a massive slate breccia consisting primarily of a few random oriented chips or flakes of black slate set in a dense structureless dark-gray matrix. The fragments, forming less than 10 percent of the rock, are angular. The matrix and the fragments are pyritic although the pyrite is of such fine grain and so intimately mixed with graphitic matter that it escapes casual inspection. The high density of the rock is, however, an indication of its presence. Analyses from several places in the Bristol mine show about 18-20 percent sulfur, or, approximately 40 percent pyrite. The exact stratigraphic position of the slate breccia is not clear, though the breccia is presumed to underlie the laminated graphitic slate here as in the Iron River area. The two beds constitute the Wauseca Pyritic Member.

The slate breccia occurs in fragments on the rock pile of the Bristol mine. It has also been seen underground on the 5th and 12th levels just east of the main shaft.

Below the Wauseca Pyritic Member are gray nongraphitic slates, and locally cherty slates and some massive black graywackes.

The thickness of the footwall strata does not exceed 1,000 feet in the NE¼ sec. 20, T43N, R32W, inasmuch as this is the interval separating the greenstone from the iron-formation at that place. Elsewhere, the interval between the iron-formation and the basement greenstone is as much as half a mile, but close folding and crumpling may readily account for the greater width.

Riverton Iron-formation

The Riverton Iron-formation, unlike the footwall slates, is exposed in many places, mainly along the north-facing slopes south of Briar Hill Creek near the dam on the Paint River, and on the northern and northwestern side of the hill on which the Crystal Falls and Hilltop mines are located. Except where oxidized, the Riverton consists of alternating, one to two inch layers of laminated to slaty gray siderite and equally thin layers of dense black chert. Steeply-plunging drag folds are very abundant. Secondary cleavage is not present. In some places the carbonate layers contain, and are interbedded with, layers rich in a chlorite-like mineral, chiefly stilpnomelane. Locally these silicate-rich layers form an appreciable part of the rock.

Fresh exposures, having the appearance just described, are rare. Weathering commonly converts the siderite to limonite. The chert beds weather white or gray and become sugary and somewhat friable.

Locally, as in the vicinity of the ore bodies, the iron-formation is profoundly oxidized. The carbonates are

changed to hematite or goethite, whereas the chert assumes a light-colored paraffin-like appearance.

The limits of the iron-formation shown on the maps are not everywhere determined with the same degree of accuracy. In general, the hanging-wall contact is rather accurately mapped from data from numerous drill holes, test pits, and outcrops. The footwall contact, however, lies mainly in swampy or low ground and its position is largely hypothetical. In discussing this contact the assumption, perhaps not wholly valid, is made that the graphitic black footwall slate encountered in drilling is infolded with the iron-formation in the same manner as are the hanging-wall strata, and that there is no major interbedded black slate in the iron-formation itself.

The thickness of the iron-formation is very difficult to ascertain but cannot exceed 600 feet in the western part of the Crystal Falls area. The great variations in width of the outcrop belt are due to close and repeated folding.

Hiawatha Graywacke

The strata overlying the iron-formation are exceptionally well exposed along the course of the Paint River just south of the municipal power dam in the SE¼ sec. 20, T43N, R32W. These exposures have been mapped in detail (plate 3).

The lowest member of the hanging-wall sequence, the Hiawatha Graywacke, is in some places a coarse chert breccia, whereas in others a massive graywacke. The breccia facies is a massive, erosion-resistant rock composed of large and small, angular, slab-like pieces of chert in a graywacke matrix. The graywacke facies is a massive, structureless rock appearing, under the hand lens, as many large rounded quartz grains and a few particles of chert set in a dark-gray to black matrix. The maximum thickness of the Hiawatha Graywacke is 75 feet decreasing to a few inches in some places.

Stambaugh Formation

Overlying the basal breccia-graywacke bed is the Stambaugh Formation, a series of slate-like rocks containing enough magnetite in places to produce a very marked magnetic anomaly. The magnetic bed itself is about 75 feet thick. It is separated from the underlying breccia-graywacke by about 20 feet of nonmagnetic, waxy green slates. The magnetic unit consists of hard flinty slate rich in magnetite, and an overlying massive, blocky dark-green stilpnomelane-rich strata interbedded with white to gray chert-like porcelanites.

Fortune Lakes Slate

Conformably above the magnetic slate and associated rock of the Stambaugh Formation is the Fortune Lakes Slate, mostly gray clay slates interlaminated with siltstones; higher in the section these slates and siltstones are interbedded with coarse, massive graywacke.

Igneous Rocks

A few one-to eight-inch microcline-bearing quartz veins cut the hanging-wall strata along the Paint River. A large dike of much altered basic rock -- probably originally a gabbro -- is exposed at the east end of the Paint River-Lamont cave. Drilling in the old Ravenna mine area disclosed a "greenstone" intrusive that may be a similar rock body.

Structure

The strata of the area have been steeply upturned. They crop out, therefore, in long narrow belts, which in this area have an east-northeast trend, with the oldest beds at the north and the youngest south. Although the trend of the formations is slightly south of west, the measured strikes are predominantly west-northwest. The magnetic crest lines also trend west-northwest. These anomalous relations are apparently due to superimposition of a series of minor folds, the axial planes of which trend west-northwest upon the regional trend. Further results of secondary folding are the pronounced zigzag course of the formation boundaries and the somewhat en echelon arrangement of the magnetic crest lines.

Most of the minor folds plunge east-southeast at a low angle, but locally the direction of plunge is reversed. These closely-spaced second-order folds (100-200 feet apart) produce a great expansion in the width of the outcrop belt in some places. Most notable is the general increase in width of the outcrop of the Riverton Iron-formation from west to east. In the SW¼ sec. 19, T43N, R32W, the formation has an outcrop width of 500-600 feet (plate 1), whereas near the center of sec. 21, the width is over 2,000 feet. Some direct evidence indicates the greatly expanded area of iron-formation in the E½ sec. 21 is the apex area of a syncline plunging west or southwest. Strikes seen in outcrops show a swing from east-west in the area northwest of the Crystal Falls mine, to northwest in the mine cave itself, to northeast near the E½ corner of the section. In the same areas, the dip changes from southward to southwestward to northwestward. This pattern of strikes and dips suggests a synclinal fold having a southwesterly plunge. This concept of structure is confirmed by the southwest-plunge of the ore body in the Crystal Falls mine. The general course of the footwall contact and the trend of the magnetic anomaly associated with the iron-formation in this area further support this idea.

South of the belt of iron-formation, particularly in the southern part of secs. 20 and 21, the post-Riverton strata are involved in a complex sequence of folds plunging southeastward (though with many local reversals of plunge direction). These strata, including the magnetic Stambaugh Formation, are truncated by two major right lateral faults, the Cayia and the Runkle Lake, where the strata on the south sides are displaced to the west. Viewed broadly, the Runkle Lake and Cayia faults isolate the north half of a major syncline, which,

despite the local southeasterly plunge of minor folds, has a general westerly or southwesterly plunge.

PAINT RIVER AREA

The outcrops along the Paint River between the municipal power plant of Crystal Falls and Michigan State Highway 69 are some of the most informative in the Iron River-Crystal Falls district, and on plate 3 are shown at a scale of 250 feet to-the-inch. The best exposure of the Riverton Iron-formation in the county is just below the power dam. In the next half mile downstream the strata overlying the iron-formation are exposed in rocky bluffs and knobs. The latter sequence of beds, the "hanging-wall strata", are better shown here than elsewhere. The standard section established from these outcrops is applicable to much of the Iron River-Crystal Falls district.

Chert breccias, found to mark a significant unconformity in this district, are best exposed in the Paint River outcrop area, also the only known site where contact of breccia with iron-formation outcrops.

The magnetic slate - also a significant marker bed - is well displayed here. Because of the abundance of outcrops, the relation between magnetic anomalies produced by the slates and the structure and lithology of the bedrock is clearly seen.

The Paint River outcrop area is characterized by a group of rocky knobs and bluffs adjacent to the Paint River. The rocky area begins at the municipal power dam and extends downstream to the crossing of Highway M-69. Although the topographic relief is only 150 feet, the area close to the river is very rough. On the west side of the river, between the stream and the railroad, a small-scale "scabland" is characterized by isolated rock knobs, rock-rimmed basins, and abandoned river channels. Largest of the isolated rock hills is on the south line of section 20. This hill, over 40 feet high, is separated from the higher ground farther west by a channel some 200 feet wide and 1,000 feet long.

This complex of knobs, basins, and channels was probably caused by a former river system having a much greater water volume than now. This glacial melt-water system superimposed on the bedrock of the area, scoured out the network of channels and isolated knobs. After the glacial ice melted away, the flow was greatly diminished and the many old channels were abandoned.

Stratigraphy

The sequence and essential features of the strata exposed along the Paint River are summarized in table 2.

Dunn Creek Slate

The rock exposed in the east bluff along the Paint River in NW¼ NW¼ sec. 28, T43N, R32W, is mostly laminated silty gray to black slate. Believed to be pre-Riverton, although good evidence is lacking within the Paint River outcrop area proper to establish relative ages, because the slate is in fault contact with Fortune Lakes Slate on the east bluff just north of the northwest corner sec. 28. Outcrops and test pits south of the mapped area, indicate similar rock continues along the Paint River beyond the south edge of the section.

Riverton Iron-formation

The iron-formation is the most extensive formation within the mapped area. It is best exposed along the river, especially just below the dam. Excellent exposures also occur in the abandoned railway cuts near the E½ corner sec. 20.

The unoxidized iron-formation consists principally of thin layers of dense black chert and light-gray to greenish-gray siderite. The beds are ½-4 inches thick and almost everywhere are crumpled or contorted. The chert is dense, black, and has a marked conchoidal fracture. Upon weathering, the chert becomes granular and white. The carbonate is commonly thinly laminated, apparently because of different proportions of a greenish chloritic material – probably stilpnomelane. The stilpnomelane forms layers ranging in thickness from about 1/100" to ½" thick. The more thinly-laminated carbonate has a parting parallel to the bedding and is commonly described as "slaty carbonate". The thicker carbonate beds tend to be blocky, owing to close-set jointing and absence of well-defined cleavage. Fresh carbonate is difficult to obtain except in deep artificial cuts or in freshly-scoured outcrops along the river. Both the slaty and the blocky carbonate weather very easily. The latter is oxidized along joints forming a brownish-black limonite crust which protects the unaltered interior. The result is a boxwork of fresh carbonate separated from the hard limonite shell by a thin mustard-yellow zone.

Unit	Description	Thickness	Formation
Graywacke	Interbedded thick layers of massive black graywacke and clay slates.	50'	Fortune Lake Slate
Gray slate	Fissile, thinly-laminated light- and dark gray sericitic slates.	200-300'	
Green mudstone and porcelanite	Mudstones with rude irregular fracture and porcelanite interbeds. Mudstones, greenish black, weathering to olive drab, with blackened submetallic tarnish on subsurface and along fractures. Highly refractive folia visible under hand lens. Porcelanites in hard compact beds, 2-14" thick; exceedingly tough. Armored with dense black hard limonite shell. Unaltered core of cream to gray, laminated flint-like rock. Without cleavage; fracture conchoidal. Harder than	35'	Stambaugh Formation

	knife; effervesces in hot HCl. Gray porcelanite is magnetic. Thin pyrite layers common below porcelanite layers.		
Magnetic slate	Very hard flinty slate with pronounced platy cleavage parallel to bedding; thinly laminated. Weathers iron-gray. Highly magnetic. Some thin porcelanite seams near top.	40’	
Green slate	Fissile, thinly-laminated gray slate. Weathers brownish green and yellow. Oxidizes near ore to soft pink and yellow slate. Nonmagnetic.	20’	
Graywacke	Compact, massive. Fresh rock is black with conspicuous vitreous quartz sand grains. Numerous small flecks of detrital cert. Locally has rude schistosity. Weathers brown. Grades down into, and is interbedded with, or grades laterally into chert breccia.	0-70’	Hiawatha Graywacke
Chert breccias	Complementary to graywacke member. Varies from very coarse breccia composed of large chert slabs with subordinate matrix to very fine breccia with small pieces of angular chert scattered throughout a dominant graywacke matrix containing large glassy quartz grains. Massive.	0-70’	
Total (hanging-wall strata only)		415-450’	
Iron-formation	Well-bedded. Consists of equal parts of laminated gray siderite in ½-2” layers, and dense black chert beds of similar thickness. On outcrop, chert weathers to semi-friable white sugary beds; siderite oxidizes to brown to mustard-yellow limonite. Commonly much crumpled. Some “chlorite”-rich seams interbedded with carbonate. Oxidizes to red hematite and white chert (“salt pork”) or to dense limonite and chert.		Riverton Iron-formation
Slate	Exposed only in river bluff in NW¼ NW¼ section 28. Laminated silty gray and black slate with some black graphitic pyritic slate.		Dunn Creek Slate

Table 2. Stratigraphic description of beds exposed in the Paint River outcrop area.

The more deeply-weathered outcrops of iron-formation disintegrate into loose pieces of sugary, iron-stained chert and to small brown to mustard-yellow chips resembling flaky pieces of pine bark.

In places alteration of the iron-formation differs greatly from that described above. The chert becomes bleached and paraffin hematite (or more rarely to a dense, metallic yellow-brown limonite) – a type of alteration apparently found only in association with the ores and, unlike that associated with the surface weathering, extends to great depths. The altered iron-formation, consisting of alternate layers of red hematite and white chert, resembles salt pork.

Drag folds of all sizes mark the iron-formation. Indeed, outcrops of any appreciable size in which the beds are not crumpled are rare. In some instances the crumpling is so intense, obtaining even a general value for strike and dip is difficult. The folding is, in the main, of the concentric type. The broad concentric arcs pass into sharp chevron folds along the axial plane. Most of the drag folds plunge in an easterly direction but reversals are common. The angle of plunge generally is at least 50°.

The internal structures characteristic of the iron-formation are superbly shown by the large outcrop below the municipal power dam. The detailed structures of this outcrop, mapped on a scale of 10 feet per inch, are shown on fig. 2. The principal element of the structure is a complex drag fold plunging westward at about 70°. Its complexity to the east contrasts strongly with its extremely simple form at the west edge of the outcrop. Minor folding along northward-plunging axes is also evident but subordinate. Numerous faults are clearly defined but the displacement small. The faults commonly branch, one passing into a bedding-plane slip, the other maintaining the fault line.

The relations between the iron-formation and the subjacent beds are not shown in this area. On the west side of the Paint River, between the power house and the road bridge southeast, is some much-sheared graphitic slate of uncertain age, possibly the Dunn Creek Slate.

The contact of the Riverton Iron-formation with the overlying beds is well displayed on the east side of the Paint River about 600-700 feet downstream from the road bridge; the relations are described in the next section.

Hiawatha Graywacke

Overlying the iron-formation and prominently exposed along the Paint River is the Hiawatha Graywacke, which consists of two distinct facies, chert breccia and massive graywacke; either may occur alone, or they may occur interbedded with one another, or one may grade into the other.

The breccia facies is a massive, erosion-resistant unit which, in its thicker parts, crops out as prominent bare knobs or ridges. Typically it consists of a jumble of chert slabs. The fragments are tabular and range in length from 1-2 inches to 20-30 inches, and in thickness, ½ to 2 inches. In the coarser breccias the chert fragments average from 3 to 6 inches in length. The tabular

fragments are subparallel, probably the way they were deposited. In general they are angular and only rarely exhibit rounding. The matrix is a dark-brown, somewhat oxidized material of uncertain character. Elsewhere, drill core shows it to be mainly graywacke. Locally the breccia is heavily sheared, exhibiting a very rude irregular cleavage. The chert fragments tend to assume rough rod-like forms, elongate parallel to the plunge of other structural features.

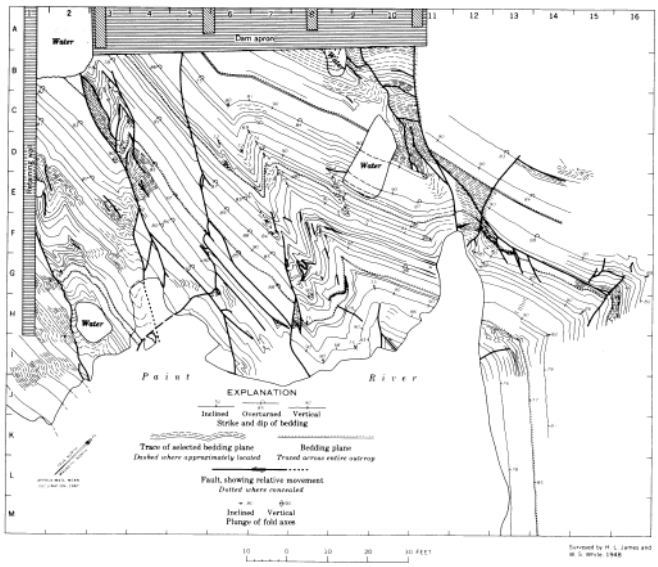

Figure 2. Structural map of iron-formation outcrop at Paint River dam (Pettijohn, 1952, pl 13).

The chert breccia grades into graywacke, and several transitional types can be seen in the field. One consists of many small, tabular chert fragments 1-2 inches, or less, in length, and ¼-½ inch thick – sprinkled liberally throughout a graywacke matrix. Matrix and fragments may occur in equal proportions, though commonly the rock is chiefly graywacke containing scattered fragments of chert. In general the flat fragments are subparallel.

In other outcrops, beds of coarse chert breccia, 5-10 feet thick, alternate with graywacke containing little or no chert. In at least one place coarse breccia seems to grade upward into breccia with small fragments and then into graywacke with few or no chert fragments.

The graywacke is black on fresh exposure; the weathered surface is a light brownish gray. The unsheared outcrops are massive, with widely-spaced joints. No bedding-plane fissility can be detected. The rock, therefore, breaks into large angular blocks. Some exposures, however, are so sheared that the rock has a rude, nearly vertical parting, analogous to the slaty cleavage of the finer-grained rocks. Close scrutiny of nearly all the graywacke will lead to detection of a few very small and widely-scattered particles of chert. In a few exposures a single large slab of chert may appear in the middle of massive graywacke.

Locally, the graywacke has some interbedded slate and even a little interbedded bluish-gray chert, in layers 2-6 inches thick.

The breccia-graywacke bed commonly is only 10-15 feet thick and locally may be even less. The maximum thickness is probably not over 50-75 feet. The apparent greater thickness in some places is probably due to twofold or even threefold repetition of the bed.

The contact of the breccia-graywacke bed with the underlying iron-formation is very sharp. It is exceptionally well displayed in the cliff on the east bluff of the Paint River about 600 feet below the road bridge. The breccia here is very coarse and the lower few feet consists of very large and little-disturbed slabs of chert. Though superficially resembling and resting directly upon the iron-formation, the contact is evident. The basal phase grades upward into normal coarse chert breccia. In other places the lowest bed appears to be normal graywacke with little or no breccia at the contact.

The breccias are mentioned but briefly in several older reports. Clements (Clements and Smyth, 1899, p. 166) says:

> "Near Crystal Falls on both banks of the river, between the wagon and railroad bridges, there is exposed a conglomeratic phase of graywacke. Several bands of these coarse conglomeratic graywackes are interlaminated with bands of fine-grained graywacke and chert. A well-developed chert reibungs-breccia is also associated with these. I do not consider this conglomeratic graywacke as representing anything more than a purely local and very slight unconformity."

From the relations shown along the Paint River and described above, apparently the chert breccia and the graywacke are but the two "end members" of a sedimentary unit marking a widespread and significant unconformity. No gradation of breccia into an unbroken interbedding of chert and graywacke was found. Even the iron-formation with its thin sharply-folded chert bands is mainly unbrecciated. The evidence conclusively indicates the chert breccia is sedimentary rather than tectonic.

The breccia is, therefore, a basal deposit, essentially a rubble derived from the underlying iron-formation. The chert rubble is analogous to the basal conglomerates commonly the initial deposits of marine transgression. A similar deposit of much younger age is well exposed in several places in northern Michigan where the Cambrian sandstone rests on the Precambrian iron-formation: tongues of breccia interbedded with and grading into sandstone, and, the characteristic mingling of locally derived coarse, angular chert with fine, far-transported, well-rounded sand.

Observations made elsewhere in Iron County have confirmed the conclusions drawn from the study of the Paint River outcrops. The chert breccia and associated graywacke is widespread and forms an important marker bed – the Hiawatha Graywacke. The unconformity on which they rest is, therefore, widespread. Possibly the local relief on this surface is great enough to cut out the

entire iron-formation. This possibility must be considered in exploration for iron ore.

Stambaugh Formation

The Stambaugh Formation consists of three lithologic units: green slate (lowest), magnetic slate, and stilpnomelane mudstone.

The green slate resting on the chert breccia graywacke unit is not well exposed. Some of the better exposures are in the small syncline west of the Paint River and about 500-600 feet south of the road bridge. The slate is waxy, greenish yellow, delicately laminated, fissile, and (unlike the overlying beds) nonmagnetic. Thickness does not exceed 20 feet.

The magnetic slate is best exposed in the northward-facing bluff west of the Paint River and east of the railroad track in about the middle of the SW¼ SE¼ sec. 20. The rock is very hard and platy; a good bedding plane yields flat sharp-edged pieces. It is iron gray, thinly laminated, and contains much magnetite visible to the unaided eye. Also highly magnetic, it is responsible for the principal magnetic anomalies of the Iron River-Crystal Falls district. The slaty facies is about 40 feet thick. In the upper part of this magnetic slate are porcelanite seams 2-3 inches thick. The upper part of the slate is not so platy and has a greenish cast. This facies is probably transitional to the next overlying beds.

Overlying the magnetic slate are inter-bedded greenish mudstone and porcelanite. The porcelanite, which occurs in beds 2-14 inches thick, is a dense rock exceedingly hard to break with a hammer. In outcrop it is marked by a hard black limonitic crust, beneath which is a chert-like greenish-gray to creamy-white porcelanite. Though delicately laminated, the fracture is conchoidal. The flakes produced by breaking are razor sharp. The rock is too hard to be scratched by a knife but effervesces nonetheless in hot HCl. The gray, laminated varieties are magnetic. The hard limonitic crust is separated from the unaltered porcelanite by a thin, soft, yellowish-ochre layer.

Associated with the porcelanites are "mudstone" rocks. In outcrop they have a, marked blackened appearance, commonly with a somewhat iridescent submetallic tarnish. The fresh surface is olive drab; the powder is khaki brown. The mudstones in the Paint River area have a rude irregular schistosity and break into irregular flakes upon hammering. Under the hand lens the fresh surface sparkles from minute scales of a highly refractive mineral determined to be stilpnomelane. In some places these greenish mudstones are notably magnetic.

The porcelanite seams within the stilpnomelane mudstone member are commonly underlain by a 1/8- to 1/2-inch bed of pyrite. This relationship has proved useful elsewhere in determining the order of superposition. A rough estimate in the Paint River section shows the porcelanite to be one-tenth to one-fifth the total thickness of this member. The mud-stone bed itself is probably about 35 feet thick.

Fortune Lakes Slate

The Fortune Lakes Slate in this area consists of a basal gray slate and an overlying graywacke.

The gray slate unit consists of thinly-laminated dark-gray clay slate and lighter gray siltstone. The laminations are 1/8 to 1 inch thick. The rock is fissile and splits without difficulty into large thin sheets. The slaty cleavage is usually parallel to the bedding. The cleavage surface has a sheen (almost silky in places) which in the correct illumination, shows faint striations – probably near-microscopic crinkling. Because of close folding, thickness of the unit is difficult to estimate, but probably is not over 200 feet, and may not exceed 100 feet in the map area.

The highest unit exposed in the Paint River section is chiefly graywacke. Outcrops of this bed occur west of the river in the northeastern part of sec. 29. The rock exposed is a badly-sheared graywacke closely resembling graywacke associated with the chert breccias. No breccia, however, was found with these graywackes. The occurrence of the graywackes with the gray slates, and the position of the graywackes in the section indicates they are probably superposed on the gray slates and therefore, the youngest exposed strata in the map area. The thickness in the area of outcrop is probably not over 100 feet.

Intrusive Igneous Rocks

Two type of crosscutting rocks are present in the northern Crystal Falls area: (1) pegmatitic quartz veins and (2) metagabbro.

The pegmatitic quartz veins are all rather small, mostly 1-2 inches wide, though one or two were 12-18 inches thick. Nearly flat, they appear to fill tension cracks in "pencil" or "split wood" slates. The best examples are the five or six rather large flat veins exposed on the east bank of the Paint River in Lot 5 (plate 3). Primarily white vein quartz, they contain 10-20 percent salmon-pink potassium feldspar. The veins tend to pinch out laterally, and at most are traceable only a few yards. In some of the small veins the quartz is columnar, normal to the vein walls.

A dikelike body of basic rock some 50-60 feet thick is exposed in the caved area of the Paint River mine and in a nearby test pit. A soft gray rock, it breaks into large irregular blocks. Although the original minerals are wholly altered, the original coarse and gabbroic texture is rather well retained. The dike is evidently the same one mentioned by Clements (Clements and Smyth, 1899, p. 183).

Structure

The structure of the Paint River outcrop area is characterized by a series of close folds with generally low easterly plunge. Between the road bridge and the south line of sec. 20 are four anticlines and four

synclines. Inasmuch as the distance involved is only a little more than 2,000 feet, the average distance from the crest of one anticline to the trough of the adjacent syncline is only about 250 feet.

In the area south of the road bridge, the minor drag folds, the minute crinkling in the slate (striations on cleavage surfaces), and the rod-like elongation of the fragments in the chert breccias all plunge to the east. Though these minor features have plunges of 25°-75°, the pattern indicates the general plunge of the folds must be less, and in some places westward.

The slates all have a prominent slaty axial-plane cleavage. Because of the general steep dip of the strata, the cleavage is nearly parallel to the bedding except in the apical parts of the folds. In these apexes, the cleavage and bedding are nearly perpendicular to each other, and this relationship causes the rock to break into "pencils" or larger fragments resembling split wood. Quartz-filled tension fractures normal to the pencils are common in these places.

Though the strata are closely folded and locally much sheared, no important faults are known except two near the south margin of the map area. The northern fault trends approximately N 70° E and crosses the Paint River near the southeast corner of sec. 20. Extending eastward to Runkle Lake, this fault is referred to as the Runkle Lake fault. The second major fault, shown near the south edge of the Paint River outcrop (plate 3) is presumed to extend eastward to the Cayia mine and is termed the Cayia fault.

The Runkle Lake fault is exposed in the east bluff of the Paint River, less than 100 feet north of the south line of sec. 21. At this exposure, heavily-sheared graphitic foot-wall slate (Dunn Creek) is in contact with sheared graywacke of the Fortune Lakes Slate. Though the prevailing strike in the area is N 70° W, beds west of the river and just north of the fault have a northeasterly strike. This anomalous strike near the fault is apparently a drag effect indicating a northeastward movement of the north wall of the fault.

The Cayia fault is demonstrated only by evidence found outside the area of the map sheet. In the Crystal Falls district proper, it is indicated only by anomalous strikes caused by drag in the vicinity of the fault. The easterly bend, and apparent termination, of the altered granite dike found on the west side of the Paint River in the NW¼ NW¼ sec. 28, T43N, R32W (plate 1, U.S. Geol. Survey Prof. Paper 570), is attributed to movement and offset along the Cayia fault.

Magnetic anomalies

Two very pronounced magnetic anomalies characterize the Paint River outcrop area and adjacent parts of secs. 20 and 21 (plate 2). The principal anomaly extends entirely across the S½ sec. 20. A related anomaly lies north of the Paint River, mainly in the SE¼ SE¼ sec. 20 and the SW¼ SW¼ sec. 21.

These anomalies were mapped with a Hotchkiss Superdip oriented in a vertical plane normal to the magnetic meridian. The angle between the gravitational and magnetic arms (sigma) was set at 2°. The first downswing, the first backswing doubled, and the second downswing were averaged. The readings thus obtained were corrected for temperature and diurnal changes. The differences between the temperature- and base-corrected readings and the mean value of a local base station were then plotted and contoured (plate 2). The stations occupied were spaced 100 feet apart on north-south traverses 200 feet apart. Points were located by pacing from stakes set at 200-foot intervals along an east-west base line. Errors of position probably do not exceed 50 feet.

As used, the Superdip measures departure from normal of the vertical intensity of the earth's magnetic field. For the lower readings each scale division was found to correspond to about 35 gammas. Inasmuch as a simple linear relation between the gamma values and scale divisions does not hold for the higher readings, the total magnetic relief of the area is not known, but is probably well above 5,000 gammas.

One of the most obvious features of the magnetic map is the parallelism of the iso-anomaly contours and the strike of the rocks, especially south and west of the Paint River. The general trend of the magnetic contours is about N 70°-80° W, about the average strike of the beds west of the river.

The anomaly in the overlap area between plates 2 and 3 is clearly due to the magnetic slate and associated magnetic stilpnomelane mudstones and porcelanites of the Stambaugh Formation. The combined thickness of these beds, however, is only about 75 feet. Where the anomaly is located over the vertical-standing magnetic strata, it is about 100 feet wide. This relationship is best shown on the west side of the Paint River near the west edge of the SE¼ SE¼ sec. 20.

In the area farther west, especially in the SE¼ SW¼ sec. 20, the anomaly is about 1,200-1,300 feet wide. Nearly any traverse across this area will show several magnetic crests, commonly three. The great width and the appearance of several crests suggest either several magnetic beds or one magnetic bed repeated by folding or faulting.

Repetition by folding is almost certainly the correct explanation of the wide anomaly. This interpretation is consistent with the close-folded nature of the structure disclosed by detailed mapping of the chert breccia-graywacke bed along the river. Furthermore, outcrops along the river reveal only one magnetic bed. The overall pattern of the anomaly west of the Paint River is a bed of close eastward-plunging folds. In fact the cardinal principle in interpreting magnetic anomalies of most folded rocks of this district is reading the magnetic anomalies the same way a geologic map is read. The anomalies are centered over the concealed (or exposed)

bedrock "outcrop" of the stratum responsible for the anomaly.

The magnetic anomaly north and east of the river is more complex and less easy to interpret. The long, somewhat "spotty" anomaly extending eastward from the river along the north edge of the SE¼ SE¼ of section 20 is closely related to the syncline involving Stambaugh Formation. Apparently this structure is deeper in some places than others. These deeper "spoonlike" structures contain magnetic slate of the Stambaugh Formation over which the anomaly reaches a higher value than elsewhere. The broad, double-crested anomaly in the golf course in the SW¼ SW¼ of section 21 is related both to a southeast-plunging anticline involving the magnetic slate and to the belt of magnetic formation terminating against the Runkle Lake fault.

Areas markedly lower in magnetic intensity are present just north of the higher positive anomalies. These lower "negative" anomalies north of the "highs" characterize this area as well as other areas in the vicinity of Crystal Falls. Also noteworthy is the larger irregular negative area just off the noses of the eastward-plunging folds of magnetic slate in the SW¼ SW¼ sec. 20. In the southeastern part of sec. 20, however, where the Stambaugh Formation is carried beneath younger strata, the magnetic anomaly continues as a weaker positive feature. A magnetically negative area at the turn of a plunging syncline, and a magnetically positive area over the nose of a plunging anticline are produced by folded beds.

Mines

The Lamont (Monitor), Paint River, and Fairbanks mines are within the Paint River map area (plate 3) and are here described. Also described in this section are the Lot 3 No. 1 mine, part of which is a short distance west of the mapped outcrop area; and the Acme exploration, adjacent to the outcrop area on the north, in the SE¼ NE¼ sec. 20.

Lamont (Monitor)

The Lamont, or Monitor mine as it was first named, is located in Lot 6 in the NW¼ SE¼ sec. 20, T43N, R32W. Work probably was begun in about 1888 by the Monitor Iron Mining Co. inasmuch as some 12,348 tons of ore was shipped the following year. In 1892 the property changed hands and became the Lamont mine owned and operated by the Lamont Iron Co. Shipments stopped in 1894 but were resumed in 1899 – apparently by Corrigan, McKinney and Co. Except for 1901 when a new shaft was sunk, production was uninterrupted from 1899 to 1907. By 1910 the lease had been surrendered and the mine dismantled.

In 1907 the underground workings were quite extensive. The principal shaft reached a depth of nearly 1,000 feet. Altogether 14 levels were extended from the shaft, the lowest at a depth of about 1,040 feet. Shipments totaled 558,524 tons. The ore was a soft, brown, non-Bessemer hematite.

The first shaft was located in the NW¼ sec. 20 (now caved ground) and ore was mined from this shaft down to about the 4th level. Below the 4th level, the mining was from a new shaft located north of the present pit. Although these workings connected with those from the Paint River shaft in the NE¼ SE¼ sec. 20, all mined ore was from the west end of the operation.

The Lamont ore body was a westward extension of the west workings of the Paint River mine, for which virtually no records are available. On the Lamont property the ore body reached its maximum dimensions at about the 9th level, where it was a pod-like mass 350 feet long and 200 feet wide. The pod appears to have plunged almost vertically from the western part of the present caved ground. Below the 9th level, the pod was increasingly restricted in size, and no ore was found at the 14th level. The mine is along the projected axis of a syncline known from the occurrence of Hiawatha Graywacke to the west, but the form of the ore body apparently does not reflect this structure.

Paint River

The Paint River mine is located in the NE¼ SE¼ sec. 20; it was actually two separate operations on the Paint River property, even though both have been referred to at various times as one mine. The first of these mines, opened in 1882 by the Paint River Iron Co., is in the west end of the Fairbanks ore body which straddles the east line of the property in secs. 20 and 21. The second mine, opened in 1885, is in the east end of the Lamont ore body, and lies across the west line of the property. Eventually the Paint River and adjoining Lamont operations were placed under one management. Most of the ore produced from the Paint River property came from the Lamont ore body. Mining ceased in 1892, but resumed in 1900. Ore from the Paint River property was regularly produced from 1902 to 1907, when it was operated jointly with the Lamont by Corrigan, McKinney and Co. In 1907 the mine was closed permanently.

Although a total of 382,078 tons is credited to the Paint River mine, a small part, about 33,000 tons, came from the Fairbanks ore body. In all, however, the Lamont-Paint River ore body yielded over 900,000 tons. Presumably the ore terminated in depth against the meta-diabase dike now exposed in the east end of the caved ground. The dike strikes northwestward and dips to the southwest. It was referred to by Clements (Clements and Smyth, 1899, p. 183) as follows:

> "In the field notes of the Lake Superior survey for 1891, I find the statement made that 'the strata of the ore formation, which here strikes nearly east and west, is cut by an eruptive dike which runs about northwest and southeast. This dike hades to the west, and forms with the hanging slates of the ore formation, a trough pitching to the west, at a very steep angle. In this trough is situated the

ore body upon which the Paint River and the Monitor mines are working.' This ore body is stated to be about 100 feet wide, 300 feet long, and of unknown depth."

Fairbanks (Lincoln)

The Fairbanks mine is located in the NE¼ SE¼ sec. 20 and the NW¼ SW¼ sec. 21. This property was originally owned and operated by the Crystal Falls Mining Co. The line between secs. 20 and 21 bisects the mined area. The property west of the line in sec. 20 belonged to the Paint River Mining Co., and was opened on four levels from a shaft in the NE¼ SE¼ sec. 20; the lowest level was at a depth of 453 feet. Ore was mined from an east-trending tabular body located a short distance south of the shaft. At the 2nd level the ore body was about 350 feet long and had a maximum width of 100 feet. Only a small tonnage, believed to be about 33,000 tons, was mined before the mine was closed because of general economic conditions at the time. The operations east of the line, in sec. 21, consisted originally of an opencut about 150 feet long east and west, 40 feet wide, and 50 feet deep. Some 8,121 tons of ore shipped in 1882, together with the estimated 30,000 tons noted above, is included with shipments from the Paint River mine.

On the same property is an extension of the Great Western ore body (plate 1) worked as a separate operation. Its development was begun in 1883 by the Crystal Falls Mining Co.

In 1891 the holdings of the Crystal Falls Mining Co. were taken over by the Lincoln Mining Co. Work was resumed on the extension of the Great Western ore body and the mine was known as the Lincoln mine. This work proved successful, with shipments made from 1891 to 1893. After 36,589 tons were shipped the mine was idle until 1899 when it was operated jointly with the Great Western by Corrigan, McKinney and Co. Shipments were made regularly from 1899-1907; the last reported shipment was in 1909. In all, 241,627 tons are credited to the Lincoln property.

The geology of the Lincoln mine is discussed under the section dealing with the Great Western mine of which it became an integral part.

Lot 3 (Crystal Falls)

The Lot 3 mine is in Lot 3, sec. 20, T43N, R32W, an area of 53 acres bounded on the northeast by the Paint River. This property, one of the oldest in the Crystal Falls district, was operated jointly by the Crystal Falls Iron Mining Co. and the Youngstown Iron Mining Co. In some of the earliest reports it was referred to as the "Crystal Falls mine" though this name was later applied to a different property located in the SE¼ NE¼ sec. 21, T43N, R32W.

Crystal Falls, also known as the Paint River Falls or Rapids, is near the center of sec. 20. At the lower end of this rapids, on the right bank (downstream), is an outcrop of lean ore said to have been noted by early land surveyors. At this place, near the bank of the stream and about 150 feet due south of the present municipal power plant, a shaft (Lot 3, No. 1) was sunk to a depth of 125 feet. This shaft was abandoned in 1882, though 1,341 tons of ore had been shipped. Drilling a short distance southwest of the Paint River is said to have disclosed additional ore. A shaft was sunk in this area and underground workings were developed. Although a considerable dump is located at the site of the old shaft, ore shipments are not recorded.

The No. 2 shaft lies about 830 feet S 80° W of the No. 1 shaft. This shaft is about 455 feet deep. Four levels were opened, of which the 4th was the most extensive. The shaft was started in "black slate". At 45 feet it passed into lean iron-formation. Available analyses show some ore in the workings, but the quantity does not seem to be large. The No. 2 shaft is located near the top of the iron-formation, 200 feet north of the Paint River magnetic anomaly (plate 2). Very little is known of the geology of the Lot 3 mine. The beds probably strike a little south of east and dip southward.

Explorations Town

43 North, Range 32 West

SECTION 20

The Acme exploration is situated in the SE¼ NE¼ sec. 20. Test pitting was undertaken just north of the railroad tracks by the Acme Mining Co. in 1882. At a later time, 12 vertical holes were drilled in the south half of this "forty" (plate 1, U.S. Geol. Survey Prof. Paper 570). They are variously described as cutting cherty iron-formation, pyritic iron carbonate, cherty iron carbonate slate, oxidized cherty iron carbonate slate, or iron-formation. Apparently the iron-formation, partly oxidized, is present. The date of the drilling and names of the driller and of the company for whom the work was done are unknown.

Conclusions

None of the ore bodies in the Paint River area constituted as much as a million tons. All seem to have been near the hanging-wall contact of the iron-formation. Inasmuch as most of the larger ore bodies of the Crystal Falls area lie in the lower third of the iron-formation, probably the lower part of the formation between the Bristol-Youngstown and the Lincoln-Great Western mines has not been fully explored. The fact that the footwall contact has not been located in most of this area demonstrates exploration has not been adequate. The generally favorable structure indicates large ore bodies of the Bristol type may occur.

RAVENNA-BRISTOL AREA

The Ravenna-Bristol map area (plate 1) includes the S½ sec. 19 and the N½ N½ sec. 30, T43N, R32W, and the E½ SE¼ sec. 24, T43N, R33W. The bedrock of this area is rather poorly exposed and the geology of much of it, therefore, is known only from mining and exploratory drilling. Where such exploration is lacking, the geology is very poorly known.

Stratigraphy

Insofar as can be determined from available data, the stratigraphic sequence in this tract is similar to elsewhere in the northern Crystal Falls area. The footwall slate (Dunn Creek) is overlain by the Riverton Iron-formation which, in turn, is overlain by the hanging-wall sequence of Hiawatha Graywacke, Stambaugh Formation, and Fortune Lakes Slate.

The footwall slate is exposed only on the northern side of the Bristol Cave, but this unit probably underlies much of the low ground traversed by Briar Hill Creek. As found in drilling, the rock is black, graphitic, and pyritic.

The iron-formation is exposed in the caved area at the Bristol mine and also on the northwestern side of Briar Hill just southwest of the Bristol mine. The best outcrops, along the old railroad grades, are the normal unoxidized formation consisting of crumpled thin-bedded siderite and chert. Two small outcrops of iron-formation occur in the SW¼ SW¼ sec. 19, just south of the Ravenna-Prickett mine.

The Hiawatha Graywacke and Stambaugh Formation are not exposed in outcrop, but the presence of the latter unit is shown by strong magnetic anomalies. The Fortune Lakes Slate is exposed in many places, outcrops being most abundant in the southwestern part of the map area, particularly in the NW¼ NW¼ sec. 30. The exposed strata consist mainly of graywacke and slate; the slate shows well-developed cleavage which, over much of this area, is at a high angle to bedding.

Structure

The structure of the Ravenna-Bristol area is very poorly known. In a general way the formations run east-west and decrease in age from north to south. The iron-formation extends from the west edge of the mapped area, where it was encountered in a test pit through the Ravenna-Prickett and the Ravenna mines to the Bristol mine.

The formation is involved in close folding and faulting at the Bristol mine and in the old Ravenna property. The principal fold at the Bristol is an anticline of footwall graphitic slate (Dunn Creek) extending across the Ravenna property north of the No. 1 shaft eastward to the No. 1 shaft of the Bristol mine. The north syncline involves only the iron-formation, whereas the downfold adjacent to the south is much deeper and includes Hiawatha Graywacke.

On the 250-foot level of the old Ravenna mine, the strike of the beds is mainly parallel to the northeastward-trending drift between the main workings and the No. 1 shaft. In the main workings the strike is about N 50° W and parallel to the magnetic high south of the mine. The discordance in strike between the areas northeast and south of the ore body suggests a possible fault separating the two areas.

Three large faults are presumed to be present in the map area based mainly on evidence to the east or west. The north fault, extended east from the Fortune Lake mine, is believed to lie virtually at the Riverton-Dunn Creek contact in the NE¼ SE¼ sec. 24, and to truncate this contact on the north side of the Ravenna-Prickett workings. The two faults to the south, the Cayia and South Kimball faults, are westward extensions of major breaks known or inferred to be present farther to the east.

Magnetic Anomalies

The magnetic anomalies in the Ravenna-Bristol map area were mapped by means of a Hotchkiss Superdip. The instrument was set to swing in the plane of the magnetic meridian. The angle between the gravitational and the magnetic arms was set at 10½° ("sigma" 3½°). The first downswing, the first backswing doubled, and the second downswing were averaged; and these values were corrected for temperature and diurnal variations. The differences between the corrected values and the values at a local base station were plotted and contoured (plate 1). Readings were made at 100-foot intervals on north-south traverses 200 feet apart. The stations were located by pace and compass traverses from established points on the south line of sec. 19. Errors of position are probably not over 50 feet.

The magnetic anomaly caused by the Stambaugh Formation is discontinuous, presumably because of facies changes within that unit, and is strongly developed mainly in the eastern and western parts of the map area (plate 1). The eastern anomaly is traceable farther east to the Paint River, where it can be related directly to magnetic slate of the Stambaugh Formation.

Locally, the Riverton Iron-formation contains enough magnetite to cause a moderate anomaly, as in the SW¼ SW¼ Sec. 19, south of the Ravenna-Prickett mine. A relatively small anomaly about one quarter mile south of the center of sec. 19 is entirely unexplained.

Mines

Ravenna and Ravenna-Prickett

The original Ravenna property, consisting of the W½ SE¼ sec. 19, later was increased by the addition of the S½ NE¼, the S½ NW¼, and the sec. 19. Allen (1912, p. 157) reported: "Considerable drilling has been done and a shaft put down from which drifting is being done on the first level proving the continuation of the iron formation

from the Bristol property. Some ore has been encountered but as yet not in any considerable quantity."

The Ravenna mine was opened in 1911 and shipments were made every year, 1912-17, during which only 296,421 tons were shipped. The ore was a hard and soft, red, high phosphorous and siliceous hematite.

The property was originally operated by the Hollister Mining Co. and later under the management of the Hanna Iron Ore Co. After the Ravenna was closed, the holdings were taken over by the Inland Steel Co. Ore, found at the west line of the property, was mined jointly with that on the adjacent Prickett property. This operation, conducted in 1940-43, was known as the Ravenna-Prickett or new Ravenna mine to distinguish it from the old Ravenna which lay on the east side of the property adjoining the Bristol.

The old Ravenna mine was operated from two shafts. No. 1 was approximately 100 feet west and 265 feet north of the center of the SE¼ sec. 19. The No. 2 shaft was about 150 feet south and 150 feet west of the same point. The 250-foot level was the most extensive. A 350-foot level was partly developed.

Two principal ore bodies were exploited. To the north the smaller ore body lay several hundred feet north of the No. 1 shaft; on the 250-foot level it was about 175 feet long and as much as 50 feet wide and trended about N 50° E. To the south, the much larger ore body lay south and west of the No. 2 shaft. On the 250-foot level it was about 575 feet long and 30-60 feet wide, and trended about N 70° W, apparently with a southerly dip. Its position and trend is indicated by the location and shape of the caved areas which formed after mining, and by the plan of the workings of the 250-level (plate 1).

The north and south ore bodies lay in iron-formation and were separated from one another by a belt of black graphitic slate, which, on the 250-foot level, is about 200 feet wide. This slate, which extends eastward to the No. 1 shaft of the Bristol, probably is a closely-appressed anticlinal fold of Dunn Creek Slate. The "greenstone" encountered by underground workings and by drilling in the slate between the northern and southern parts of the mine is assumed to be an altered basic intrusive.

Probably the northern ore body, like the northern ore bodies of the Bristol, is situated in a narrow attenuated syncline of iron-formation flanked by the black footwall slate. The structural position of the larger ore body to the south is far from clear. The strike of the iron-formation on the 250-foot level is highly irregular, especially in the vicinity of the No. 2 shaft. A northeasterly strike prevails in the drift between the west end of the southern ore body and the No. 1 shaft. A northwest strike is dominant in the vicinity of the southern ore body. Therefore, the Ravenna mine is probably located on a large complex drag fold. This discordance in strike between most of the formation and that part adjacent to the southern ore body – which is apparently flanked on the southwest by magnetic hanging-wall strata with a northwest strike – suggests faulting or shearing along the hanging-wall contact. If so, the main Ravenna ore body may be related to a fault rather than to a simple synclinal fold.

On the 350-foot level the southern ore body was much reduced in size. A long drift was extended southwestward to a small pocket of ore located approximately 450 feet south and 1,000 feet west of the center of the SE¼ of section 19.

Rather extensive drilling failed to locate any other appreciable quantity of ore on the Ravenna holdings except in the southwestern part of the NW¼ SW¼ sec. 19. Several drill holes penetrated ore in this area and in the contiguous part of sec. 24, T43N, R33W. The latter property, known as the Prickett, includes the NE¼ SW¼, the \\h SE¼, and the SE¼ NE¼ sec. 24. The control of these properties was acquired by the Inland Steel Co. which operated them as a unit. The Ravenna-Prickett mine on the Prickett property was opened by stripping in about 1940, and the first shipments from the open pit were made in the same year. A vertical shaft was sunk on the Ravenna side of the property. Mining ceased in 1943, the last operations being conducted from the 275-foot level. Shipments from 1940 to 1943 totaled 338,806 tons.

All the workings were developed in iron-formation which, except near the shaft, was thoroughly oxidized. Footwall slate was reached in holes drilled just northwest of the open pit. Within the limits of the pit the strike is generally north to northwesterly (fig. 3) – distinctly unlike the regional strike. Presumably the formation is cut off on the north by the Fortune Lakes fault. Near the shaft, however, the strike is about east-west. The new Ravenna, like the old Ravenna, seems to be located on a major drag fold in the iron-formation. Much more exploration would be needed if the structure of the Ravenna-Prickett mine were to be delineated accurately and the relation of the ore determined.

Figure 3. Ravenna-Prickett pit. (Diagonal pattern indicates bottom of pit (mapped by C. F. Park and J. R. Balsley, 1943. Contours by Inland Steel Co.).

The ore occurred in four relatively isolated ore bodies. The relation between ore and structures or stratigraphy

is obscure. The small total production indicates none of the ore bodies were large.

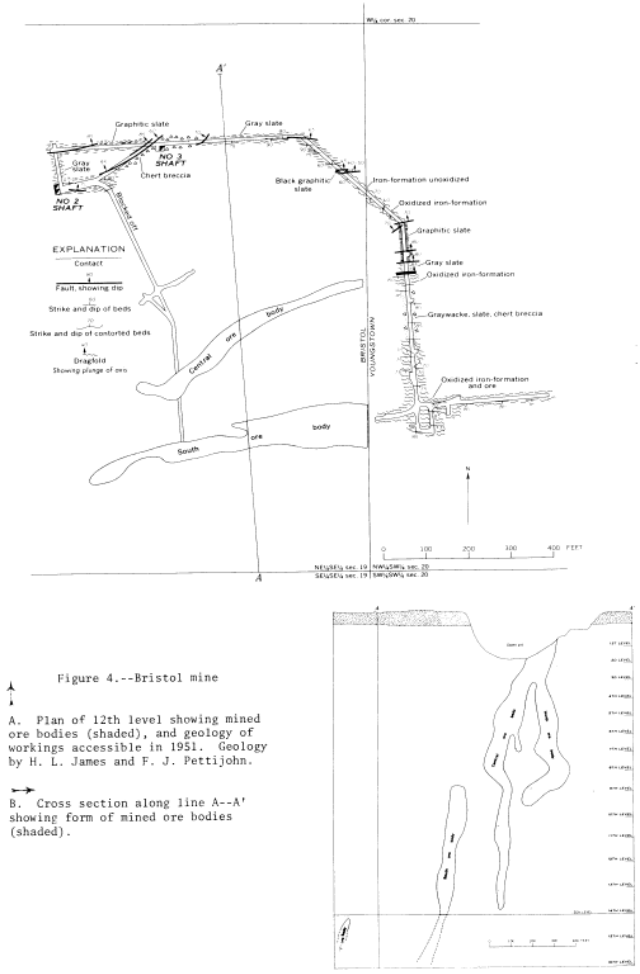

Figure 4.--Bristol mine

A. Plan of 12th level showing mined ore bodies (shaded), and geology of workings accessible in 1951. Geology by H. L. James and F. J. Pettijohn.

B. Cross section along line A--A' showing form of mined ore bodies (shaded).

Figure 4. Bristol mine.

A. Plan of 12th level showing mined ore bodies (shaded), and geology of workings accessible in 1951. Geology by H. L. James and F. J. Pettijohn.

B. Cross section along line A—A' showing form of mined ore bodies (shaded).

Bristol (Claire)

The Bristol mine, originally known as the Claire (also Clare), is in the E½ SE¼ sec. 19. This property was acquired about 1889 by the Claire Mining Co. Prior to that date, when part of the Youngstown mine, several small ore shipments were made.

Not much was done until 1892 when considerable stripping was undertaken; 57,352 tons of ore from this operation was shipped. The property was acquired by the Bristol Mining Co. in 1899, and under Oglebay, Norton and Co. management, underground operations were begun. Shipments in 1899 amounted to 80,915 tons; but not until 1903, when 246,581 tons was shipped, were operation on a large scale. The daily capacity of the mine was then 350 tons, one of the most important in the Crystal Falls area. A record 562,836 tons were shipped in 1929.

Shipments were made regularly until 1934 at which time 16 levels had been developed, the lowest of which is at a depth of 1,525 feet. In 1948-49, under management of the Inland Steel Co., the mine was dewatered and operated to the present. The lowest workings are at the 19th level, at a depth of 1,950 feet, the deepest mining in the district except the Hiawatha at Iron River.

According to Allen (1912, p. 157): "The ore in the Bristol mine is apparently not related to slate walls or slate troughs but is simply enriched layers in the iron formation which may occur anywhere in the mine." This interpretation is questionable because the iron-formation is completely folded. The width of the iron-formation (more than 1,000 feet on the 15th level) exceeds the probable thickness of the iron-formation. The width and spacing of the ore bodies is similar to the width and spacing of folds in the strata along the Paint River to the east.

Three principal ore bodies have been mined: the northern, the central, and the southern. Each is a nearly-vertical lens about a quarter mile long, a quarter mile in vertical dimension, and 100 feet thick. The geology at the 12th level and the form of the ore bodies down to the 16th level are shown on figure 4. The discussion of structure that follows is keyed to the surface geology map (plate 1), and to figure 4 (page 15).

The No. 2 and No. 3 shafts are located in a narrow tight anticline of Dunn Creek Slate north of the main ore bodies. The No. 1 shaft is in an equally tight anticline of the same strata partly separating the central and northern ore bodies. These structures have a general eastward plunge, so that in the eastern part of the workings the latter anticline, with respect to the footwall slate, plunges beneath the surface, and the north and central ore bodies merge.

The plan of the 12th level indicates the central ore body is in a limb of iron-formation that has been greatly thinned along an east-trending fault. The rock adjacent to the fault on the north is gray sericitic slate stratigraphically below the pyritic graphitic slate (Wauseca Pyritic Member), and the iron-formation is only 50 feet wide at the intersection in the drift; the entire Wauseca Pyritic Member and most of the Riverton Iron-formation is missing. The north contact of the east extension of the central ore body (Riverton) is a normal contact with graywacke, chert breccia, and slate assigned to the Hiawatha Graywacke. On the south, the Hiawatha Graywacke is again in normal contact with the extension of the southern ore body (Riverton). Apparently the central and southern ore bodies are on the flanks of an extremely deep tight syncline containing Hiawatha Graywacke to at least the 12th level. The Hiawatha is exposed at the surface in the southern part of the caved ground over the Bristol workings.

The rocks mapped in the vicinity of the No. 2 shaft and east of the No. 3 shaft at the 12th level are dominantly

the gray sericitic slate stratigraphically below the Wauseca Pyritic Member of the Dunn Creek Slate. The rock at the No. 3 shaft, however, is a chert breccia-chert fragments in a graywacke or slate matrix similar in all respects to the breccia facies of the Hiawatha Graywacke. Possibly the breccia is stratigraphically within the Dunn Creek Slate; if so, it is a facies not elsewhere represented in the mine or the area. The breccia is bounded by faults. A more acceptable interpretation is that the breccia is a horse of younger rock in a fault zone. Similarly, a small block of unoxidized iron-formation (Riverton) is present in the fault zone at the point where the 12th-level drift turns from an easterly to a southeasterly direction.

Just north of the No. 2 and No. 3 shafts, drill holes pass through a zone of strong shearing into a narrow belt of unoxidized iron-formation bounded on the north by Dunn Creek Slate. Hole NB1, drilled horizontally north from the 3rd level, cuts 170 feet of unoxidized Riverton, then from 170 feet to 355 feet passes through an anticline of Dunn Creek Slate and back into Riverton Iron-formation, here oxidized. The contacts on both sides of the anticline appear to be normal: each cutting of the Riverton shows the formation in contact with pyritic slate (Wauseca Pyritic Member, including the diagnostic "speckled gray" slate breccia) with gray sericitic slate occupying the core of the structure. From 355 feet to 790 feet, the hole is in Riverton, then enters graywacke which generally persists to 1,105 feet. From 1,105 feet to the end at 1,220 feet, the hole again is in Riverton Iron-formation, here unoxidized. In summary, the tight anticline at the No. 2 and No. 3 shafts is bounded to the north by a fault, beyond which lies (a) a tight syncline of unoxidized Riverton Iron-formation, (b) an anticline of Dunn Creek Slate, and (c) a syncline containing Hiawatha Graywacke at the elevation of the 3rd level. This latter syncline, the south flank of which contains oxidized iron-formation and ore, has been explored further by drilling elsewhere on the 3rd level and by drilling from the 7th level.

The Bristol ore locally is manganiferous and some shipments of a grade known as "manganate" contain as much as 4 percent manganese. Hausmannite has been identified but does not seem to be abundant, at least to the unaided eye.

Youngstown

The Youngstown property originally consisted of the \\h SE¼ sec. 19 and the W½ SW¼ and the SE¼ SW¼ sec. 20. This 200-acre area was held on lease and worked by the Youngstown Iron Mining Co. Later the W½ SE¼ of sec. 19 became the Quincy mine, then still later the Bristol mine. The Youngstown property thus became only the W½ SW¼ and the SE¼ SW¼ sec. 20. In 1889 it was acquired by the Florence Iron Mining Co. Still later, it was taken over by the Illinois Steel Co. for whom it was operated by the Oliver Iron Mining Co. In 1926 it was operated as a part of the Bristol mine by Oglebay, Norton and Co. for the Bristol Mining Co. under an agreement with the Oliver Iron Mining Co.

In 1882 two ore bodies had been shown by drilling. The north "blue hematite" body was stripped prior to opencut mining. Several shafts were sunk to open the south "brown hematite" body. About 8,000 tons was shipped from the sec. 19 part of the property in 1883. The mine was worked periodically until 1926 when it was operated as a part of the adjoining Bristol mine. The Youngstown is credited with 151,425 tons of ore up to 1897. The Bristol-Youngstown property was closed in 1934. Reopened in 1949 it was operated as a unit until again closed in 1969. The Bristol-Youngstown shipped a total of 14,804,319 tons of ore.

The geology of the mine has been summarized in the preceding section dealing with the Bristol mine.

GREAT WESTERN-HILLTOP AREA

The bedrock geology of the Great Western mine area (plate 1), chiefly the S½ sec. 21, T43N, R32W, and the Hilltop mine area, the W½ W½ sec. 22 of the same township, is poorly known, mainly because of an extensive and thick drift cover. Outcrops are confined to the Crystal Falls golf course in the SW¼ of section 21 and the hill in sections 21 and 22 on which the Crystal Falls and Hilltop mines are located Many old test pits show bedrock near the surface over most of this hill. In the area near Runkle Lake and the Crystal Falls airport and in the north half of section 21, however, the drift is very thick – 200 feet beneath much of the airport area and over 250 feet just north of Runkle Lake.

Stratigraphy

The stratigraphic sequence in the Great Western-Hilltop area is nearly the same as elsewhere in the Northern Crystal Falls area. The Dunn Creek Slate, exposed in numerous test pits and as a few outcrops in the Crystal Falls mine area, consists of lustrous phyllite or slate and a minor quantity of graywacke. These rocks are dark gray where unoxidized, red or yellow or "bleached" where oxidized. Oxidation seems rather widespread in the NW¼ of section 22. The graphitic member of the footwall sequence (Wauseca Pyritic Member) is reached in test pits near the E¼ corner of section 21. As seen oh the dumps it is a very black sooty rock. Locally it has been sheared so that the fragments are polished and slickensided. Superficially the debris from the test pits resembles slaty anthracite coal. It soils the fingers and readily marks paper. A little chert is associated with the graphitic slate.

The Riverton Iron-formation is best exposed in the caved areas of the Crystal Falls and Hilltop mines where it is thoroughly oxidized and consists of alternating layers of red hematite and white chert. Oxidized formation also occurs in the caved area of the Fairbanks mine in the NW¼ SW¼ sec, 21. Unoxidized formation was, however, found in test pits just south of the W¼ corner

of sec. 22 and in the old railroad cuts northwest of the Crystal Falls mine. A single outcrop occurs near the north line of the NW¼ SW¼ sec. 21. Where seen, the formation closely resembles that found elsewhere in the Crystal Falls area. One of the drill holes in the SW¼ NW¼ sec. 21, however, encountered a facies not found elsewhere. The iron-formation consists of jaspery chert bands alternating with thin layers rich in magnetite and stilpnomelane. This phase is apparently responsible for the notable magnetic anomaly in this “forty" and probably also the cause of the anomaly in the eastern part of the SE¼ NE¼ sec. 21. The magnetite-bearing member apparently forms the lowest part of the iron-formation. Oxidation and leaching of this member may have produced the hard limonitic bands in the Victoria exploration and in the drilling in the SW¼ NW¼ sec. 21.

The post-Riverton beds are exposed only in the SW¼ sec. 21. A little chert breccia and graywacke occur in the NW¼ of this quarter section. Several small outcrops of gray slate are found on the golf course in the SW¼ of the same quarter section. Black slate is poorly exposed near the road south of the Great Western mine. Some slate was reached in drilling in the center of the SE¼ sec. 21 and also near the west margin of this same quarter section. These rocks probably can be assigned stratigraphically to the Hiawatha Graywacke.

Structure

The structure of the area is outlined by the footwall contact of the Riverton Iron-formation. Although a narrow belt of black graphitic slate (Dunn Creek) is present in a narrow anticlinal infold east of the W¼ corner of sec. 21, the main Riverton-Dunn Creek contact was located by drilling just south of the center of the NW¼ sec. 21. The contact extends northeastward, passing through the Hilltop mine pit. From this point it runs southward, between numerous outcrops and test pits, in a slightly irregular manner to the E¼ corner of sec. 21 where several test pits are in black graphitic slate. Beyond this point the course of the contact is less clear, but is assumed to continue southward to the Runkle Lake fault. The iron-formation encountered in the Victoria exploration probably occurs in an isolated downfold surrounded by Dunn Creek Slate.

The outcrop belt of the iron-formation is extraordinarily wide. From about 600 to 700 feet near the Fortune Lake mine west of the map area, the belt widens to more than 2,000 feet along the north-south center line of sec. 21. The divergence of the hanging-wall and footwall contacts is most marked in the Great Western area. As a result the iron-formation underlies a large triangular area within the W¼ corner of sec. 21, the Hilltop mine area, and the southeast corner of the section near the west end of Runkle Lake. This tract occupies about 250 acres, a little less than half square mile.

Strike and dip show this triangle to be the apex of a large syncline. Near the W¼ corner of sec. 21, the strike is nearly east-west and the dip southward. In the Crystal Falls and Hilltop mines area, near one point of the triangle, the strike changes from slightly southeastward at the mine itself, to south-westward just east of the mine. The dips are about 60°-70° south or west. A general change in strike is also shown by the outcrops on the golf course in the SW¼ SW¼ sec. 21. Near the north line of this "forty" the beds trend nearly east-west, but in the southeastern part they are more nearly north-south. The structure is also outlined in part by the magnetic contours which generally follow the strike. They trend northeast by east in the northern part of the section, nearly north-south just east of the Crystal Falls mine, and southwestward near the E¼ corner of sec. 21 and in the adjoining parts of sec. 22.

Most definite evidence bearing on the structure is obtained from the maps of the Crystal Falls mine. The workings show a progressive southwesterly displacement of the ore body from the caved ground in the eastern part of the SE¼ NE¼ sec. 21 to the extreme southwest corner of the "forty". The plunge is about 45° southwest. The shaft itself was inclined in the same direction. Minor drag folds in the same area confirm the southwesterly plunge of the structure.

The southern part of the area is assumed to be crossed by the Runkle Lake fault (discussed previously). No exposures are known of the strata south of the fault. Drill holes 13 and 16 in the SE¼ SW¼ sec. 21 both enter sheared pyritic graphitic slate assumed to be the Wauseca Pyritic Member of the Dunn Creek Slate. Drill hole 12 in the same "forty" cuts fine- to medium-grained graywacke.

Magnetic Anomalies

The magnetic data (plate 1) were obtained with a Schmidt-type vertical magnetometer. The magnetic values represent departures, in gammas, of the vertical intensity of the earth's magnetic field from an assumed gamma value of a local base station.

The total magnetic relief in the area is small – about 350 gammas. In general, although the isoanomaly contours are widely spaced and irregular over much of the area, a magnetic gradient from southwest to northeast is clear. The prevailing west-northwest trend of the magnetic contours in the S½ sec. 21 probably reflects the general attitude of the strata in that area. Near the E¼ corner of the same section, the contours have a general northeasterly trend, and in the area around the Crystal Falls mine, the trend is northerly or even northwesterly. In general the trend of the anomaly contours throughout the area is consistent with the observed strike of the underlying beds.

The largest anomaly in the area is in the SW¼ NW¼ sec. 21, where a linear anomaly with a peak value of about 350 gammas can be traced for a quarter mile. A magnetite stilpnomelane facies of the iron formation causes the anomaly, and is well displayed in core from drill hole 2111. Similar material, partly oxidized, is cut by several other holes in this vicinity.

Mines

Great Western (Iron Star)

The Great Western mine is located in the E½ SW¼ and the SW¼ SE¼ sec. 21. This property, opened in 1882, soon became the leading mine in the Crystal Falls area.

Small shipments were made from 1882 to 1884. No shipment was made in 1885 when only development work and some exploratory drilling were done. The mine was then operated by the Iron Star Co. and sometimes referred to as the Iron Star mine. Mining was resumed in 1886 and continued with only minor interruptions until 1893 when, like many other mines in the district, was closed because of the financial panic. In 1899 the Great Western was acquired by Corrigan, McKinney and Co., who also took over the adjoining Lincoln mine. Shipments then continued regularly until the property was shut down permanently in 1910; the remaining 30,000-ton stockpile was shipped in later years.

Underground operations were conducted from three shafts of the Great Western, the No's. 1, 2 and 3, and from the Lincoln shaft. Sixteen levels were worked, the lowest 1,257 feet. The Lincoln shaft extended to the 9th level. Located in a swamp, mining operations were hampered by a heavy inflow of water. During its existence, however, the mine was one of the most modern and most productive in the area. Shipments from 1882-1910 totalled 2,296,739 tons.

The geology of the mine is poorly known. No rock is exposed in the caved area, now filled with water, and outcrops are very scarce.

The form of the mined ore bodies at the 7th, 9th, and 14th levels, as taken from company maps, is shown on figure 5. The western ore body at the 7th level is tabular, and dips steeply to the south. The eastern ore body is in a crenulated belt with nearly vertical dip. At the 10th level the ore bodies are connected, or nearly so. In general, the ore bodies are located on the south limb and in the axial zone of a fold complex that plunges steeply to the west. The main synclinal axis of this fold system probably is approximately through the caved area over the mine workings (plate 1). The north limb of this syncline has not been adequately explored; it would lie in the southern part of the NW¼ sec. 21

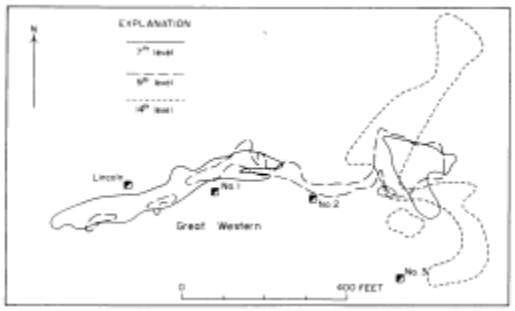

Figure 5. Generalized outlines of mined ore bodies of the Great Western mine.

The Lincoln and the Great Western No. 1 and No. 2 shafts apparently are within the iron-formation for their entire depths. The Great Western No. 3 shaft, however, at the 14th level is reported to be in black graphitic slate, and its contact with iron-formation is crossed in the workings about 100 feet north of the shaft. This contact also was intersected in a long, nearly horizontal hole drilled south from the 12th level between the No. 1 and No. 3 shafts. The slate cut in the drilling and in the mine workings almost certainly is the "footwall" (Dunn Creek Slate); the rock occurs on the same anticline that brings similar material to ledge surface along the south edge of the SW¼ NW¼ sec. 21.

The ore shipped is described as "high grade blue hematite". The material remaining on the dumps, however, is much the same as from other mines in the district — a mixture of reddish hematite and yellow goethite. The ore in the southern part of the main ore body at the 14th and 15th levels was reported to be manganiferous, but apparently no separate shipments were made. At several of the levels, the more northeasterly parts of the ore body were high in sulfur. Clumps of gypsum several inches across have been observed on the present mine dump.

Crystal Falls

The Crystal Falls mine, located in the E½ NE¼ sec. 21, was an early development. Shaft sinking had begun by 1891, but, owing to financial difficulties, work was suspended until 1894. At that time the property was acquired by Corrigan, McKinney and Co., and some ore was mined from an open pit in 1895. During 1896 shipments totalled 44,526 tons. After 1900, the mine was operated by the Crystal Falls Iron Mining Co., a subsidiary of Corrigan, McKinney and Co.

Although some initial mining was from open pits or cuts, the principal operations were underground. The main shaft, located on the northeast or footwall side of the ore body, is inclined southwestward at about 65°, which is the prevailing dip of the ore-bearing zone. A three-compartment shaft had been extended to a depth of 1,060 feet by 1907. At that time the daily capacity of the mine was 400 tons. Thirteen levels had been extended from the shaft by 1908, after which the mine was idle. Mining operations were continuous from 1895 to 1907, and shipments were made annually. A few small shipments were made later than 1907, apparently from stockpile. The total production credited to the Crystal Falls mine was 1,744,015 tons of "soft brown non-Bessemer hematite". This amount apparently includes a 1,341-ton shipment in 1882 from the Lot 3 mine.

The Crystal Falls mine is located in what seems to be the apical area of a large southwest-plunging syncline. Northwest of the mine, along the old railroad grades, are low outcroppings of unoxidized iron-formation with east-west to northeast strike and south dip. In the opencut and caved area, proper, the strike is northwest and the dip southwest. A-long the railroad grade southeast of the mine the strike is northeast and the dip northwest.

The mine workings confirm the structure interpretation based on surface outcrops. Each successive level is shifted southwestward down the dip of the formation, as shown in figure 6. The lowest level workings are in the extreme southwest corner of the property. The over-all pattern of the workings indicate an ore body elongated parallel to the bedding and plunging southwestward. Apparently mining operations ceased at the 13th level because the property limits were reached. Probably the ore extends farther southwestward.

The ore body apparently does not rest on the footwall slate but on a leaner nonproductive member of the ore-bearing formation. This lower bed produces a weak but distinct magnetic anomaly in the mine area. An area of distinctly low magnetic readings lies to the west of the anomaly and seems to be centered over the workings of the mine, perhaps due to extensive oxidation.

Figure 6. Crystal Falls mine. Outlines of mined ore bodies, generalized from plans of mine workings at 4, 6th, and 8th levels at elevations of 1,155, 1,030, and 868 feet, respectively.

Hilltop

Adjoining the Crystal Falls mine is the Hilltop (also Hill Top) property comprising the SW¼ NW¼ and Lot 3 (essentially NW¼ SW¼) of sec. 22. Though explored as early as 1897, this property was not opened until 1899, when 3,496 tons of ore were shipped. The mine was then operated by the American Mining Co., of Duluth, Minn. In 1902 the mine was reported to have been operated by the Oliver Iron Mining Co. In 1912 the lease was assigned to the Roberts Ore Co. The mine, however, was operated by the Cuyahoga Mining Co., and in 1917 by J. E. Thropp. The Victoria mine, in the NW¼ NW¼ sec. 22, was operated together with the Hilltop for a short time. The combined production — mainly or entirely from the Hilltop — was only 98,202 tons. Shipments were made during the years 1899-1901, 1906, 1914, and 1917-19.

The Hilltop mine is situated on top a prominent hill. Over most of the hill the drift cover is thin, bedrock being reached in most of the many test pits in this area. Inspection of these old pits indicates very little of the property is underlain by iron-formation. The iron-formation present seems to be confined to a very small area in the extreme northwest corner of the SW¼ NW¼ sec. 22 (containing Hilltop mine) and to an equally small area in the extreme southwest corner of the same "forty" and the adjacent part of Lot 3. Rock exposed in the west and south sides of the caved area is well-oxidized iron-formation. On the northeast side it is badly altered to bleached graywacke and soft glossy slates. The graywacke is "punky" and white to yellow and locally stained red. Near the contact, the graywacke and the iron-formation are sheared. Both the graywacke and slates are believed to belong stratigraphically to the footwall Dunn Creek Slate.

Between the Hilltop and the Victoria are numerous test pits in which were encountered soft, glossy, phyllitic slates. These rocks, minutely crinkled, are dark gray to black, though in many places they have been oxidized to red or yellow and commonly are variegated. Graywacke is a minor constituent. Chert seems to be absent, and the rocks are principally nonmagnetic. These strata are assigned to the Dunn Creek Slate.

The Hilltop mine was developed in a narrow syncline of Riverton Iron-formation that appears to pinch out only a short distance southeast of the mine. Likely it contains little ore.

The iron-formation at the southwest corner of the "forty" is likewise believed to be a shallow syncline infolded into the footwall strata.

Explorations

Town 43 North, Range 32 West

SECTION 22

The Victoria exploration lies in the NW¼ sec. 22. This property apparently was explored at about the same time as the adjoining Hilltop mine area and was operated jointly with the Hilltop. There are no records of underground workings at the Victoria, and if shipments were made they probably were small and included with the Hilltop.

In most places the drift cover is thin; and bedrock was reached in many test pits. Iron-formation, everywhere oxidized, is restricted to a small area in the south half of the property — mainly on the north slope of a large hill. The south contact is readily traceable across most of the property by study of the many test pits. The north limit is more uncertain, as only one test pit reaches graphitic black slate, but, as the prevailing strike is nearly east-west, the position of the contact can be projected reasonably well. No evidence indicates the iron-formation extends eastward from the Victoria property. Excavations for a well, a basement, and several scattered test pits are all in oxidized slaty material (Dunn Creek Slate). The west limit of iron-formation is quite uncertain, although it probably does not extend very far. The iron-formation is interpreted as being contained in a shallow, doubly-plunging, synclinal fold, isolated from the Hilltop mine to the south.

Although many fine specimens of hard limonite and hematite can be seen on the Victoria dumps, most of the iron-formation is cherty. Because of the small size of the structure, and its shallowness (verified by drilling) probably no large ore body occurs in the Victoria area. Two vertical holes, Nos. 271 and 273, drilled in 1950 by the Republic Steel Corp. in the central part of the structure, reached the footwall slate at depths of 175 and 353 feet.

Nine holes ("N" series on plate 1), the Neely exploration, were drilled in the E½ SW¼ sec. 22 in 1909-10 by the Jones and Laughlin Ore Co., on what was known as the Benjamin Neely option. The descriptions in company records of the materials encountered are extremely brief; all of the holes reportedly cut slate of one variety or another.

SECTION 21

The Oswald-Pfister exploration consists of 13 holes (211, etc. on plate 1) drilled in 1931 by the Jones & Laughlin Ore Co. on the Oswald option (SW¼ NW¼ sec. 21) and the Pfister Land Co. option (SE¼ NW¼ and NW¼ SW¼ sec. 21). The core was examined at the company warehouse at Negaunee, Michigan. Additional holes were drilled later in the same area by Pickands Mather & Co. (see Lincoln and Great Western exploration below).

Holes 211 and 212, angle holes drilled north and south, respectively, from near the same location in the NW¼ SW¼, both cut long sections of unoxidized iron-formation. Hole 211 ended in this material at 1,112 feet, but hole 212 ends in laminated dark-green slate and fine-grained graywacke (presumably Hiawatha) at 808 feet.

Holes 217, 219, 2111, and 2112 are interesting because each cuts footwall pyritic graphitic slate (Wauseca Pyritic Member of the Dunn Creek Slate) at bedrock surface. Evidently these holes are located on the western extension of the anticline passing through the southern part of the Great Western mine workings. The complementary syncline north of this structure is crossed by holes 218 and 2110, with the latter hole ending in Dunn Creek Slate at 455 feet after cutting oxidized iron-formation. The footwall contact also is reached in hole 2113, which begins in footwall slate and cuts the entire syncline of Riverton Iron-formation.

Hole 2111 has been previously mentioned in discussion of the Riverton Iron-formation. From 263 feet to 555 feet this hole cuts a laminated iron-formation consisting of interlayered chert (some reddish jasper), siderite, and dark-green stilpnomelane with disseminated magnetite. When examined at Negaunee, Michigan, the core was thought to be Negaunee Iron-formation, which it strongly resembles, and that it had been stored in error with the Crystal Falls materials. Later, the area of drilling was surveyed magnetically, and a moderate but well-defined anomaly was discovered. Material somewhat similar to that found in hole 2111, but oxidized, was noted in holes 215 and 2113.

Twenty holes (401-413, 101-108) in the W½ sec. 21 comprise the Lincoln and Great Western explorations. These holes were drilled in 1949-50 by the Iron Range Mining Co. (Pickands Mather & Co.). Some of the core, which was stored at the Pickands Mather & Co. offices at Caspian, Mich., was examined, but most of the descriptions are from company logging by Irvin Beckwith.

Except for the most southern hole (hole 412, in the SW¼ SW¼ sec. 21), the drilling adds relatively little knowledge beyond that known from the earlier Oswald-Pfister exploration. Hole 412, drilled north at 30°, starts in un-oxidized iron-formation, and ends in oxidized iron-formation at 1,050 feet. Evidently the graywacke and chert breccia are contained in a narrow syncline extending westward toward the Fairbanks mine.

Most of the holes are drilled in the broad expanse of iron-formation underlying much of sec, 21, and are in oxidized iron-formation for their entire length. Hole 107, in the NE¼ SW¼ sec. 21, provides data on the southeastward extension of the anticlinal axis passing through the southern part of the Great Western workings. The hole was drilled south at 57°. From about 600 feet to the end of the hole at 790 feet, it is in pyritic graphitic black slate (Wauseca Pyritic Member of the Dunn Creek Slate).

The Crystal Falls exploration consists of 11 holes (Nos. 2, 5, 6, 8, 9, 15, 17, 19, 21, 22, 23) in the SW¼ SE¼ sec. 21 and 4 holes (10, 12, 13, 16) in the SE¼ SW¼ sec. 21. These holes were drilled in 1948 by the Iron Range Mining Co. (Pickands Mather & Co.). Descriptions of most of the holes were obtained through core examination at the Pickands Mather storage facility at Caspian, Mich.; descriptions of the other holes were obtained from Irvin Beckwith, company geologist.

The most westerly holes, Nos. 13 and 16 in the SE¼ SW¼ have previously been mentioned. Both are in pyritic black slate (Dunn Creek). The slate in hole 16 is veined with quartz, denoting proximity to the Runkle Lake fault. Holes 10 and 12 in the same area cut massive fine- to medium-grained graywacke. The materials cut are very similar, but on the basis of other geologic data the graywacke from hole 10 is presumably of the Hiawatha Graywacke, whereas the material from hole 12 is Dunn Creek Slate stratigraphically below the Wauseca Pyritic Member.

The rest of the holes are in the northern part of the SW¼ SE¼. The more southerly holes (5, 6, 8), all relatively shallow, cut glossy slate, phyllite, and fine-grained graywacke similar to hole 10 to the west. Lithologically these materials are more similar to the Dunn Creek Slate in the NW¼ sec. 22, than to typical Hiawatha Graywacke to which they are assigned. Hole 17, which is 300 feet to the north of the 5-6-8-10 line of holes, establishes the general stratigraphic position. This hole, drilled vertically to 920 feet, is in graywacke and graywacke-chert breccia to 675 feet, then enters unoxidized iron-formation. The graywacke and breccia can be assigned definitely to the

Hiawatha Graywacke, so the hanging-wall contact of the iron-formation here is closely controlled; this contact must extend between the iron-formation cut in holes 2 and 19 and the graywacke cut in hole 5, 200 feet to the south.

The Neely, Great Western, and Hagerman properties comprise the E½ SE¼, the SW¼ SE¼, and the NW¼ SE¼ respectively, of sec. 21.

The Neely exploration consists of seven holes (1-7) drilled in about 1910. The area drilled, the E½ SE¼, is a level outwash plain with 146 to 213 feet of overburden. Six of the holes, mostly near the center of the SE¼, encountered oxidized iron-formation or "jasper"; the southernmost (No. 3) reportedly cut black slate. Allen, in the annual report of the Geological and Biological Survey for 1911 (Allen, 1912, p. 157), noted: ". . . a large tonnage of ore has been developed"; the reserves estimated for tax purposes (p. 158) were given as 587,000 tons.

At about the same time, some drilling was done on the Hagerman property (NW¼ SE¼) and on the Great Western Extension (SW¼ SE¼). These holes are the "G" series on plate 1. Drilling shows the iron-formation to occupy only the northeast corner of the SW¼ SE¼. A considerable amount of later drilling has been done on the Hagerman property by Republic Steel Corp., but the records were not made available this study. The “forty” is assumed to be almost wholly underlain by iron-formation, and an eastern extension of the Great Western ore body seems likely.

REFERENCES CITED

Allen, R. C., 1912-20, Mineral resources of Michigan: Michigan Geol. Survey, Pub. 8, 16, 19, 21, 24, 27, 29.

Clements, J. M., and Smyth, H. L., 1899, the Crystal Falls iron-bearing district of Michigan: U.S. Geol. Survey Mon. 36, 512 p.

Dutton, C. E., 1969, Geology and magnetic data for central Iron River area, Michigan: Michigan Geol. Survey, Report of Investigation 5.

James, H. L., Dutton, C. E., Pettijohn, F. J., and Wier, K. L., 1968, Geology and ore deposits of the Iron River-Crystal Falls district, Iron County, Michigan: U.S. Geol. Survey Prof. Paper 570, 134 p.

James, H. L., Dutton, C. E., and Wier, K. L., 1967, Geology and magnetic data for northern Iron River area, Michigan: Michigan Geol. Survey, Report of Investigation 4.

James, H. L., Pettijohn, F. J., and Clark, L. D., 1970, Geology and magnetic data between Iron River and Crystal Falls, Michigan: Michigan Geol. Survey, Report of Investigation 7.

James, H. L., and Wier, K. L., 1969, Geology and magnetic data for south-eastern Iron River area, Michigan: Michigan Geol. Survey, Report of Investigation 6.

Lake Superior Iron Ore Association, 1938, Lake Superior iron ores: Cleveland, Ohio, 364 p.

Lake Superior Iron Ore Association, 1952, Lake Superior iron ores, 2d ed.: Cleveland, Ohio, 334 p.

Michigan Geological Survey, 1951-68, mimeographed reports, variously titled, on general statistics covering costs and production of Michigan iron mines.

Michigan Commissioner of Mineral Statistics, 1879-1909, reports variously titled-Annual reports, Mineral resources, Mines and mineral statistics: volumes issued for 1877-78, 1880, 1881, 1882, 1883, 1885, 1886, 1887, 1888, 1889, 1890-91, 1895, 1897, 1900, 1901, 1901-2, 1906-7, 1907.

Pettijohn, F. J., 1970?, Geology and magnetic data for southern Crystal Falls area, Michigan: Michigan Geol. Survey, Report of Investigation 9.

Pettijohn, F. J., Gair, J. E., Wier, K. L., and Prinz, W. C., 1969, Geology and magnetic data for Alpha-Brule River and Panola Plains areas, Michigan: Michigan Geol. Survey, Report of Investigation 10.

Smith, R. A., 1922, 1924-29, Mineral resources of Michigan: Michigan Geol. Survey, Pub. 32, 34, 35, 37.

Smith, R. A., and Martin, Helen M., 1923, Mineral resources Of Michigan: Michigan Geol. Survey Pub. 33.

Wier, K. L., 1970?, Geology and magnetic data for northeastern Crystal Falls area, Michigan: Michigan Geol. Survey, Report of Investigation 11.

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