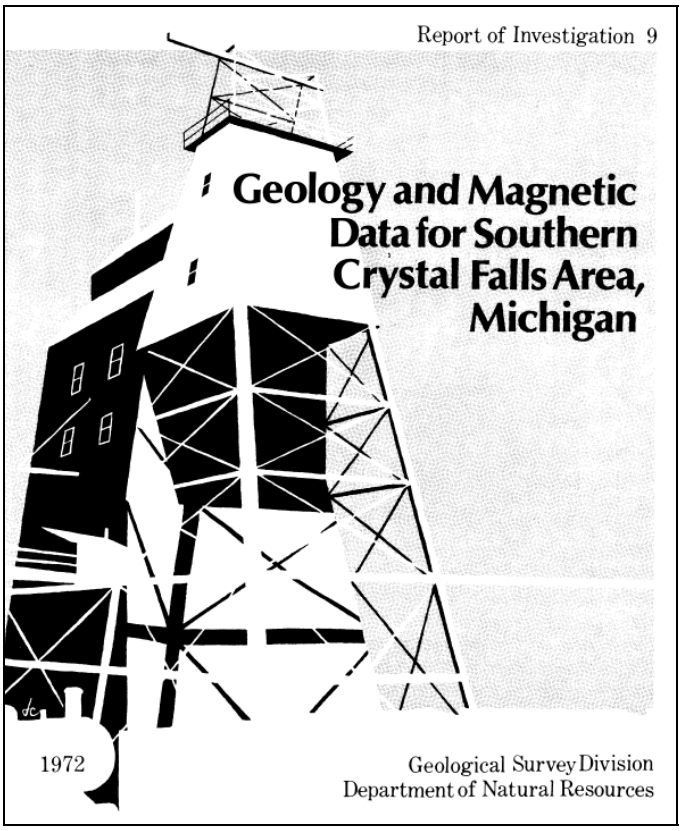

Front cover:

The Tobin mine, opened in 1882, is located southwest of Crystal Falls. Through 1963, more than 13.5 million tons of iron ore have been shipped from this and contiguous properties of the Republic Steel Corporation -- almost half the total for the southern Crystal Falls area.

Artwork by Jim Campbell

STATE OF MICHIGAN
DEPARTMENT OF NATURAL RESOURCES
GEOLOGICAL SURVEY

Report of Investigation 9
GEOLOGY AND MAGNETIC DATA FOR SOUTHERN CRYSTAL FALLS AREA, MICHIGAN

by
F. J. Pettijohn

Prepared in cooperation with the Geological Survey United States Department of the Interior

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PREFACE

The purpose of this report, last in a series of eight reports being published by the State, is to preserve detailed information on explorations, mines and magnetic surveys not included in U. S. Geological Survey Professional Paper 570 (1968), 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 1943-1955. Some of the results of the work were published as preliminary reports during the course of the field study. The broader conclusions on the geology and ore deposits of the district are presented in Professional Paper 570.

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., the M. A. Hanna Co., Pickands Mather & Co., the Republic Steel Corp., the Mineral Mining Co., the Inland Steel Co., the North Range Mining Co., the Jones & Laughlin Steel Corp., and the 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.

Baltimore, Maryland
July 1967

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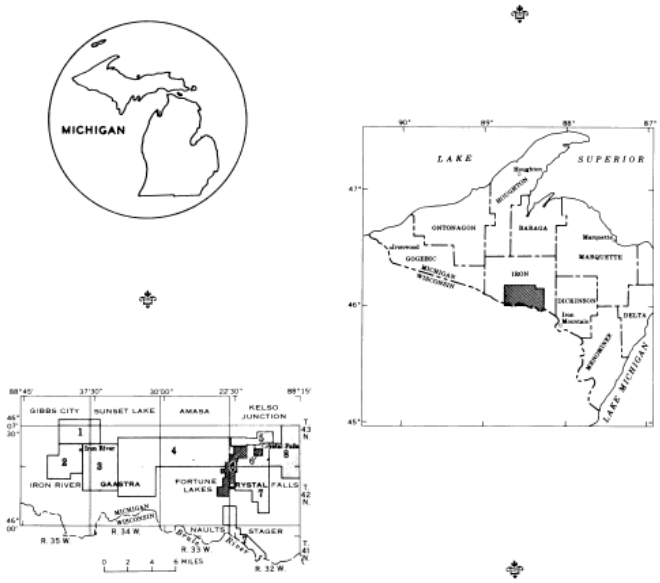

Figure 1. Location and index maps

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

1. Northern Iron River Area -- James, Button, 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. Northern Crystal Falls Area -- Pettijohn
6. Shading delineates area of this report, 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 Southern Crystal Falls area lies mainly between the towns of Crystal Falls and Alpha and constitutes an irregular zone of about 5 to 6 square miles along the eastern part of the Iron River-Crystal Falls synclinorium. Strata of the Animikie Series -- which, from oldest to youngest, comprise the Dunn Creek Slate, Riverton Iron-Formation, Hiawatha Graywacke, Stambaugh Formation, and Fortune Lakes Slate -- involve a series of closely spaced northwesterly plunging folds and form a

zigzag pattern of southerly trending belts. Igneous rocks consist of a few dikelike bodies of granite and metadiabase. Major northwesterly trending faults near the northern border of the area, and minor faults at several other places, offset the strata -- commonly with a right lateral displacement.

Most ore bodies are associated with synclines and occur within a stratigraphic horizon near, but not at the base, of the Riverton Iron-Formation. About 28 million tons of ore have been shipped from the 16 mines that have operated in the area. Areas of outcrop, partial extent of mine workings, drill-hole and test-pit information, and magnetic data are shown on three geologic maps. Brief histories and descriptions of mines and explorations are given.

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 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 shown in figure 1.

Information on early mining history was taken from the annual reports, 1879 to 1909, of the Commissioner of Mineral Statistics of the State of Michigan and from 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, 1951-61). Some of the results of U. S. Geological Survey work in the "Southern Crystal Falls Area" have been presented as preliminary reports by Pettijohn (1948) and Pettijohn and Clark (1946).

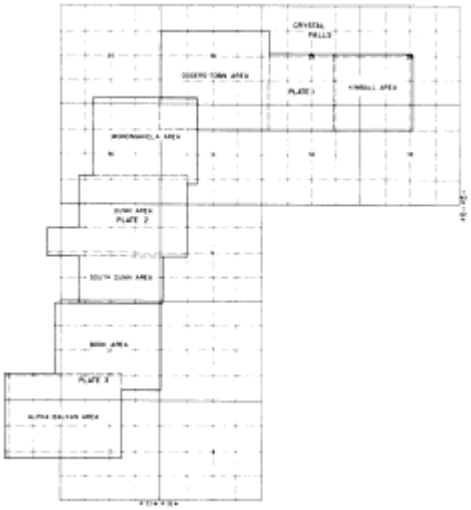

Figure 2. Southern Crystal Falls area, with index to individual areas described in text.

Location

The southern Crystal Falls area lies between the towns of Crystal Falls and Alpha. It is not sharply defined, but in general the area of this report is a belt about a mile wide and 5 miles long (fig. 2). It includes three map areas: the Kimball and Odgers-Tobin areas (plate 1); the Monongahela, Dunn, and South Dunn areas (plate 2); and the Book and Alpha-Balkan areas (plate 3). It also includes the Mastodon-Nighthawk area, not covered by a separate map but described in text.

Topography

The relief of the area is low -- about 200 feet. The ridgelike high ground along the western part of the area reaches elevations of a little more than 1,580 feet. The lowest elevation, about 1,380 feet, is on Dunn Creek. The relief of the bedrock surface is slightly greater inasmuch as the low areas are, in the main, incompletely glacial drift filled rock-cut valleys. The maximum bedrock relief is probably about 400 feet.

The drift cover is very thin over most of the area. Outcrops, though generally small, are abundant. Many of the higher and larger hills are bedrock with little or no drift cover. There are no well-defined or extensive moraines. Depths of glacial overburden greater than 200 feet are shown by the drilling in the NW¼ SW¼ sec. 31, T43N, R32W, but the average thickness is probably less than one fourth this value.

Despite the fact that the topography is largely controlled by bedrock, there is no striking correlation between local relief and bedrock lithology nor any marked relation between topographic forms and the underlying bedrock structure. With the exception of the more massive greenstones, none of the rocks are notably erosion resistant. The same rock which underlies low ground in one place may underlie high ground elsewhere.

In general, the iron-formation follows low ground. This is especially true of the oxidized ore-bearing parts of the formation. Of the 14 mines which have shipped some ore at one time or another, 11 are at decidedly low elevations. Only the Kimball, one of the least productive, is on high ground.

GEOLOGY

The geology of the southern Crystal Falls area consists in essence of a south-trending belt of Riverton Iron-Formation, which is bordered on the east by the older Dunn Creek Slate and on the west by the younger Hiawatha Graywacke, Stambaugh Formation, and Fortune Lakes Slate. The iron-formation crops out in a zigzag belt which extends without gaps from the Odgers mine in the S½ NE¼ sec. 30, T43N, R32W, to the

Balkan and Judson mines at the south edge of the area described. From there it continues to the Brule River southeast of Stager. The strata are all steeply inclined, and as the zigzag pattern implies, are involved in a series of close folds with steep plunge.

Stratigraphy

Dunn Creek Slate

In contrast to most of the rest of the Iron River-Crystal Falls district, the Dunn Creek Slate is exposed in many places in the southern Crystal Falls area. The bulk of the exposures, however, are within the Panola Plains area to the east, and the major discussion of the field occurrence of this unit is taken up in the report on that area (Pettijohn, Gair, Wier, and Prinz, 1969).

The uppermost part of the Dunn Creek Slate, as elsewhere in the district, is a distinctive pyritic graphitic slate -- the Wauseca Pyritic Member. This is one of the best marker beds of the whole sequence in the district. It is, however, very rarely found in outcrop because it rapidly deteriorates upon exposure to the atmosphere. It is known, therefore, largely from drilling and underground workings, though several test pits have reached this member.

The upper 20-30 feet are the most characteristic part of the Wauseca Pyritic Member. This material is a very fissile coal-black to dark-gray slate. The slate is highly graphitic (up to 23 percent carbon) and charged with iron sulfide in the form of scattered fine-grained pyrite crystals and veins. The slate is sooty, readily marks paper, and soils ones fingers. It has a greasy black streak. In places the laminated graphitic slate shows an excellent slaty cleavage which crosses the bedding.

Associated with these fissile, laminated slates is a massive, nonbedded, graphitic slate breccia. This rock consists of a dense, structureless matrix in which are scattered thin angular fragments of black graphitic slate. The slate flakes or fragments are randomly oriented, and are 1/16 to 1/2 inch in maximum diameter. This facies, the "speckled gray", is widespread and is known throughout the Iron River Crystal Falls district. It is found on test-pit debris in the NW¼ SE¼ sec. 13, T42N, R33W, and it has been observed south of the map areas in drill core from the SE¼ SE¼ and the NE¼ NW¼ sec. 24, T42N, R33W near the Delphic mine.

One of the most striking characteristics of the graphitic slate is its rapid deterioration when it is exposed to the air. Even drill core will, in due time, swell, become stuck in the core box, and finally disintegrate into a sooty "duff." A white efflorescence coats the material in the late stages of disintegration. Similarly, in underground workings the rock forms soft ground which will not stand unless heavily timbered. This behavior is, no doubt, due to the rapid oxidation of the iron sulfide in which the rock abounds.

Drilling shows the thickness of the graphitic and pyritic slate to be about 20-30 feet. This slate grades downward, however, into a laminated slate consisting of thin seams of black, graphitic slate that alternate with fissile gray slate which contains small disk-shaped chert nodules. The combined thickness of the two types of slate must be about 65-75 feet. These beds grade downward into gray sericitic slate and silty graywacke.

The contact with the overlying iron-formation appears to be sharp, both as shown by drilling in the Monongahela area and as shown in a road-ditch exposure northwest of the Mastodon mine.

Riverton Iron-Formation

The productive iron-formation of the southern Crystal Falls area crops out mainly along an almost continuous, but zigzag, belt extending from the Odgers mine, to the south edge of the area here described, thence to the Brule River southeast of Stager. This belt can be traced with certainty by outcrops, test pits, and drilling from the northeastern part of sec. 30, T43N, R32W, through the northwestern part of sec. 31 of the same township, across sec. 36, T43N, R33W, then through sections 1, 12, and 13 of T42N, R33W. Along this belt were found some of the largest ore bodies of the district. From north to south, the mines located along this belt are the Odgers, the Volunteer, the Genesee (Ethel), the Tobin, the Shafer (North Columbia), the West Columbia, the Monongahela, the Carpenter, the Dunn, the South Dunn, the Book, the Alpha, and the Balkan-Judson. The zigzag course of the outcrop belt is due, as pointed out elsewhere, to a series of close, northwest-plunging folds in which the iron-formation and adjacent strata are involved.

The iron-formation is known to occur in several lesser areas apparently not connected with the chief occurrence. The iron-formation at the Mastodon mine, in the E½ sec. 13, T42N, R33W, seems to be isolated from the main belt. Certainly that which occurs at the Kimball mine in the SE¼ SE¼ sec. 29, T43N, R32W, is completely detached. The iron-formation exposed northeast of the Kimball mine at the May exploration, if there is any at this place, must also be a detached part of this bed.

Various terms have been used to describe the "iron-formation". The unoxidized parts of the iron-formation consist mainly of thinly bedded chert and siderite. The unoxidized iron-formation commonly has been called "cherty iron carbonate" or less commonly "sideritic chert". The more fissile carbonate-rich layers have occasionally been reported as "gray slate". The term "sideritic chert" is not appropriate, inasmuch as it does not indicate whether the rock is a bed of chert with siderite (which it is not) or whether it is a rock consisting of thin alternating layers of chert and siderite (which it actually is). In some records, the term "unoxidized iron-formation" is used. Locally the formation has been much altered by oxidation -- and in some places profoundly so.

The siderite has been partly or wholly converted to hematite or goethite. To the oxidized phases the terms "banded ferruginous cherts", "ore formation", "soft ore jasper", and "salt pork" have been applied. The term "oxidized iron-formation" is also used.

In this report, and on the accompanying maps, the terms used are those reported on the drill records unless the core has been seen by the author, in which case the material seen is recorded as "chert and hematite," "chert and siderite," etc. The term "iron-formation" is not used for single outcrops, test pits, etc., but is reserved for the whole complex, which in the unoxidized state is a thin bedded generally crumpled rock consisting of an alternation of layers of chert and siderite together with some iron-silicate.

The iron content of the oxidized formation ranges from 30 percent to 55 percent or more. That which runs 40 to 50 percent iron is commonly called "lean ore" -- a nonmerchantable material. The term "ore" is reserved for material in excess of 50 percent metallic iron. Iron content alone is not a certain guide to iron-formation. Some beds in the Stambaugh Formation may carry as much iron as the leaner parts of the iron-formation. The pyrite-rich graphitic slate -- the Wauseca Pyritic Member -- also is iron rich.

At no place is there a completely exposed section of the Riverton Iron-Formation. In addition to inadequate exposure, the complexity of structure makes the piecing together of a section very difficult. It is even difficult to estimate the thickness of the formation with any reasonable accuracy. Very probably, however, the formation does not exceed 800 feet at any place. At the Odgers mine the formation is about 500-550 feet thick inasmuch as this is the distance, normal to strike, between the base and the top of the formation on the 6th level. The beds are vertical.

Footage	Description
0-5	Somewhat slaty bed; mainly nonmagnetic; chert occurs as both small and large nodules.
5-10	Cherty iron-formation; mainly nonmagnetic; chert in layers 1/2 inch to 3 inches thick.
10-15	Cherty iron-formation as above; a few magnetic layers; dip vertical or steeply north.
15-20	Cherty iron-formation; several magnetic laminae.
20-25	Cherty iron-formation; considerable chert; small drag fold with northwest plunge; mainly nonmagnetic.
25-30	Cherty iron-formation; nonmagnetic; small drag fold which has 25° plunge to northwest.
30-45	Slaty iron-formation; mainly nonmagnetic; chert in layers; 1-foot shear zone between 40 and 45 feet.
45-50	Cherty iron-formation; several magnetic laminae.
50-55	Cherty iron-formation; numerous magnetic layers. The fissile slaty layers seem to be magnetic; the chert layers are nonmagnetic.
55-65	Same (?); poorly exposed.
65-70	Slaty iron-formation; few magnetic layers.
70-75	Slaty iron-formation; numerous hard platy layers; magnetic zones common.
75-80	Slaty iron-formation; a little nodular chert; nonmagnetic.
80-95	Slaty carbonate and thin chert layers; nonmagnetic.
95-100	Laminated, vuggy chert; chert beds 2-4 inches thick.
100-130	Very cherty iron-formation; little or no slaty material; nonmagnetic
130-135	Same; poorly exposed.
135-145	Cherty iron-formation.
145-170	Same; less cherty, but that chert present is in thick beds.
170-180	Same; 6 inch chert bed near top.
180-195	Cherty iron-formation; poorly exposed. North end of cut, transfer to outcrop along next grade cut to the east.
195-200	Cherty iron-formation; steep south dip.
200-205	Slaty carbonate and chert.
205-210	Carbonate and cherty iron-formation.
210-220	Same (?); poor exposure.
220-245	Covered. Numerous angular fragments of limonite and chert leave no doubt that iron-formation is present in this interval.
245-250	Chert and carbonate; poorly exposed.
250-265	Covered.
265-270	Covered. Transfer to outcrop east of railroad grade.
270-275	Slaty iron-formation; same strike.
275-300	Broken outcrop iron-formation.

Table 1. Measured section of Riverton-Iron Formation along old railroad grade west of Odgers pit, SW¼ NE¼ sec. 30, T43N, R32W. Section measured from south to north -- upward in the stratigraphic section. Strike about N 80°-85° W; dip vertical to steeply southward.

On an old railroad grade just west of the Odgers cave (see plate 1), some 300 feet of iron-formation is exposed in virtually continuous section. No discernible change in

strike occurs within this section nor is there any obvious repetition by folding or faulting. Neither the base nor the top of the formation is visible. It is obvious, therefore, that the formation must exceed 300 feet in thickness. The description of this section is given in table 1.

The formation is known to contain a magnetic bed about midway between its base and its top. This magnetic zone is exposed in the Odgers cut and was the lowest part of the section measured at this place. The magnetic bed consists of interbedded, nonmagnetic chert and thin-bedded platy magnetic slate. About 75 feet of more or less magnetic rock is exposed. Above the magnetic zone is 20 feet of slaty iron carbonate which contains little chert, overlain by a zone, 40 feet thick, rich in chert. The uppermost 165 feet exposed is chert poor and is mainly slaty carbonate. It is clear that the section here exposed is the upper half of the iron-formation.

In all the mines in the southern Crystal Falls area, with the possible exception of the Kimball, the ore was formed from a bed within the iron-formation. The base of this bed apparently lay about 100-125 feet above the footwall graphitic slate. The top of the bed probably was the base of the magnetic horizon though evidence on this point is not clear. The ore-forming bed probably was a very cherty zone, below which lies a dark slaty zone characterized by small pea-sized chert nodules -- the "raindrop slate". This bed, though rich in iron, is somewhat graphitic and is prone to resist oxidation. It seems to be the footwall of most of the ore bodies. Below it, and above the true footwall, is a cherty iron-carbonate bed which in many places is unoxidized.

The approximate subdivisions of the iron-formation would then seem to be, from the base upward: (1) cherty iron-carbonate, 75 feet, (2) graphitic cherty sideritic slate, 25 feet, (3) ore-forming bed, 75 feet, (4) magnetic slate and chert, 75 feet, (5) slaty iron carbonate, 20 feet, (6) cherty iron-carbonate, 40 feet, and (7) slaty iron carbonate, 190 feet.

Hiawatha Graywacke

The Hiawatha Graywacke, Stambaugh Formation, and the Fortune Lakes Slate comprise the upper part of the Paint River Group. Commonly these strata are referred to as the "hanging-wall" strata or sequence. The occurrence and characteristics of these units are summarized in table 2.

The lowest formation in the hanging-wall sequence, the Hiawatha Graywacke, consists of two facies: (1) chert breccia, and (2) graywacke. Either facies may occur alone or they may be interbedded or gradational into each other. The Hiawatha is poorly exposed in the southern Crystal Falls area although it probably overlies the iron-formation throughout the area.

Although the chert breccias, the associated graywackes, and the unconformity below them are best displayed in the northern Crystal Falls area in outcrops along the Paint River in the SE¼ sec. 20, T43N, R32W, they are known to occur elsewhere in the district. Apparently the breccias and their contact with the underlying iron-formation were well exposed in the workings of the Odgers mine (plate 1). The relations were described by Mr. Frank Blackwell[1] as follows:

> "The unconformity between the iron formation and the upper slates has been observed on both the 3rd and 4th levels. The materials above the contact consist of conglomerate grading into graywacke and then into graphitic slate, then broken gray carbonate slate (these materials are of various thicknesses). Lying above the broken gray carbonate slate is gray carbonate slate which is very blocky, the thickness of which is not known for it extends beyond the ends of the crosscuts."
>
> "The contact between the iron formation and the upper slates is found approximately 80 feet south of the center line of No. 2 Shaft. The contact is at an angle to the bedding planes of the iron formation and strikes approximately N 53° W at this point. Butting up against the iron formation is the basal conglomerate of the upper slates. This conglomerate consists of broken fragments of iron formation, most of which are angular, some are well rounded, and strongly resembles a breccia in appearance. The conglomerate varies in thickness, being approximately 7 feet thick on the east side of the crosscut and 4 feet thick on the west side. The conglomerate is composed of coarse fragments at the base, the fragments become smaller as the top of the belt is reached and grade into graywacke. The graywacke varies in thickness and grades into a fine-grained graphitic slate. The total thickness of graywacke and slate is approximately 7½ feet on the east side and 6½ feet on the west side of the crosscut. Overlying the graywacke and graphitic slate is about 4 feet of broken gray carbonate slate."
>
> "The contact between the iron formation and the upper slates on the 4th level is just south of No. 2 Shaft. The contact is very irregular, being observed in three places, the general strike is approximately N 80° W. The thickness of the conglomerate varies and could be measured in but one place, namely, the drift from the pump station to the shaft. Here it is 13½ feet thick."

The basal breccias and associated graywackes were encountered in several drill holes in the vicinity of the Monongahela mine in the sec. 36, T43N, R33W (plate 2). The chert breccia in this area consists of large and small fragments of chert set in a medium to course grained dark graywacke matrix. The breccia, which is 15-20 feet thick, grades up into a black massive, somewhat graphitic graywacke, which may or may not contain scattered grains of chert. The graywacke is 10-30 feet thick so that the combined thickness of breccia and graywacke is approximately 30-45 feet at this place.

The formation is exposed at both the Dunn and Book mines. A dark coarse graywacke, having a rude verticle schistosity, crops out in an old road bed and in low ledges about 300 feet northwest of the Dunn open pit in the NW¼ NE¼ sec. 1, T42N, R33W (plate 2). Chert breccia was encountered in an old test pit in the same location. Dark graphitic graywacke of the basal hanging-wall series was exposed in a diversion ditch near the southwest corner of the open pit at the Book mine in the SE¼ NE¼ sec. 12, T42N, R33W (plate 3). The basal graywacke was also reached in an old test pit near the S½ corner of sec. 24, T42N, R33W. In the test pit it is somewhat sheared and greenish in appearance. The basal graywacke was also encountered in a test pit near the Alpha mine, in the SE¼ SE¼ sec. 11, T42N, R33W, and in drill holes on the Balkan property in the NW¼ sec. 13, T42N, R33W (plate 3).

[1] Unpublished geological report of Odgers mine, dated 1922. (The McKinney Steel Company).

Stambaugh Formation

The breccias and graywackes of the Hiawatha Formation are overlain by slate, the basal part of the Stambaugh Formation. In outcrop, the slate is laminated, gray on fresh fracture. It oxidizes to a very soft, fissile, laminated red and green slate. The slate contains little or no chert and is nonmagnetic. In the Monongahela area (plate 2), in the E½ NE¼ sec. 36, T43N, R33W, some 68 feet was encountered in drilling.

The most distinctive unit within the Stambaugh Formation is a flinty fine-grained rock, thinly laminated, iron-gray to black on fresh surface, commonly mauve or purplish where slightly weathered. It commonly has a subconchoidal fracture, but in places has a platy parting parallel to bedding. Magnetite is disseminated throughout as very small grains, and the unit generally gives rise to a strong magnetic anomaly. The thickness in outcrop is about 40 feet, and a like thickness has been disclosed by drilling in the Monongahela area. To the south the flinty magnetic slate gradually loses its distinctive lithologic character and assumes more the appearance of a normal slate. The flinty facies is well exposed in the SE¼ SE¼ sec. 25, T43N, R33W (plate 2) and the more slaty facies is exposed in many outcrops in the Stager area to the south, in the SW¼ SW¼ sec. 31, T42N, R32W.

In the northern part of the area, the magnetic slate grades upward into mudstone interbedded with porcelanite. The term "mudstone" is more appropriate than slate (or shale) for these beds inasmuch as they are without bedding-plane laminations or fissility. They have a "blocky" habit. Regular jointing in two directions intersects the bedding and divides the rock into small cubical or prismatic blocks. Internally these blocks are structureless and they consequently fracture in a very irregular to subconchoidal manner. Most outcropping ledges are heavily tarnished with a metallic, iridescent blackish film -- probably limonite. Even apparently fresh pieces will break along irregular surfaces which exhibit such a tarnish. The rock is fine-grained and is composed of quartz, chlorite, and minor stilpnomelane. In drill core it is dark green -- almost black -- and tends to remain in long segments. In addition, the rock characteristically contains minute flecks of pyrite. Some of the mudstone is slightly magnetic and is in part responsible for the anomalies attributed to the underlying magnetic slate.

Always associated with the mudstones are porcelanites[2] which occur in beds from one half inch to a maximum of 24 to 36 inches in thickness. They are actually sideritic chert, a very tough, dense rock lacking any kind of cleavage, and are snow white to light gray or pale green. Like ordinary chert it yields sparks when struck with a hammer, breaks with a conchoidal fracture, and has a dull porcelaneous luster. But, unlike ordinary chert, the porcelanite effervesces vigorously in hot dilute acid and, on weathering, acquires a dense, heavy crust or armor of black limonite. The limonite armor, 1/2-1 inch thick, so effectively coats the porcelanite beds that the presence of these beds in the tarnished mudstones often is not suspected, and the discovery of the snow-white varieties upon breaking through the black limonite coating comes as a repeated surprise. The limonite oxidation proceeds naturally from the outside in and is so rapid that pieces are tarnished black after a one year exposure. The oxidized material is apparently the first alteration product of the siderite, disseminated throughout the porcelanite beds. Some of the gray porcelanite is magnetic. Close inspection of the porcelanite commonly shows delicate laminations marked by faint ill-defined color differences. In some places the laminations are minutely crumpled and occasionally show small scale faulting. However, no fractures or fracture fillings can be seen and it seems probable, therefore, that the deformation took place in the soft sediment at the time of deposition. The porcelanite-mudstone member is about 35 feet thick in outcrop.

[2] The term "porcelanite" has been applied to various rocks. It is purely descriptive and denotes a rock with the appearance of unglazed porcelain. It has been applied mainly to calcerous and argillaceous cherts. It is here applied to a sideritic chert.

Fortune Lakes Slate

The uppermost mudstone unit of the Stambaugh Formation grades into the Fortune Lakes Slate, the lowest strata of which consist of light and dark-gray slate, and locally of interbeds of mudstone, porcelanite, and pyrite. On the whole, the rocks are rather fissile. Like the underlying beds, they acquire a heavy metallic and iridescent tarnish on exposure. To some extent the various rock types within the lower part of the section are repeated in a cyclical fashion. The pyrite, which occurs in a very thin seam (1/8-1/2 inch thick), underlies a thin porcelanite bed (1/2-2 inches thick), which in turn grades upward into and is overlain by a thin gray carbonate-rich slate which grades upward into a thicker stilpnomelane mudstone. (Elsewhere in the district these pyritic rocks occur with the Stambaugh Formation). The whole

sequence is but 3-30 inches thick, the bulk of which is the carbonate slate and the stilpnomelane mudstone. The position of the sulfide layer below the porcelanite seam is a criterion useful in determining the order of superposition where such order is otherwise unknown.

Interbedded with these slates are some course sandy beds. These dense and massive graywacke beds are 6 inches to 2 feet thick, and record the first influx of coarse clastic material into the basin in which the peculiar chemical sedimentation was taking place. The graywackes occur as distinct beds and contain large well-rounded quartz grains and, in places, fist-sized pieces of porcelanite. Such pieces are evidence of contemporaneous channeling of the porcelanites. The graywackes in some places seem to be dikes which traverse the porcelanites and other beds.

The lower slate unit is not well exposed in the southern Crystal Falls area though rather poor outcroppings can be seen in several places (See for example plate 2). The thickness of the unit is certainly several hundred feet.

The lower slate of the Fortune Lakes Slate is succeeded by a unit that consists mainly of (1) heavy massive quartzitic graywacke beds, and (2) intercalated slates. Though several thin beds of graywacke appear in the underlying slate, the unit here defined has at its base a very heavy and massive graywacke bed. This bed, over 30 feet thick, crops out over much of the southern Crystal Falls area. There are several good exposures of this bed and associated rocks west of the Tobin Location in the N½ SW¼ sec. 30, T43N, R32W (plate 1), also in the southeastern part of sec. 25 and the SW¼ SW¼ sec. 36, T43N, R33W. Good exposures are found in the NE¼ NW¼ and the NE¼ SW¼ sec. 1, T42N, R33W (plate 2). Rather poor roadside exposures occur in the NW¼ sec. 12 of the same township (plate 3). Exposures are rare south of sec. 12 except near the Brule River where they abound.

The thickness of this unit is poorly known as its top is not well defined. Estimates based on the outcrops in the NW¼ sec. 30, T43N, R32W indicate a thickness of at least 1,000 feet of graywacke and slate.

The graywackes are very massive, almost structureless, except for a rude foliation locally present as a result of severe mashing and shearing. The massive beds are broken only by widely-spaced joints, which together with the bedding planes, set free very large blocks of the formation that appear as float both near broken outcrops and in the glacial drift. In size and angularity they are rivaled only by the greenstones and in company with the latter they appear in great abundance in the stone fences traversing the outcrop area of this formation.

Individual graywacke beds vary greatly in thickness. Rarely are they less than 1-1½ feet thick and none were observed to exceed 30 feet (though thicknesses of 23 and 27 feet were measured on beds the exact limitS½ of which were not exposed). A 77 foot section, exposed at the intersection of Superior and High Streets, Crystal Falls, contained six graywacke beds varying from 1 foot to 12 feet in thickness and averaging over 4 feet each. The section, as measured, follows:

Section from north to south across vertical beds exposed in sec. 29, T43N, R33W, on west side of street, Superior and High Streets, Crystal Falls, Michigan.

	Thickness
Slate	17 ft.
Graywacke	2½
Slate	14
Graywacke	1
Slate	5
Graywacke, cut by 2 inch feldspar-bearing quartz vein	4
Slate	7
Graywacke	5¼
Slate	½
Graywacke (sample 44MC-300)	2
Slate	5
Graywacke	12
Slate	2
Total	77¼ ft.

As might be expected, the massive graywacke beds are most conspicuous in outcrop, whereas the interbedded slates are more commonly concealed. The slate in the above measured section forms nearly two-thirds of the whole section and, in general, it probably forms about nine-tenths of the graywacke-slate unit.

The individual graywacke beds are almost devoid of any internal structure. No ripple marks were seen nor was there any unmistakable cross bedding. Some gradation of grain size was noted. So massive are many of the beds that they show a large-scale conchoidal fracture indifferent to either the bedding planes or the constituent grains. The joints seen in some places are widely spaced, usually perpendicular to the bed, and commonly filled with feldspar-bearing quartz veins. These veins, 1-4 inches wide, terminate abruptly against the slate beds on either side. They resemble the rungs of a ladder, the sides of which are the bounding slates. So massive are most beds that the strike and dip of the rock cannot be ascertained unless the contact with the adjacent slate beds is discovered.

The graywackes weather but slightly and are light to dark dull gray in color. The fresh surface is a dark glistening gray black. In general the graywacke is an arenaceous, medium-grained rock containing large conspicuous rounded "glassy" quartz grains. Locally it is loaded with sharp angular chips of chert. In places, these, together with numerous flakes of dark-gray slate, are abundant enough and large enough to warrant the term "breccia," albeit, a breccia on a somewhat reduced

scale as compared with the coarse breccias which mark the basal part of the hanging-wall strata. Careful inspection of some of the pea-sized grits show that they contain a few large fresh pinkish feldspar grains.

The slaty interbeds, commonly laminated, have a well-defined slaty cleavage which, near the axial portions of the folds, makes a large angle with the bedding. The slaty cleavage, however, does not extend through the adjoining graywacke beds but is instead truncated by the graywacke-slate contact. The slate-graywacke contact is minutely "scalloped" in many of these outcrops with convex graywacke "lobes" between which are sharply pointed infolds of slate. The bedding of the slaty layers is commonly crumpled and it seems clear that much of the adjustment between beds during folding was taken up in these layers.

In some places the slaty interbeds are carbonate rich and are now deeply weathered to limonite. They show a box structure much like that displayed by the carbonate phases of the iron-formation.

The succession above the upper graywackes is very uncertain. Outcrops are too sparse to permit detailed description of the succession. A short distance north of the center of sec. 25, T43N, R33W, are outcrops of a strikingly banded slate. These outcrops are scattered in and between the NW¼ NE¼ and the NE¼ SW¼. In general the strata trend N. 10°-20° E. Though there is some irregularity of strike of the bedding in the individual outcrops, there is no such irregularity in the slaty cleavage which is uniformly about N. 70° W. In nearly all places, therefore, the bedding crosses the cleavage at a high angle, commonly nearly 90°.

The slates are generally gray on the weathered face with conspicuous somewhat dark layers. These layers apparently contain carbonate as they tend to be more deeply etched than the rest of the rock. Some chert is present. The remarkable banding, the near perpendicularity of cleavage and bedding, and the chert content make these slates a distinctive member of the hanging-wall formation.

The bedding-cleavage relations and the prevailing strike of the banded slates show them to belong to the same structure as the graywackes and slate of sec. 30 just to the east. They are structurally discordant with the iron-formation and associated slates which occur near the north edge of sec. 25, from which they are probably separated by a major fault.

Igneous Rocks

Granite

Several small masses of granite are present in the eastern part of the Iron River-Crystal Falls district. Their occurrence and general aspect are discussed in U. S. Geological Survey Professional Paper 570 (James, Dutton, Pettijohn, Wier et al, 1968). Two of the dikelike bodies occur within the southern Crystal Falls area, and some of the details of their field character are given here.

The larger of the two bodies is a salmon-colored rock that forms a poorly exposed dike-like body of considerable size west of the Paint River. It is conspicuously exposed in only one place -- a rock knob on the west bank of the river about 1,000 feet south of Highway M-69 (See fig. 3, page 10). Elsewhere the outcrops, much broken and badly sheared, consist of a few very large angular blocks readily mistaken for glacial erratics. The blocks are, however, angular and of considerable size -- 3-6 feet or more in length -- and distributed and related to a few undisputed outcrops, which leaves no doubt that they are actual outcrops. In some places the rock is so shattered and broken by a rude platy parting that the outcrop is mainly rubble. The salmon color of the rock is apparently due to potassium feldspar, which forms poorly shaped, almost round, crystals. Quartz is present but not readily visible. Sericite is abundant, and dark minerals are virtually absent.

The granite dike seems to parallel the structure in the slates for approximately half a mile. At the north end the dike turns sharply eastward, like the slates, and crosses the Paint River. This eastward bend in the dike is interpreted as an eastward "drag" adjacent to a major transcurrent fault.

A similar dikelike body occurs 1½ miles south, in the W½ sec. 4, T42N, R32W, and a single outcrop of granite of like character is present in sec. 33, T43N, R32W.

A smaller body of granitic rock occurs in the SE¼ NW¼ sec. 30, T43N, R32W (plate 1). Three small, badly sheared outcrops in this area, apparently a somewhat altered quartz porphyry, indicate the presence of a dikelike body striking approximately N. 60 W. This direction is nearly normal to the prevailing strike in this area.

Metadiabase

The basic intrusives of this area are dikes of more or less altered diabase. Several small dikes are exposed in the workings of the Shafer (North Columbia) mine. Two rather large dikes were encountered in both drilling and mining operations in the Balkan mine area just south of Alpha in secs. 12, 13, and 14 of T42N, R33W (plate 3). The large dikes, approximately 50 feet thick, strike about N. 60-65° E, and dip about 45° to the southeast.

No exposures of the dikes have been observed. A reported outcrop of metadiabase near the road fork in the NW¼ SE¼ sec. 7, T42N, R32W, could not be located. If present it would suggest that the north dike has a length of at least 2 miles. The south dike has an inferred length of about half a mile. The southwest ends of the dikes appear to be offset along northwestward-trending faults.

Structure

Casual inspection of any outcrop in the southern Crystal Falls area shows that the strata of the area have been closely folded. The dip of the beds is everywhere nearly vertical. Only rarely is a dip recorded of less than 70°-80°. Nowhere are the beds horizontal. The angle of dip is usually of little significance inasmuch as overturning of the beds is common. The structures in which the strata are involved are determined, therefore, not by plotting dips but by tracing beds of known stratigraphic position and by study of the patterns disclosed by such mapping.

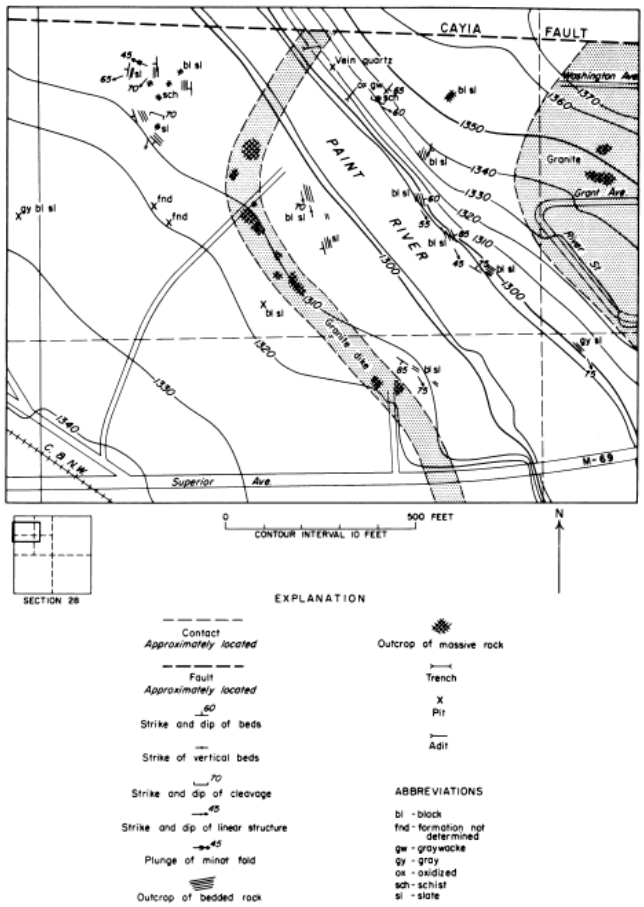

Figure 3. Outcrops in NW 1/4 section 28, T43N, R32W with area of granite stippled. Geology and topography by F. J. Pettijohn and J. R. Balsley, 1943.

Crumpling is a characteristic feature of the iron-formation. These minor drag folds, especially well shown in the weaker, less competent layers, exhibit plunges ranging from 0° to 90°. They would perhaps average 45°. The form of most drag folds bears definite relation to the fold of next-order magnitude. Consequently they are of considerable aid in locating the position of larger structural features.

The slaty rocks have pronounced cleavage. In general, the bedding and cleavage are nearly parallel, but locally, near the axial portions of the folds, these two structural features may be widely divergent. In axial regions the slates break up into "pencils" or fragments of the size and appearance of split wood. Such slates are, moreover, characterized by cross veins, commonly low dipping, which are perpendicular to the pencil structure. These various features are well shown in the striped slates near the center and in the northeastern part of sec. 25, T43N, R33W.

Folds

Two-thirds to perhaps three-quarters of all strike readings in the southern Crystal Falls area fall in the northwest quadrant. The average strike is about N. 50°-60° W. The prevailing strike of the slaty cleavage is likewise northwesterly. There is a tendency for the cleavage, and to a certain extent the bedding also, to show a more westerly strike near the west limits of the southern Crystal Falls belt and a more northerly strike in the central and eastern parts of the area. Unlike the strike, the dip shows no prevailing habit. Northeasterly and southwesterly dips are about equally common.

Despite the great dominance of northwesterly strike of the bedding, the trend of the formations as a whole is about north-south, as well shown by the Riverton Iron-Formation. The zigzag map pattern is the expression of a series of steeply plunging folds, the plunge of which is northwesterly. The axial planes of these folds appear to be nearly vertical, though they may be locally overturned. The axial planes of the principal folds are 500-2,500 feet apart and average about 1,500 feet.

One notable feature of these folds is the slight warping of their axial planes. This curvature of the axial plane is in accord with the general change of the strike of the slaty cleavage from N. 10°-20° W. in the central part of the belt to N. 70° W. in the western part. Many axial planes have about a N. 70° W. trace on the horizontal plane near the west edge of the area; farther east the trace becomes more nearly N. 45 W. and in a few places it may become nearly north-south.

For the most part, the limbs of the folds are equally well developed. In a few cases, however, one of the limbs is faulted out.

Faults

The southern Crystal Falls belt is broken by faults in several places. The principal faults, however, are at the north end of the belt. The most northern of these faults -- the Runkle Lake and Cayia faults -- have been noted (Pettijohn, 1970) in discussion of the structure of the northern Crystal Falls area but will be reviewed here also. The Cayia fault, together with the North Kimball and South Kimball faults, virtually separates the northern and southern Crystal Falls areas.

The Cayia fault, though not so named, was first noted on the 1929 Geological Map of Iron County (Barrett, Pardee, and Osgood, 1929). As shown on this map, it was traced from sec. 32, T43N, R31W, west and slightly northwest to sec. 27, T43N, R32W, a distance of about 4 miles. This fault displaces an iron-formation, with associated rocks, between the Cayia and Hope mines.

The apparent horizontal displacement is about 3,000 feet. The fault was not shown to extend west of the east end of Runkle Lake.

It now seems probable that this fault continues much farther west, across secs. 28, 29, and 30, and into sec. 25, T43N, R33W. Therefore, it probably extends 6 miles, and may be over 8 miles, along its strike. (See Plate 1, U. S. Geological Survey Prof. Paper 570, James, Dutton, Pettijohn and Wier, 1968).

The chief evidence for the westward extension of the Cayia fault is the areal map pattern, particularly with respect to the Riverton Iron-Formation and the Stambaugh Formation. The magnetic anomaly related to the latter formation terminates in the SW¼ SW¼ sec. 21, T43N, R32W, and resumes in the NE¼ NW¼ sec. 29, three-fourths of a mile southwest. A small (500 gamma) anomaly in the NE¼ NE¼ sec. 29 (See Northern Crystal Falls Area report, Pettijohn, 1970) is assumed to reflect an isolated segment of the formation, caught between the Runkle Lake and Cayia faults.

South of the Cayia fault is the northwestward-plunging Kimball syncline (plate 1). The syncline is marked by V-shaped patterns of formations and is cut off by faults both to the north and south. The faults are referred to as the North Kimball and South Kimball faults. Of these, the South Kimball fault is better established. This fault is a major structure running east southeast from the NE¼ sec. 25, T43N, R33W, to the NE¼ sec. 32, T43N, R32W. The horizontal displacement seems to be at least 4,000 feet.

The evidence for existence of this fault is also largely drawn from the areal map pattern. Iron-formation occurs at the Odgers and Kimball mines. No connection of iron formation between them has been found. Drilling near the west line of sec. 29 apparently passed from hanging-wall into footwall strata without cutting the normal thickness of Riverton. The strong and well-defined magnetic anomaly produced by the Stambaugh Formation terminates just north of the Odgers mine in sec. 30. The formation is displaced southeastward into the western part of sec. 29. Furthermore, the graywacke beds (Fortune Lakes Slate) north of exposed Stambaugh Formation in sec. 29 strike westward. So, if they are not interrupted, they would extend into an area south of the Odgers mine known to contain footwall slate (Dunn Creek). It appears virtually certain, therefore, that a major fault separates the iron-formation and associated strata of the Kimball syncline from the same strata in the Odgers anticline.

Extension of the South Kimball fault west of the Odgers mine is based on outcrop data in the NW¼ sec. 30, T43N, R32W and parts of the adjoining sec. 25, T42N, R33W (See Northern Crystal Falls Area report, Pettijohn, 1970). The striped slates exposed in this locality are stratigraphically high in the Fortune Lakes Slates. The most western exposures are separated by a mile of cross strike distance from the underlying Stambaugh Formation west of the Odgers mine. Yet these same slates are in places within 1,000 feet of the north (Fortune Lakes) belt of Riverton Iron-Formation. Probably at least 1,500 feet of strata is missing. North of the fault both bedding and cleavage strike east-northeast; south of the fault the beds have general northerly strike and are crossed by a cleavage that trends about N. 70° W.

The evidence for the North Kimball fault and its northern split is sparse; it consists mainly of truncation and segmentation of the magnetic anomaly that is assumed to be due to the Stambaugh Formation (See plate 1).

KIMBALL AREA

The Kimball area (plate 1) includes the E½ SE¼ sec. 29, the SW¼ sec. 28, slightly more than half of the N½ NW¼ sec. 33, and the NE¼ NE¼ sec. 32, all in T43N, R32W. The Kimball mine is in the SE¼ SE¼ sec. 29. Also within the map area are the May exploration and the exploration of James and Rahrer.

Geology

The outcroppings of bedrock are found principally on Kimball hill, mainly on the southward or eastward-facing slopes near the southeast corner of sec. 29. Bedrock is close to the surface and crops out in three or four places along or near the grade of the Chicago and North Western Railroad on the west side of the Paint River. Bedrock was encountered in most of the many test pits shown along the railroad from the north edge of the map area to its southeastern extremity.

Unlike most areas in the southern Crystal Falls area, all outcrops in the Kimball map area, with one or possibly two exceptions, are the Dunn Creek Slate. In the Kimball mine area proper these outcrops are cherty black slates with a number of prominent beds of coarse black graywacke, some of which contain numerous small chips of chert. The rock encountered in the May and in the James and Rahrer explorations is mainly soft gray to black slate or phyllite, commonly oxidized to a red or yellow color, together with a red or bleached and somewhat "punky" graywacke. Soft graphite slate was also encountered in several places.

The Riverton Iron-Formation is poorly exposed in a low bank just south of the No. 2 shaft of the Kimball mine. It was reached in several test pits west and north of the shaft. In all places, the formation is thoroughly oxidized and consists of hard limonite or red hematite and chert. The iron-formation is not certainly known to occur in either the May or the James and Rahrer explorations, though a little hematite and chert may be found in the dumps of two test pits together with much black slate.

The dominant structure is the Kimball syncline, the axis of which enters the map area at the northwest corner and extends southeastward from this point to the southeast corner of sec. 29. This structure is best delineated by the magnetic anomaly associated with the

magnetic slate of the Stambaugh Formation. This anomaly has a V-shaped map pattern, the apex of which lies in the Kimball map area on the west line of the NE¼ SE¼ of sec. 29. The Kimball syncline is further defined by the attitude of the bedding in the footwall slate on Kimball hill. The strike southwest of the Kimball shafts is northwesterly and the dip is easterly. Near the SW¼ corner of sec. 28 however, the strike is northerly or even northeasterly and the dip is generally westerly. Drag folds in several places show that the structure plunges northwestward as would be inferred from the pattern of the magnetic slate anomaly of sec. 29.

The structure in the east half of the map area is uncertain. In general, the strike is apparently northwesterly, roughly parallel to the railroad grade.

Magnetic Anomalies

The Kimball area was surveyed magnetically with a Schmidt-type vertical magnetometer. Readings were made at 100 foot intervals along lines spaced 200 feet apart. Outcrops and test pits were located on the same grid. Two strong magnetic anomalies occur within the area. The strongest, which exceeds 2,000 gammas, is at the apex of the V-shaped anomaly produced by the Stambaugh Formation. The relation to the Stambaugh Formation is demonstrated by a small outcrop in the backyard of a house on the northeast corner of Wisconsin Avenue and Seventh Street. This is in the NW¼ SE¼ sec. 29, about 1,000 feet west of the map area. A locally pronounced anomaly occurs in the northwest part of the SW¼ SW¼ sec. 28. The magnetic relief exceeds 500 gammas at several points. The cause of this anomaly is not known with certainty. A single test pit on the anomaly yielded fragments of laminated, somewhat oxidized, slate. The fragments were, however, nonmagnetic. In the southern Crystal Falls area only the Riverton Iron-Formation and the Stambaugh Formation are known to produce anomalies of the magnitude and character of that mapped. Although possibly due to a bed within the iron-formation, it seems more probable that the anomaly is produced by the Stambaugh Formation. If so, then a body of this slate seems to have been isolated, presumably by faulting, from the same bed in the northwest part of the map area.

A strong negative anomaly lies in the northwestern corner of the NE¼ SE¼ sec. 29. This is no doubt the complement to the strong positive anomaly produced by the Stambaugh Formation. The magnetically low area north of the No. 2 shaft of the Kimball mine may be produced by the oxidation of the iron-formation known to occur in this place.

Mines

Kimball

The Kimball property (plate 1), located in the E½ SE¼ sec. 29, T43N, R32W, was formerly known as the Juniette (also Juniata and Junietta). Exploration in 1882 was confined to the north "forty" and apparently proved fruitless although a banded ore formation was reported. The property was later leased by the Kimball Iron Company and by 1887 six test pits had been sunk in the south "forty", north of the slope which forms the footwall of the ore. The iron-bearing formation was shown to trend east and to dip north. The exploration is said to have shown ore over a width of 40 feet in one place and traceable some 400 feet along the strike.

Apparently little further work was done until 1889 when shaft sinking was undertaken. The results could not have been promising as no additional work was apparently done until 1909 when the workings were dewatered and re-examined. Mining was not undertaken, however, until 1906, when further exploration was done by Corrigan, McKinney and Company. Operations in 1907 resulted in shipment of 16,224 tons of ore. By that date the shaft was 360 feet deep and four levels were extended from it. The ore came from the 3rd and 4th levels. The mine was idle in 1908 and has apparently remained so since that time. Total shipments were 35,757 tons in 1915, including shipment from stockpile. The ore was reported to be a hard, red, high-phosphorous nonbessemer hematite.

The ore body apparently lay near the axis of the Kimball syncline. The general trend of the ore was about east-west. Apparently some effort was made to trace the iron-formation beyond the limits of the workings, without success. A north-south row of test pits near the east line of the property disclosed only slate and graywacke, in the main unoxidized. Inasmuch as the strike of the slate that crops out near the southeast corner of sec. 29 is generally northward, the iron-formation east of the Kimball workings must also turn northward.

The Kimball mine was reopened in about 1961 as a tourist attraction, but the author had no opportunity to examine the now accessible workings.

Explorations

Section 28, Town 43 North, Range 32 West

There is some uncertainty concerning the location of the May and the James and Rahrer explorations. The May exploration is shown in *Lake Superior Iron Ores*, published by the Lake Superior Iron Ore Association in 1938, as forming the SW¼ NW¼ sec. 28. It also has been reported to be in the SE¼ SW¼. This latter area, however, is shown in the report of the Lake Superior Iron Ore Association as the "James and Rahrer Exploration." Residents of Crystal Falls place the May "mine" in the NE¼ SW¼ (Lot 7). The date of the May exploration is

uncertain. It seems to have been active during the decade 1882-92. The James and Rahrer exploration, generally shown as the SE¼ SW¼ sec. 28 (Lot 6), was probably explored sometime between 1882 and 1889.

None of the explorations in the SW¼ sec. 28 or in the adjacent NE¼ NW¼ sec. 33 seem to have located any ore. Certainly no ore was ever shipped. The work done seems to consist solely of test pits of which there are a great many. In the NE¼ SW¼ sec. 28, mainly on the west side of the Paint River, are many pits most of which encountered soft, red and gray slate or phyllite. A little graphitic slate, together with some hematite and chert, was also found. A group of test pits and a small shaft near the center of sec. 28 reached the same kinds of rock. In the SE¼ SW¼ sec. 28 are numerous test pits, mainly southwest of the railroad grade, which reached oxidized and partly oxidized soft gray slate and graywacke. In the NE¼ NW¼ sec. 33, a little graphitic slate and some hematite and chert were also encountered. Inasmuch as the strike of the outcrops near the river is slightly west of north, it is probable that these pits encountered the same beds as those reached in the NE¼ SW¼ sec. 28. It is unlikely that there is appreciable iron-formation in these areas. Probably the hematite and chert came from the cherty carbonate member (Dunn Creek Slate) of the foot-wall strata rather than from the Riverton Iron-Formation.

ODGERS-TOBIN AREA

The Odgers-Tobin map area (plate 1) lies mainly in sec. 30, T43N, R32W. It includes the S½ and the S½ N½ of this section. In addition, the N½ N½ sec. 31 of the same township is included. Within the area are the Odgers, Volunteer, Genesee (Ethel), Tobin, and Columbia (Shafer) mines. The combined production of these properties was nearly 14 million tons. This area is, therefore, one of the most productive in the Crystal Falls part of the district.

Geology

Outcrops are fairly numerous in most of this area. The overburden is generally thin except along the east and southwest borders of the map area where it attains a thickness of about 100 feet. The cover is greatest in the low ground in which the Odgers, Genesee, and Tobin mines are located.

The stratigraphic section is normal for the Crystal Falls area. As usual, the foot-wall strata (Dunn Creek Slate) are poorly displayed. Exposures are limited to one very small obscure outcrop of slate in the road ditch some 700-800 feet west of the E¼ corner of sec. 30, a small outcrop of slate about 800 feet west of the southeast corner of the section, and several outcrops of graywacke and slate near the S¼ corner of the same section. Footwall beds were encountered in test pits in the NW¼ NE¼ sec. 31 and were penetrated by numerous drill holes. The rocks of the Dunn Creek Slate are dark slate with some minor beds of graywacke, except for the uppermost beds, which are black, graphitic, and pyritic rocks (Wauseca Pyritic Member).

The Riverton Iron-Formation is exposed in several places. It is also visible in the pits of the Shafer, Tobin, and Odgers mines, but no iron-formation could be seen in the Genesee cave. The iron-formation apparently rests with sharp contact on the graphitic footwall slate and consists mostly of the usual alternating thin layers of chert and siderite. Oxidation, extensive near the ore bodies, has converted the siderite to hematite. In the Odgers mine, company records indicate that the formation contains a calcium carbonate bed, but this report has not been verified. A somewhat fissile, black graphitic and slaty member, characterized by small pea-sized chert nodules, lies about 50 feet above the base of the iron-formation and separates a lower cherty siderite bed from the rest of the formation. In the Odgers mine area in particular, the iron-formation contains a strongly magnetic member. The exact position of this bed is somewhat uncertain but it probably lies either near the middle of the formation or about one-third the distance upward from the bottom of the formation. Strongly magnetic material can be found in test pits and in outcrop near the center of the NW¼ SE¼ sec. 30. The magnetic beds are also exposed along the old railroad grades just west of the Odgers pit in the section previously described. This member does not differ greatly in appearance from the normal iron-formation, as it seems to consist of thin slaty beds alternating with the usual thin chert layers. The magnetite seems to be confined to the slaty layers.

The Hiawatha Graywacke is not exposed in this area, but it was found in the Odgers No. 2 shaft. The magnetic strata of the Stambaugh Formation are exposed several places north of the Tobin cave, and the overlying porcelanite-mudstone beds crop out in a road cut at the end of a street in the northwest part of the SW¼ SE¼ sec. 30. The pyritic gray slates that are the lower part of the Fortune Lakes Slate are found in several places in the Tobin location and elsewhere. The massive heavy-bedded graywackes and grits of that formation make their appearance some 500 feet above the Riverton-Hiawatha contact. Excellent exposures of these rocks are found at many places. Especially good outcrops occur some 1,300 feet west and 400 feet south of the center of section 30.

The Odgers-Tobin area is characterized by two principal structural features, the Odgers anticline, and the Tobin syncline. The Odgers anticline is an incomplete structure inasmuch as the northeastern limb is in part cut out by the South Kimball fault. The structure is shown by the magnetic anomalies of both the Stambaugh Formation and the magnetic member of the Riverton Iron-Formation. The workings of the Odgers mine lie on the northeastern flank of the anticline.

The Tobin syncline is a large structure especially well delineated by the magnetic line produced by the Stambaugh Formation and is confirmed by outcrops of

both the iron-formation and post Riverton beds. The beds in the Tobin mine area strike about east-west and dip north. To the north, in the NE¼ SW¼ sec. 30, the prevailing strike is northwest, and south dips prevail. Drag folds at several places confirm the west plunge of the syncline which is evident from the fact that the limbs diverge westward.

The axial plane of the Tobin syncline is decidedly warped. The trace of this plane is northwesterly near the west margin of the map area, whereas in the vicinity of the Genesee mine it is southwesterly.

In addition to the major South Kimball fault, previously discussed, there are two lesser faults within the Odgers-Tobin area. The smaller of the two lies about 500-600 feet south of the center of sec. 30. It offsets the magnetic line produced by the Stambaugh Formation. The strike of the fault is inferred to be about N. 60° W. The south wall of the fault seems to have moved some 200 feet northwestward relative to the north wall. The second fault is inferred from the offset in the magnetic anomaly in the SE¼ SW¼ sec. 30. The inferred fault has a strike of N. 60°-70° W. The south side seems to have been displaced about 600 feet westward relative to the north side. In the SW¼ SE¼ sec. 30 the fault places graywacke of the footwall Dunn Creek Slate about 250 feet from the hanging-wall Hiawatha Graywacke. The fault has not been recorded as occurring in the workings of the Tobin mine, though it probably formed one wall of the ore body mined.

Magnetic Anomalies

The Odgers-Tobin area was surveyed magnetically with a Hotchkiss Superdip oriented normal to the magnetic meridian and set with a "sigma" of 2°. Measurements were made at paced 100-foot intervals along traverse lines 200 feet apart. The instrument units were converted to approximate gamma values of vertical magnetic intensity above or below a local base station and were contoured. Outcrops and test pits were located with respect to the points of magnetic observation.

Sharp, well-defined magnetic anomalies are centered over the concealed "outcrop" of the Stambaugh Formation. The crest of this anomaly exceeds 3,000 gammas in several places and nearly everywhere reaches 2,000 gammas. The anomaly outlines the Tobin syncline and most of the Odgers anticline, beginning in the northwest part of the SW¼ SE¼ sec. 30 and extending southward to the center of the section, thence southeast to about the center of the SE¼ where it turns sharply southwestward. The anomaly lies just north of the Tobin pit and ends at the west end of this cave. A gap of about 600 feet, believed due to a fault, separates the south end of this anomaly from another anomaly, which runs southwestward to the southwest corner of sec. 30. Small irregularities in the course of the crest of the anomaly probably reflect minor drag folds.

A strong magnetic anomaly associated with a magnetic bed in the iron-formation occurs in the Odgers mine area. This anomaly locally exceeds 3,500 gammas and, together with the complementary "low", has a relief of nearly 5,000 gammas. The anomaly can be traced westward from the Odgers caved area around the nose of the Odgers anticline and southward into the NW¼ SE¼ sec. 30, where it ends abruptly. Magnetic rock, responsible for the anomaly, occurs in several outcrops and test pits along this feature. The abrupt ending of the anomaly at both ends can best be explained as being the result of oxidation of the magnetite in the oxidized and ore-bearing areas around the Odgers and Genesee mines. It is noteworthy that this anomaly, like that produced by the Stambaugh Slate, is asymmetrical in profile. The profile is steeper on its eastern side than on its western side, reflecting the over-all westward dip of the magnetic strata.

Mines

Odgers

The Odgers mine in the S½ NE¼ sec. 30 was opened in 1916. It shipped ore every year through 1935 except for 1931. It was operated by the Corrigan, McKinney Steel Company (which merged with the Republic Steel Corp. in 1935). The mine extended to a depth of 868 feet. The ore was a soft, reddish-brown, nonbessemer hematite rather high in sulfur content. Shipments totaled 2,101,381 tons.

The Odgers ore body lay on the north flank of the Odgers anticline. It was parallel to the bedding of the iron-formation, ran approximately N. 60°-70° E. and had a nearly vertical dip. On the 4th level it was about 700 feet long and had a maximum width of about 200 feet. It tapered toward both ends. The ore body contracted in all dimensions with depth. Unlike many ore bodies in this district, the ore seems to bear no clear relation to structure.

Unusually detailed geologic data are available for the Odgers mine from company records. A description of the relations at the top of the iron-formation has previously been quoted (p. 6). Other data are shown in figure 4, which is adapted from a cross section probably drawn in 1928 by Mr. Frank Blackwell, geologist for the McKinney Steel Company. As shown on the cross section, about 20 feet of conglomerate (certainly the Hiawatha Graywacke of this report) separates the iron-formation from "upper slates". The uppermost 150 feet of the iron-formation is "cherty iron carbonate" (unoxidized iron-formation), and this is separated at the lower levels from "ferruginous chert and ore" by a 30 foot layer of "calcium carbonate". This is the only record in the district of a limestone bed in the iron-formation. Its existence has not been verified.

At the 6th level, the total thickness of iron-formation between the "upper" and "lower" slates is about 500 feet. The ore body clearly is in a layer within the iron-

formation, rather than at its base as is common in the Iron River area. At depth it passed into oxidized iron-formation and at least locally thence into unoxidized iron-formation.

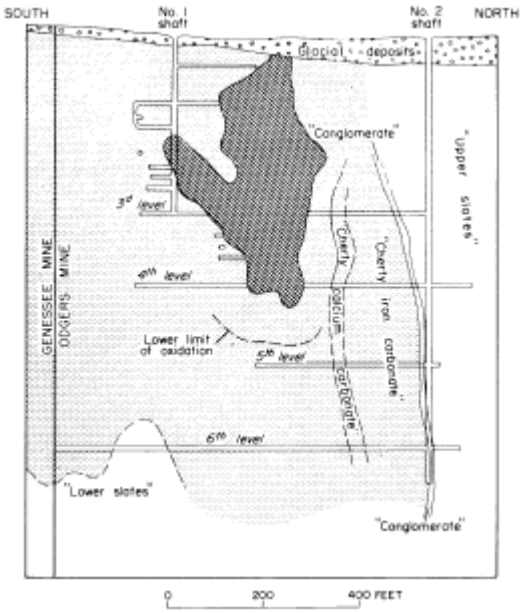

Figure 4. Section approximately through No. 1 and No. 2 shafts of Odgers mine, showing mined ore body (diagonal pattern in iron-formation (stippled pattern). Lithologic units and descriptions from company records.

Genesee

The Genesee property, once known as the Ethel, includes the SE¼ sec. 30, and the W½ SW¼ and NE¼ SW¼ sec. 29, T43N, R32W. The early ore shipments, made between 1902 and 1915, were from the Tobin ore body, which lies across the west line of the Genesee property. As the Tobin ore body was mined to greater depths, it was found to pitch westward so that in due time no ore was obtained from the Genesee part.

In 1928, ore was again shipped from the Genesee holdings. This ore, however, came from the NE¼ SE¼ sec. 30 where drilling had earlier shown the presence of ore. The operations were wholly underground and were connected on the 6th level to the Odgers. A long drift was also extended northeastward from the 14th level of the Tobin and was connected by a raise to the 6th level workings of the Genesee.

The mine was operated by Corrigan, McKinney Steel Company and its successor, the Republic Steel Corporation. The Genesee proper was extended to a depth of 860 feet. No shipments were made after 1935. The total ore credited to the Genesee is 1,198,383 tons of which the most, about 630,000 tons, came from the Genesee mine proper and the rest came from the Tobin operations. The ore was a soft, reddish-brown, nonbessemer hematite.

The Genesee ore body lay in the "keel" of the Tobin syncline. Like the ore bodies on adjacent properties, it did not rest directly on the Dunn Creek Slate but lay instead approximately 100 feet above that contact. Here, very probably as in the Odgers and the Tobin mines, the footwall bed to the ore was the somewhat slaty bed that is 75-100 feet above the base of the iron-formation. Similar relations prevail in the Monongahela and Carpenter mines.

Tobin

The Tobin property, which is primarily the north part of the old Sheldon and Shafer holdings, consists of the SW¼ sec. 30. The Tobin mine proper is confined to 80 acres of land and consists of the S½ SW¼ sec. 30, but the operation extended into the Genesee property to the east and the Columbia properties to the south. The main Tobin shaft (No. 3) is located in the NE¼ NW¼ sec. 31. From it, drifts connected workings of the Tobin property in the SW¼ sec. 30 with those of the Columbia (Shafer) property in the NW¼ NW¼ sec. 31, and those of the West Columbia property in the SW¼ NW¼ sec. 31 (plate 2). The entire operation has been known in recent years as the Tobin mine and the production records were combined after 1905. The three main ore-bearing areas -- Tobin, Columbia, and West Columbia -- are, however, entirely separated, and the properties are discussed separately in this report.

Shipments from the combined properties were made regularly from 1905 to 1957, excepting the years 1921, 1926, 1929 and 1931. Ore was also shipped in 1959, mainly from stockpile, and in 1960. Since then the mine has operated intermittently on a small scale. The aggregate shipments are well over 9 million tons.

Little work apparently was done on the Tobin property in the earliest mining days, although by 1891 a shaft had been sunk and the 100-foot level extended. Like most mines in the region, the Tobin was closed by the panic of 1893 and apparently remained idle until 1900 when it was acquired by Corrigan, McKinney and Company. In 1901 the first shipment of ore was made. After this time development was so rapid that by 1906 the mine had a capacity of 350 tons per day and 235,867 tons of ore was shipped in that year. The shaft was then down 735 feet and eight levels had been developed. In subsequent years the mine reached a depth of 1,701 feet. The Tobin ore body was developed on seven additional levels and yielded more than 4 million tons. The ore was classed as a semi hard, reddish-brown, nonbessemer hematite.

The Tobin main ore body lies on the south limb of the Tobin syncline. It is elongated east west, parallel to the strike of the bedding. At the 2nd level it was about 500 feet long and averaged about 70-80 feet in width. The length and breadth remained more or less constant down to the 14th level though the ore body as a whole plunged 60°-65° westward. The westward plunge is reflected by the position of the 14th level workings as compared with the position of the open pit. (See plate

1). The ore did not rest on the true footwall slate but lay 50-75 feet above it.

The reasons for the location of the ore body and the cause of its westward plunge are not apparent. There seems to be no fold which would localize the ore. Possibly the ore is controlled by a west-plunging trough formed by the bedding of the iron-formation and the oblique fault inferred from outcrop and magnetic data. A south dip on such a fault would be required to explain a westward, rather than northwestward, migration of the ore body. There are no records of such a fault on the mining company plans or cross sections.

Columbia (Shafer, Union)

One of the earliest properties developed in the Crystal Falls area is the old Union mine, now known as the Columbia and operated as part of the Tobin mine. The Union mine was opened on the Sheldon and Shafer property which consisted of the NW¼ sec. 31 and the SW¼ sec. 30. At a later date the section 30 part became the Tobin property.

As the Union mine, the property was explored and opened prior to the building of the railroad in 1882 so that there was a considerable stockpile of ore ready for shipment when the track was laid. The mine was developed originally as a narrow opencut about 200 feet long and 80 feet deep located in the N½ NW¼ sec. 31. It was operated by the Union Iron and Steel Company of Chicago. The Company failed and the mine was then taken over and operated by the Shafer Iron Company. The property was then known as the Shafer (also Schafer, Schaffer, Schafter) mine. Two shafts were sunk, one from the bottom of the pit and a second at a point north and east of the pit. Eventually a third shaft was sunk and as the underground workings expanded the mine achieved a capacity of 700 tons per day.

The mine was renamed the Columbia in 1893 and was taken over by the Huron Iron Company. The property was idle in 1893 but work was resumed in 1894. In 1896 the main shaft, down some 520 feet, was lost by caving. A new shaft (No. 4) was sunk near the southwest end of the ore deposit.

In 1901 the property was sold to the Oliver Iron Mining Company. Operations apparently ceased in 1905. By that date the mine had reached a depth of 700 feet and had yielded 944,795 tons of ore. The Columbia eventually came into the hands of the Corrigan, McKinney Steel Company and its successor, the Republic Steel Corporation.

Ore was later discovered in the SW¼ NW¼ sec. 31 (plate 2). This ore body, known as the West Columbia, was stripped in 1941 and shipments were made from the open pit. Shortly afterward it was mined by underground methods. The workings were connected by long drifts on the 7th and 10th levels to the Tobin shaft and all ore from this property was hoisted through the Tobin. The workings were also connected with the New Monongahela shaft in the SE¼ NE¼ sec. 36, T43N, R33W, which was used primarily for ventilation. At the same time further work was done in the old Columbia or Shafer mine. Thus the operations in the Columbia (Shafer), West Columbia, and Tobin properties were merged into a single mine -- the Tobin.

Information on the geology of the Columbia, or Old Shafer mine, is very meager. It seems probable, however, that there were several rather small adjacent ore bodies. These do not seem to be on any major structure but are located in an area of large-scale crumpling. The crumpling is reflected in the irregular course of the magnetic anomaly in the SW¼ SW¼ sec. 30 and in the complex folding of the lower part of the iron-formation, as shown on figure 5. The net effect of this crumpling combined with a relatively low northwest plunge is to greatly widen the "outcrop" belt of the iron-formation. In the Columbia or Shafer mine area the formation is expanded to a width of at least 1,400 feet.

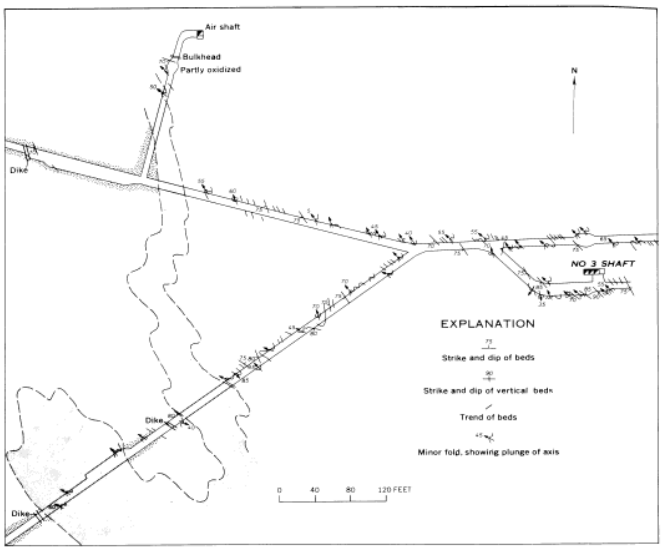

Figure 5. Trend and attitude of bedding and minor folds and plunge of fold axes in iron-formation, 7th level Tobin mine. Slaty iron-formation ("raindrop slate" unit) shaded; oxidized iron-formation, which contains ore bodies, stippled. Geology by H. L. James and M. W. Leighton, Jr., 1959.

Explorations

Section 30, Town 43 North, Range 32 West

The Wagner exploration consisted of the S½ SE¼ sec. 30, and may have also included the SW¼ sec. 29. Exploration was undertaken in 1889-91. A shaft was reported sunk in the SW¼ SE¼ sec. 30 but was reported abandoned and full of water in 1894.

The precise location and the results of the work done are in doubt although it is probable that the two old shafts, known as the Volunteer and the Genesee (plate 1), were the result of the early exploration. Years later the property became a part of the Genesee mine. Although considerable ore was shipped from the Genesee property, it apparently was not from the site of the old

Wagner exploration. Little can be said about the Volunteer shaft except that the material on the dump shows that oxidized iron-formation was reached.

MONONGAHELA AREA

The Monongahela map area (plate 2) included the NE¼ and the N½ SE¼ sec. 36, T43N, R33W, and the W½ NW¼ and the NW¼ SW¼ sec. 31, T43N, R32W. Within this area are the Old Monongahela mine, the West Columbia mine (of the Tobin group), the New Monongahela mine, and the Carpenter mine.

Geology

The Monongahela area is heavily drift covered, amounting to more than 200 feet in the southeastern part of the map area. Only three outcrops are known.

The character of the Dunn Creek Slate is well shown by a near horizontal hole (No. 215) drilled S. 10° E. from the 630-level of the Carpenter mine, at a point 3,123 feet south and 194 feet east of the northwest corner of sec. 31, T43N, R32W. This hole passed through about 35 feet of iron-formation, 28 feet of fissile, pyritic, graphitic, black slate (Wauseca Pyrite Member), 63 feet of silty gray slate interbedded with black, graphitic slate, 7 feet of coarse, black graywacke, 194 feet of gray slate interbedded with black, graphitic slate and chert, and 145 feet of fine-grained silty graywacke, and ended in 23 feet of finegrained graywacke and sericitic slate. As the bedding is nearly perpendicular to the core, the thicknesses penetrated are very near the true stratigraphic thickness of the beds. About 425 feet of footwall strata immediately below the iron-formation are, therefore, present in this hole.

The succession of beds just above the iron-formation is best shown in the core of Monongahela hole No. 306, which is a nearly horizontal hole drilled N. 30 W. from the 330-level of the Monongahela mine at a point 1,292 feet south and 765 feet west of the northeast corner of sec. 36, T43N, R33W. The geologic data from the hole are summarized as follows (drilled footages corrected according to angle of bedding with core to give true stratigraphic thicknesses):

Stratigraphic thickness	Rock	Formation
104 ft.	Oxidized iron-formation.	Riverton
22	Chert breccia with graywacke matrix.	Hiawatha
2½	Dark graywacke	Hiawatha
8½	Dark graywacke containing scattered chert fragments.	Hiawatha
68	Slate, pink to green, laminated, nonmagnetic.	Stambaugh
26	Slate, flinty, laminated, magnetic.	Stambaugh
15	Slate interbedded with porcelanite.	Stambaugh
32	Slate, laminated, red to green.	Fortune Lakes (?)

The strata in the Monongahela area are involved in close folds with northwest plunge. There are two narrow, tight anticlines and two broader more open synclines. These are, from north to south, the old Monongahela anticline, the West Columbia syncline, the New Monongahela anticline, and the Carpenter syncline.

Magnetic Anomalies

The western two-thirds of the Monongahela area was surveyed magnetically by means of a Superdip oriented normal to the magnetic meridian. Measurements were made on lines spaced 200 feet apart with readings taken at 100-foot intervals. Outcrops and test pits were located relative to these positions. The contoured values of the magnetic determinations, as expressed in instrument units above or below a local base station, are given on plate 2.

Two belts of pronounced magnetic anomaly are produced by the Stambaugh Formation. The strongest anomaly occurs at the north edge of the map area where the magnetic relief probably exceeds 5,000 gammas. The flinty magnetic slate (Stambaugh Formation) responsible for the anomaly is well exposed along the north edge of the road some 800-900 feet west of the northeast corner of section 36. The anomaly faithfully depicts the structure in the northeast part of the section and outlines the two anticlines and the intervening West Columbia syncline.

The other anomaly occurs in the NE¼ SW¼ and N½ SE¼ of section 36. This anomaly marks the south limb of the Carpenter syncline. Owing to deep drift cover, the anomaly is broad and not so high as that near the Old Monongahela mine. The anomaly ends near the New Monongahela mine. The gap between the two magnetic anomalies is probably due to extensive oxidation which characterizes this area.

Mines

West Columbia

The West Columbia property occupies the W½ sec. 31, T43N, R32W. The ore body, in the northwestern part of the property, was opened up in 1941 by surface stripping. After 2 years of operation as an open pit it was worked as an underground mine, part of the Tobin group of the Republic Steel Corporation. The workings are connected on the 7th and 10th levels with the Tobin No. 3 shaft some 2,300 feet northeast of the ore body. Production was in excess of 4 million tons.

The West Columbia ore body lies on the keel of a syncline that plunges to the northwest. In the axial area of the syncline the rocks of both the Riverton Iron-Formation and the Hiawatha Graywacke are thoroughly oxidized. The Hiawatha is known only from drilling, however, as neither the upper or lower contact of the Riverton Iron-Formation was encountered in the workings. The stratigraphic position of the ore body is not certainly known but is probably above the slaty carbonate member as in the Tobin and Columbia workings to the northeast.

Monongahela

The Monongahela property consists of the NE¼ NW¼, the N½ NE¼, and the SE¼ NE¼ sec. 36, T43N, R33W. Early work was confined to the Old Monongahela mine in the NE¼ NE¼ where a shaft was put down 70 feet in 1892. A 10-foot width of ore was said to have been exposed. One level at least was laid out some 75 feet below the surface. After considerable work was done by Oglebay, Norton and Company, the property was taken over in 1901 by the Pitts-burg and Lake Angeline Company of Ishpeming, Michigan. In 1902 the mine was said to have been operated by Jones and Laughlin, Ltd. Later, the Monongahela property was taken over by the M. A. Hanna interests who also acquired the nearby Carpenter property. By 1911 drilling had disclosed some 320,000 tons of ore on these properties.

The small early shipments of 2,397 tons in 1901 and 6,913 tons in 1903 were presumably made from the Old Monongahela mine in the NE¼ NE¼, whereas the later shipments of 1916 came from the New Monongahela mine in the SE¼ NE¼. The mine was operated by the Hanna Furnace Company (Hollister Mining Company) and its successor, the Hanna Ore Company. Shipments continued, with interruptions, until 1934. Aggregate shipments were 1,352,424 tons. The ore was classed as a hard and soft, red, nonbessemer hematite. Shipments (435,232 tons) also were made from the Monongahela property in the period 1952-56, but the ore was produced from an extension of the West Columbia ore body and taken out by way of the Tobin shaft.

The workings of the Old Monongahela mine lie near the north edge of a very sharp, northwestward-plunging anticline. The structure is so narrow that the iron-formation in its core cannot exceed 200 feet in width at the bedrock surface.

The main ore body of the New Monongahela mine is a part of the same ore body which was mined at the Carpenter mine in the NW¼ SW¼ sec. 31, T43N, R32W, also operated by the M. A. Hanna Company. The New Monongahela mine was operated from a shaft some 1,850 feet south and 100 feet west of the northeast corner of sec. 36, T43N, R33W. The main levels were 330, 480, and 630 feet below the shaft collar of the Carpenter mine (1,402 feet above sea level).

The New Monongahela shaft lies near the axis of the Monongahela anticline, the axial plane of which strikes N. 50°-55° W. The fold plunges northwest at about 20°. Though a little ore was found north of the shaft on the north limb of this anticline, most of the mined ore occurred on the south flank of this structure, on the north limb of the Carpenter syncline. This limb of the syncline strikes about N. 35° W. and is presumed to dip south-westward. Therefore, the iron-formation, and the ore, is carried downdip into the Lawrence (Wilkinson) property in the NE¼ SE¼ sec. 36. The ore body on the north flank of the Monongahela anticline was small, owing possibly to a slight overturn of this limb. Very probably it is a western extension of the larger productive ore body of the adjoining West Columbia property in sec. 31, T43N, R32W.

Apparently in the New Monongahela mine, as in the Carpenter mine, the ore did not rest directly on the Dunn Creek Slate. Dark slaty rock was encountered in the main drifts south of the shaft and east of the ore body. As the iron-formation above this horizon appears to be only 400 feet thick at this place, the slate probably is the same as that known as the "raindrop slate" in the adjacent Columbia and Tobin mines (see figure 5).

Carpenter

The Carpenter mine is located in the NW¼ SW¼ sec. 31, T43N, R32W. This property, opened in 1913, shipped ore in 1914 and every year through 1928. It was formerly operated by the Hanna Furnace Company (Hollister Mining Company). Shipments totaled 2,735,452 tons. The ore, similar to that of the Monongahela mine, is classed as a hard and soft, red, nonbessemer hematite. The principal development was on levels 330, 480, 630, and 760 feet below the shaft collar, which is at an elevation of 1,402 feet.

The carpenter ore body lies along the axis of the Carpenter syncline. The axial plane of the syncline locally trends S 75° W and the fold plunges westward at 40°-60°. The south limb strikes N 45° E and dips 60°-65° northwest. The north limb strikes N 80° E. Its dip is unknown. The ore was at bedrock surface near the north line of the Carpenter "forty" and plunged southwestward with the structure into the adjacent Lawrence "forty" (the NE¼ SE¼ sec. 36). The ore body worked at the New Monongahela mine is an extension along the north flank of the syncline.

The inactive Carpenter property was taken over by Pickands Mather & Company in about 1950 and the shaft was rehabilitated to some extent. The only workings examined were those at the 100-foot sublevel above the 330-level. The geology is shown on figure 6. Previously it has been noted that a hole drilled southward from the 630-level of the Carpenter began in iron-formation, then intersected a "foot-wall" sequence normal for the district. From the data shown on figure 6, however, it is apparent that the relations at the base of the iron-formation are complex. The ore body seems to have rested on a slaty member of the Riverton Iron-Formation, presumably the "raindrop slate" present in

the Tobin mine (see figure 5), but the lower chert-siderite unit is missing. The slaty member of the Riverton is in fault contact with strata of the Dunn Creek Slate that consist mainly of medium to coarse grained graywacke. The fault, actually a zone several feet wide of sheared, quartz-veined graphitic slate, trends about N. 10° E and dips 80° to the east. Toward the shaft, the graywacke grades into a banded chert and siderite rock interlayered with graywacke and gray slate. These strata differ greatly from the normal sequence in the upper part of the Dunn Creek Slate. They resemble to some degree, particularly in the occurrence of bedded chert and siderite, the rocks that are much deeper in the formation. It is concluded, therefore, that several hundred feet of strata, including the basal 100 feet of the Riverton, has been cut out by the fault. In essence, this fault cuts across the nose of the Carpenter syncline.

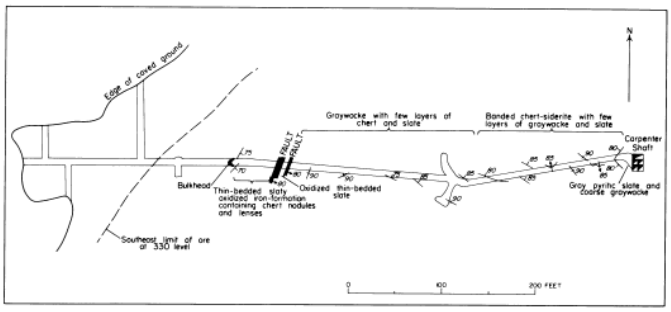

Figure 6. Carpenter mine, 100-foot sublevel above 330 level, showing lithologic units, attitudes of bedding, and plunge of minor fold axes. Geology by H. L. James, 1951.

Explorations

Section 36, Town 43 North, Range 33 West

The Lawrence property, also known as the Wilkinson, is the NE¼ SE¼ sec. 36, T43N, R33W, and is held by the Verona Mining Company (Pickands Mather & Company, agents). It was drilled in 1946. The results of the exploration, however, have not been released. The tract is bounded on the north by the Monongahela property and on the east by the Carpenter property. Ore was mined in these adjoining properties up to the Lawrence property line. In fact, a trespass shipment of 584 tons is reported from the Lawrence for 1920. The Carpenter ore body plunges westward and continues into the Lawrence property. The Lawrence property was briefly exploited in 1954-56 by way of the Carpenter shaft and shipments of 6,379 tons were made in 1956.

DUNN AREA

The Dunn map area (plate 2) includes most of the N½ sec. 1 and part of the SE¼ NE¼ sec. 2, T42N, R33W, the W½ NW¼ sec. 6, T42N, R32W, and the S½ SE¼ sec. 36, T43N, R33W. Within this area is the Dunn mine, one of the oldest mining properties in the Crystal Falls area.

Outcrops are numerous though somewhat unevenly distributed. Exposures of rock are most abundant around and west of the Dunn pit. North and northeast of the pit the drift cover is thick, nearly 200 feet in several drill holes in the northeastern part of the map area.

Geology

The stratigraphic section exposed in the area is rather complete and is normal for the district. The footwall Dunn Creek Slate as usual is poorly exposed, though a fair number of outcrops occur on the high hill southeast of the Dunn cave, and there are several fine outcrops along and near the abandoned Chicago and North Western Railroad grade in sec. 6, T42N, R32W. The rocks exposed are mainly slates, in part sideritic. Also exposed are impure graywackes and, near the southwest corner of the SE¼ NE¼ sec. 1, some sooty black graphitic slates. The latter has disintegrated to a loose "duff". Apparently the topmost beds of the Dunn Creek Slate are here, as elsewhere, pyritic graphitic slates (Wauseca Pyritic Member).

The Riverton Iron-Formation is well exposed in several places, especially in the Dunn pit where it is strongly oxidized, and various places west and southwest of the pit. The footwall contact with the Dunn Creek Slate is nowhere exposed and is, in general, not as well located as is the hanging-wall contact with the Hiawatha Graywacke.

The post-Riverton strata are well displayed on the high ground northwest of the Dunn pit. The Hiawatha Graywacke crops out in an old road bed about 500 feet southwest of the No. 3 shaft of the Dunn mine. The rock is notably schistose. The breccia facies occurs in a test pit about 75 feet southeast of the outcrop of graywacke. The magnetic slate of the Stambaugh Formation is exposed in several places and is responsible for a strong magnetic anomaly in the NW¼ NE¼ sec. 1. Associated with the magnetic slate are beds of porcelanite and greenish magnetic mudstone. These crop out in several places as do the pyritic gray slates (basal unit of the Fortune Lakes Slate), which overlie them. Heavy massive, somewhat quartzitic graywacke, stratigraphically higher in the Fortune Lakes Slate, forms conspicuous ledges in the NE¼ NW¼ sec. 1, as well as a very large outcrop in the SE¼ NE¼ sec. 2.

The dominant structure of the Dunn area is a syncline, the axis of which runs diagonally across the area from northwest to southeast. The structure plunges northwest. The syncline is flanked by two anticlines. The south limb of the northern anticline is in part overturned and dips steeply northeastward.

Magnetic Anomalies

The Dunn area was surveyed with a Hotchkiss Superdip oriented to swing in the plane of the magnetic meridian. The angle between the magnetic and gravitational arms

was 11½° ("sigma" angle 3½°). In most places a scale division has a value of approximately 40 gammas.

Within the Dunn area there are several anomalies. These fall into two groups, those produced by the Stambaugh Formation and those caused by magnetic strata of the Riverton Iron Formation. The iron-formation anomalies are weaker and discontinuous. The discontinuous anomalies are in large part due to "spotty" oxidation of the formation, which leaves irregular areas of unoxidized and magnetic rock. In the area known from outcrops and test pits to be largely unoxidized, namely in the anticlinal structure in the SW¼ SE¼ sec. 36, the iron-formation anomaly is reasonably continuous. It seems to be absent near, as well as north of the Dunn pit, though it is present just southwest of the pit.

The Stambaugh Formation anomaly is strong and continuous from the N½ corner of section 1 southward to the 1/16 corner just north of the center of this section. It reappears about 500 feet south of this point from which place it is traceable westward across the SE¼ NW¼ sec. 1. In the SW¼ NW¼ of the same section it joins the anomaly which extends from the center of section 1 to this point. The convergence and junction of these two anomalies are an expression of the westerly plunge of the anticlinal fold which they delineate.

Mines

Dunn-Richards

The Dunn mine lies in the W½ NE¼ sec. 1, T42N, R33W. In 1887, after several years of unsuccessful exploration, ore shipments were made from an open pit by the Cherry Valley Iron Works. About 1888 the property was taken over by the York Iron Company. In 1891, with shipments of 162,721 tons, the Dunn was the second largest mine of the Menominee range. Two shafts, 280 and 470 feet deep, were in operation.

The York Iron Company failed in 1893 and the property was acquired by the Dunn Iron Mining Company. In 1899, Corrigan, McKinney and Company took over the mine. Owing to caving of the old workings, a new shaft (No. 3) was sunk. By 1907 this was down 834 feet and production had reached 400 tons per day. By 1911 the shaft was 1,420 feet deep and 11 levels had been extended from it.

The plunge of the ore body carried it northwestward onto the Richards property in the S½ SE¼ sec. 36, T43N, R33W. Shipments from the Dunn ended in about 1915, whereas the Richards shipments began in 1913 and continued to 1927, except for 1922 and 1924-25. The shipments from the Dunn property totaled 2,208,511 tons, and for the Richards property 534,448 tons. The total production, therefore, was 2,742,959 tons. The ore shipped was a soft reddish-brown, nonbessemer high phosphorous hematite.

Mining extended to a depth of a little more than 1,800 feet below the collar of the No. 3 shaft. The bottom level of the Dunn mine, the 11th, was about 800 feet above sea level. The second level of the Richards mine had about the same elevation. The 15th level, the lowest in the Richards workings, was approximately 350 feet below sea level.

In the Dunn pit a horse of rock separates caved areas that mark the "ledge outcrop" of two ore bodies. The north ore body plunged N 25° W at an angle of about 45 (figure 7). As a result, it extended downward and northward and entered the Richards property at the 11th level of the Dunn mine (2nd level, Dunn-Richards mine). Mining operations ceased at a depth of nearly 1,800 feet below the surface. This ore body, though over 2,400 feet long, was small in cross section. In horizontal section it averaged less than 100 feet in width and was rarely more than twice this length on any given level. On and below the 6th level (Richards), it seems to have separated into two closely adjacent ore bodies.

The south ore body was mined on the 5th level (Dunn) but was not found on the 6th level. It appeared to pitch southward or south-westward from its outcrop.

The Dunn ore body, like others in the Southern Crystal Falls area, apparently rested on a slaty member within the iron-formation and not on the Dunn Creek Slate. Apparently it lay near the "keel" of the Dunn syncline. Its progressive northward divergence from the surface trace of the axial plane of this structure is overturned -- that is, the axial plane dips to the north.

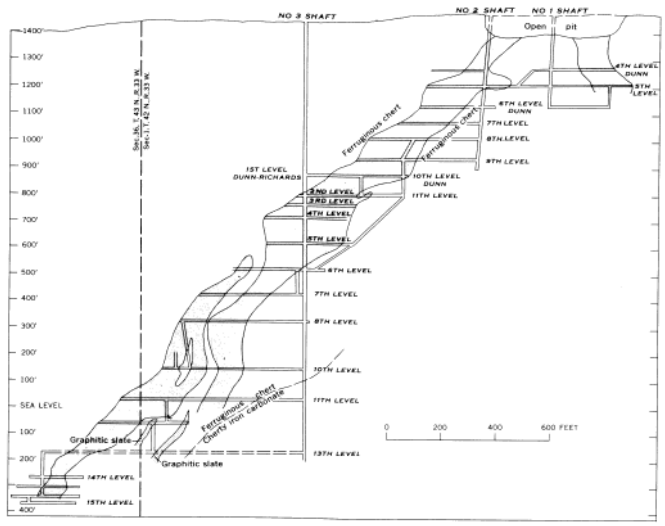

Figure 7. Section through Dunn-Richards mine, viewed toward the northeast, showing generalized outlines of mined ore (shaded), including pillars. Adapted from mining company records.

Explorations

Section 1, Town 42 North, Range 33 West

The Kimberly exploration is in the E½ NE¼ sec. 1. This exploration consisted primarily of 11 drill holes in the north "forty". The drilling, probably done about 1913, disclosed a small amount of ore in two holes. A drift was

run from the Dunn No. 3 shaft (Dunn-Richards 1st level) to this ore body. Apparently, however, little or no ore was mined as no shipments are credited to the Kimberly. The drift was reported to be all in ferruginous chert.

Several of the Kimberly holes reached the Dunn Creek Slate, so it is clear that only the lowest part of the iron-formation is present on the property. As this part is not generally productive in the Crystal Falls area, it is not likely to be so here, despite the fact that the area is favorably located with respect to structure.

SOUTH DUNN AREA

The South Dunn map area (plate 2) includes the SE¼ and the E½ SW¼ sec. 1, T42N, R33W. Within this area is the South Dunn mine. So far as is known, this mine has never shipped iron ore.

The South Dunn area has few outcrops though the overburden is generally very thin. The average depth of glacial cover over much of the area is probably 15 feet. The cover is thin along the county road in the western part of the area where outcrops are most common. It is thickest in the southeast corner of the area where drill holes penetrated about 100 feet of overburden before reaching bedrock.

Geology

The stratigraphic succession extends from the upper part of the Dunn Creek Slate, through the Riverton Iron-Formation, Hiawatha Graywacke, Stambaugh Formation, and into the Fortune Lakes Slate. The footwall strata (Dunn Creek Slate) exposed in the northeast corner of the map area are gray slates and siliceous graywacke. Test pits nearest the footwall contact of the iron-formation reveal the usual black graphitic slate (Wauseca Pyritic Member).

The iron-formation crops out in three places near the center of sec. 1, in at least two places near the South Dunn shaft where it was also found in test pits and in drill holes, and in a single small outcrop in the SE¼ SW¼ of the same section. It was also found in numerous drill holes in the southeastern part of the map area. Oxidation is confined to two small areas, one near the South Dunn mine, and the other near the south 1/16 corner of the SE¼ of sec. 1.

The hanging-wall (post-Riverton) beds are well exposed along the Tobin-Alpha county road. The slates which lie between the magnetic slate of the Stambaugh Formation and the massive graywacke of the Fortune Lakes Slate are well shown along this road, especially in the SE¼ SW¼ of the section. The porcelanite-mudstone beds can be seen on the road leading west from the center of the section.

Magnetic Anomalies

The area was surveyed with a Hotchkiss Superdip oriented normal to the magnetic meridian, with a "sigma" angle of 2°. The data later were converted to approximate gamma values of vertical intensity and contoured. The magnetic anomalies are sharp and well-defined, as might be expected where overburden is thin and oxidation rather limited. Two anomalies are present. One, caused by the magnetic member of the Riverton Iron-Formation, extends from northwest to southeast through the center of the SE¼ sec. 1. It has a maximum magnetic relief of a little over 1,000 gammas. It is clear from the map relations that the bed responsible for this anomaly must lie in about the middle of the iron-formation. The second and rather complex anomaly is that produced by the Stambaugh Formation. This anomaly has a local relief of about 5,000 gammas. It is, nevertheless, very narrow, in places not much over 100 feet in width.

The magnetic anomaly delineates in precise detail the distribution of the Stambaugh Formation and the structures in which it is involved. As can be seen from the map pattern, a well-defined northwestward plunging anticline is present in the southwestern part of the map area. This anticline is not only shown by the converging magnetic lines which join just west of the county road, but also by the converging strikes in the outcrops. South of the anticlinal axis the strike is N 30° W; north of it the beds strike N 70° W. North of the anticline the magnetic anomaly defines a syncline within which is a smaller medial anticline. As is characteristic of a plunging syncline, there is a complementary crescent-shaped negative anomaly at the "turn" of the structure. The buried continuation of the apical area of the plunging anticlines, however, are marked by a weak magnetic anomaly.

The anomaly caused by the Stambaugh Formation dies out or becomes very weak near the south edge of the NW¼ SE¼ of the section. The reason could not be determined by the author. Test pits and outcrops along the west side of this tract do not show any oxidation, the presence of which might account for the failure of the anomaly.

Explorations

Section 1, Town 42 North, Range 33 West

The South Dunn exploration consists of the NW¼ SE¼ sec. 1. Little is known about early work except that reported by R. C. Allen (Allen 1912, p. 155-156), who said "Exploration was conducted here in 1908 by the Munroe Iron Mining Company. A shaft was sunk and considerable underground work was done which on the whole seemed not to yield satisfactory results and the exploration was abandoned. The best ore was encountered south of the shaft in a drift from the 175 foot level which passed through forty feet averaging about 60% in iron, nonbessemer".

An exploration in the E½ SE¼, conducted by the E. J. Longyear Company, consisted of 9 holes, seven of which were drilled near the west line of the property. The property apparently was held by the Nevada Land Company. Bedrock was reached at depths of 5 to 39 feet. All holes, except one, reportedly reached cherty carbonate slate which probably is unoxidized iron-formation. Inasmuch as several old test pits in the north "forty" reached graphitic and black slates, the footwall contact of the iron-formation can be traced diagonally across the Nevada Land holdings from the northwest corner of the property to a point near the southeast corner of the same property.

More recently, Jones and Laughlin drilled 11 holes in the S½ SE¼. Bedrock, reached at hole depths of 11 to 102 feet, is iron-formation, in part unoxidized, and in part oxidized and orebearing.

BOOK AREA

The Book map area (plate 3) lies in sec. 12, T42N, R33W, and includes principally the S½ NW¼, the N½ SW¼, and the S½ NE¼ of this section. Within this area is the Book mine, part of which is in the NE¼ NE¼ sec. 12.

Although the drift cover is rather thin over much of the area, outcrops are few. They occur mainly along the Tobin-Alpha county road. Bedrock was reached in many test pits, especially near the center of sec. 12. Along the east margin of section 12 the drift cover is heavier and locally exceeds 120 feet.

Geology

The area underlain by the footwall beds (Dunn Creek Slate) is very small, and the strata are nowhere exposed. Graphitic slate (Wauseca Pyritic Member) was encountered in drill holes in the SE¼ NE¼ sec. 12 and in test pits in the SE¼ SE¼ sec. 12.

The Riverton Iron-Formation is at bedrock surface over a wide area along the eastern and southern parts of the Book area. It is well exposed in the Book open pit, was reached in numerous test pits near the center of sec. 12, and is present as inconspicuous outcrops along the Tobin-Alpha road in the NE¼ SW¼ sec. 12. It crops out in two places along the south edge of the N½ SW¼. The formation in the vicinity of the Book mine is thoroughly oxidized. The oxidized area extends south from the Book mine into the NE¼ SE¼ sec. 12. Westward from this area oxidation is spotty and incomplete.

The best exposed rocks in the area are the Hiawatha Graywacke, the Stambaugh Formation, and the Fortune Lakes Slate. The chert-breccia facies of the Hiawatha was encountered in a test pit near the center of sec. 12 and the graywacke facies (here dark and graphitic) is exposed in the diversion ditch just west of the Book open pit. The graywacke is in sharp contact with the underlying Riverton Iron-Formation. Porcelanite and slate of the Stambaugh Formation were reached in test pits just north of the center of sec. 12. Strata of the Fortune Lakes Slate -- the lower pyritic gray slate and mudstone, and the higher graywackes and slates -- are exposed along the Tobin-Alpha road in the NW¼ sec. 12.

The dominant structure of the area is the Book syncline, which is well defined by the magnetic anomaly produced by the Stambaugh Formation. The axial plane strikes about N 60 W and plunges to the northwest. There is a little evidence to indicate one or two minor cross faults on the north limb of this structure just south of the Book open pit. The displacement, however, is small.

South of the Book syncline is the Alpha anticline, which is in fact an anticlinorium, with a pronounced medial syncline. The half of the structure north of the dividing syncline, west of the center of sec. 12, is fairly well outlined by the Stambaugh Formation anomaly. Within the core of this structure is the pyritic graphitic footwall slate (Dunn Creek) in the SE¼ SE¼ sec. 12. The medial syncline extends southeastward from the center of the SW¼ of sec. 12 to the 1/16 corner just east of the S½ corner of sec. 12. Iron-formation is exposed in a road ditch 600 feet northwest of this 1/16 corner. Graphitic footwall slate occurs in a road outcrop about 400 feet west of the outcrop of iron-formation and in test pits 700 feet to the east.

Magnetic Anomalies

The Book area was surveyed with a Hotchkiss Superdip oriented normal to the magnetic meridian, with a "sigma" angle of 2°. The only pronounced anomalies of the area are those due to the Stambaugh Formation. Owing to shallowness of the overburden, the anomaly is well defined and rather narrow, but markedly irregular in magnitude and in course. The irregularities in the trend of the anomaly are probably due to drag folding on the larger folds. These are most pronounced in the axial part of the Alpha anticlinorium. The anomaly becomes very weak near the axis of the Book syncline and on the north limb of this structure within the map area. It is probable that intense oxidation near the Book ore body is responsible. The anomaly also seems to die out in the neighborhood of the medial syncline of the Alpha anticline near the center of the SW¼ sec. 12. There seems to be no oxidation in this area and the reason for the absence of the magnetic anomaly is not known. The anomaly reappears, however, in sec. 11 just west of the Book map area where it is quite strong.

Mines

Book

The Book mine is located in the E½ sec. 12. The mine, operated by the North Range Mining Company, was begun as an open pit in 1943, then later converted to an

underground operation. Three levels were developed, the lowest at a depth of 535 feet. Ore was shipped each year from 1943 to 1958 when the mine was closed. During the later years of operation some of the shipments were of beneficiated ore. The total ore shipped amounted to 2,273,122 tons. An additional 44,401 tons was shipped from stockpile in 1965.

The structure in relation to position of ore bodies is shown in figure 8. Despite the fact that in a general way the mine is located on the northeast flank of the Book syncline the structure is complex in detail. As can be seen from inspection of figure 8 the dominant strike of bedding is northwesterly but the over-all trend is northeasterly, as the strata are involved in a series of northwest plunging folds. The structure in the mine area reflects that of the footwall contact (Riverton-Dunn Creek) rather than that of the hanging-wall contact (Riverton-Hiawatha). The ore, which occurred as small disconnected bodies, was formed in a zone approximately in the middle of the formation but without a clearly defined footwall contact. Most of the mine workings are in oxidized cherty iron-formation which contains local slaty beds, but a lower unit that is dominantly slaty is cut in the northern part of the 2nd-level workings (figure 8). This unit is well displayed in the shaft area at the 3rd level where it is a laminated slaty rock consisting of thin layers of dark carbonate interbedded with pyritic slate and nodular chert. The rock is much like the "raindrop slate" of the Tobin mine (figure 5) and may be the same bed. It is about 40 feet thick. (Although not shown on figure 8, a small amount of cherty iron-formation is present in the core of the anticline crossed by the 2nd level north of the shaft. Presumably this defines the lower contact of the slaty unit).

Other than occurring at a fairly definite horizon in the Riverton Iron-Formation, no clear-cut structural control is evident for the ore bodies. Each of the ore bodies tended to diminish in size with depth; they lack the persistence of ore bodies that occur in well-defined structures.

A complete analysis of the ore, representing material mined in 1950, is given in U. S. Geological Survey Professional Paper 570 (James and other, 1968). As evident from the content of combined H_2O, the ore is hematitic rather than limonitic.

ALPHA-BALKAN AREA

The Alpha-Balkan map area (plate 3) mainly includes the SE¼ SE¼ sec. 11, the S½ SW¼ sec. 12, the NW¼ sec. 13, and the NE¼ sec. 14, all in T42N, R33W. The town of Alpha is in the northeastern part of the area.

Bedrock is very poorly exposed. In all, only nine outcrops -- less than one per 40 acres -- were mapped. Actually, however, the overburden is not very thick, especially in the west half of the map area, and bedrock was reached in many test pits. The overburden is thicker in the east half of the map area, especially southeast of Alpha. In places it exceeds 100 feet. It is thickest over the areas underlain by ore.

Within the area are the Alpha, Balkan, and Judson mines. The Alpha mine was of little importance. The Balkan and Judson mines, however, were very productive.

Geology

The footwall Dunn Creek Slate is confined to the east border of the Alpha-Balkan area where the rock was reached by drilling and test pitting. A single, rather poor exposure of the graphitic pyritic slate member occurs in a roadside ditch in the village of Alpha approximately 500 feet east and 300 feet north of the S¼ corner sec. 12. As is usual, this bed is much deteriorated as a result of exposure to the atmosphere.

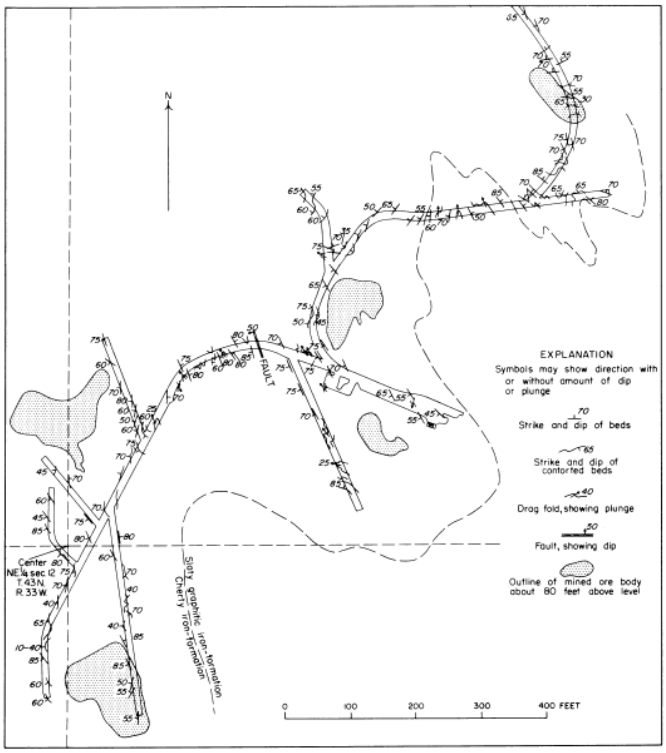

Figure 8. Book mine at 2nd level showing structure, approximate contact between cherty iron-formation and underlying slaty graphitic iron-formation, and position of mined ore bodies about 80 feet above the level. Adapted from map by L. E. Smith, North Range Mining Company.

The Riverton Iron-Formation is exposed in the northeastern part of the SE¼ SE¼ sec. 11 where it is wholly unoxidized. Oxidation is more general elsewhere. The limits of the formation are rather well defined by the extensive drilling done in connection with the development of the iron ores of this area. Unoxidized formation is confined to the northwestern most part of the area in sec. 11 and to sec. 14.

Post-Riverton strata underlie most of the west half of the Alpha-Balkan area. The Hiawatha and Stambaugh

Formations are not exposed but the Stambaugh Formation is located by the magnetic survey, and the anomaly caused by this bed outlines in a very clear manner the structures of the area. The youngest exposed post-Riverton strata are of the massive graywacke member of the Fortune Lakes Slate, which lies several hundred feet above the base of the formation.

The youngest rocks of the area are the two large metadiabase dikes that strike about N 70° E, dip 45° SE, and cross the folded strata. No outcrops of either dike are known, although diabase, probably of the north dike, is said to have been once exposed in a small quarry near the road "Y" just south of the center of sec. 7, T42N, R32W. The size, position, and character of the dikes are known only from drilling and mining operations. The dikes were encountered in many drill holes and were well exposed in the workings of the Balkan-Judson mine. The northernmost of the two dikes is apparently the larger and is about 50 feet thick. The south dike is about half as thick. None of the dike material has been seen by the author. Apparently it is a somewhat altered diabase.

The strata of the Alpha-Balkan area are involved in an anticlinal-synclinal couple. The anticline -- the Judson anticline -- lies in the southern part of the area. The axis of this fold trends about N 70° W, through the center of sec. 13, and the center of the NE¼ sec. 14. At the center of sec. 13 the footwall Dunn Creek Slate is at ledge surface in the core of the structure. Elsewhere, iron-formation fills the axial area except in the central part of the NE¼ sec. 14 where the northwesterly plunge of the structure carries the iron-formation beneath hanging-wall rocks. The apex of the fold, as defined by the magnetic anomaly of the Stambaugh Formation, is just north of the center of the NE¼ sec. 14.

North of the Judson anticline lies the complementary Balkan syncline, the axial plane of which is parallel to that of the Judson anticline. It runs through the south edge of the Balkan cave northwestward to the 1/16 corner west of the southeast corner of sec. 11 and beyond. The ore bodies of the Balkan and Judson mines were in the iron-formation at the east end of this fold.

Magnetic Anomalies

The Alpha-Balkan area was surveyed magnetically, using a Superdip oriented normal to the magnetic meridian with a "sigma" angle of 2°.

The pronounced magnetic anomalies of this area are caused by the Stambaugh Formation of the hanging-wall succession. These anomalies, though locally spotty or discontinuous, outline the Balkan-Judson synclinal-anticlinal couple. Owing to the northwesterly plunge of this structure, the anomalies delineate a large reversed or backward "S" running from the corner common to sec. 11, 12, 13, and 14, to the center of the NW¼ sec. 13, thence westward to the center of the NE¼ sec. 14, and thence southeastward to the W¼ corner of sec. 13. The gaps in the anomaly, especially on the north side of the Balkan syncline, may be due to oxidation that in this area is known to involve the hanging-wall beds.

The lowest magnetic readings were obtained in the area of oxidized iron-formation near the Alpha mine. No readings were made, however, in the Balkan-Judson mine area proper.

Mines

Alpha

The Alpha mine lies in the SE¼ SE¼ sec. 11 and the SW¼ SW¼ sec. 12, T42N, R33W. It was explored in the early 1880's and by 1883 a shaft had been sunk. A small amount of drifting is reported to have disclosed a deposit of ore 16 feet wide. In 1890 an east-west crosscut some 200 feet long was driven from the shaft at a depth of 85 feet. Although ore was reported mined, none was shipped until 1903 when a shipment of 1,370 tons was reported. The ore was classed as a soft, red, nonbessemer hematite.

The old Alpha holdings were extensively drilled by the Nevada Land Company about 1910 or 1911 but results were discouraging. The drilling was extended southeastward into the Balkan area where it proved to be highly successful, ore being first found near Mastodon Creek.

The Alpha mine is located on the north limb of the Balkan syncline or well into the next adjacent anticline -- the Alpha anticline. Most of the iron-formation northwest of the property is unoxidized. Oxidation is apparently confined to the area near the southwest corner of sec. 12. Like most properties located in anticlinal structures it proved unproductive.

Balkan

The Balkan mine was opened in 1915 and at first operated as a separate property by the Balkan Mining Company (Pickands Mather & Company, agents). Later the operations were combined with those of the Judson mine and all the ore was produced through the Judson shaft.

The Balkan mine proper was opened on three main levels which were 136, 236, and 336 feet below the shaft collar (elevation 1,387 feet). The main ore body had a fishhook shape in plan. The "shank" extended some 500 feet N 55° W. from the 1/16 corner north of the center of sec. 13. The "hook" was bent south-westward from the same point. The hook is in the axial part of the Balkan syncline, whereas the shank is on the northeast limb of this structure. This interpretation is confirmed by study of the mine maps which show steep dips in the shank area and relatively low northwesterly dips on the inside of the hook. The size of the ore body in horizontal plan was somewhat diminished on the 3rd level. The

ore came to an end in the northwest against the north metadiabase dike.

A smaller ore body lay farther west on the Balkan property. On the 2nd level this ore body was about 500 feet long in a north-south direction and varied in width from 20 to 140 feet. It, too, abutted the dike at its north end. On the 3rd level this ore body was either very small or was nonexistent. A southeastward encroachment by the diabase dike is in part responsible for the reduction in size.

The relation of the ore to the diabase dikes is of some interest. Many of the drill holes were terminated in the dikes apparently because it was thought that no ore would occur beneath them. To some extent this conclusion is supported for the north dike. In several drill holes, a considerable body of ore ranging in iron content from about 48 to 60 percent was found overlying the dike, whereas the iron-formation below the dike carried only 16 to 18 percent iron. Drilling encountered ore and thoroughly oxidized formation both above and below the south dike, which is, however, less than half as thick as the north dike. In several holes the iron content of the formation was no different just below the dike than it was immediately overlying this rock.

Judson

The Judson mine, opened in 1913, was started as a single operation, but was later worked in combination with the Balkan mine. Shipments were made regularly from 1914 to 1935, except for 1932. The shipments from the Balkan and Judson mines totaled 3,994,484 tons. The ore was reported to be a soft, red, nonbessemer and manganiferous hematite. A small quantity of manganate grade ore containing 9 percent manganese was produced. The property was operated by Pickands Mather & Company.

The Judson shaft, located just beyond the south edge of the map area, is in the footwall Dunn Creek Slate. Most of the mine workings lie north and west of the shaft where the iron-formation is crumpled on a large scale. Despite local irregularities of strike, the prevailing trend is N 30°-35° E across the SE¼ NW¼ sec. 13. There were apparently several small ore bodies in this area. On the 4th level there were six that ranged in length from less than 100 feet to over 400 feet, and in width from 10 to nearly 100 feet. These lie along an irregular line extending diagonally across the SE¼ NW¼ sec. 13. Each is elongated parallel to the strike and each plunges northwestward with the structure. In the SE¼ NW¼ sec. 13, the strike is northwestward. The ore body in this area is, therefore, elongated northwest-southeast. On the 4th level it is about 500 feet long and 150 feet wide.

It is apparent that, as in the adjoining Balkan, the ore bodies are not in the lowermost part of the iron-formation. Most of them seem to follow structure, however, and are thus stratigraphically controlled. The productive part of the iron-formation appears to be stratigraphically below the middle of the formation as in the Book mine (see figure 8).

MASTODON-NIGHTHAWK AREA

The Mastodon-Nighthawk area, as here discussed, adjoins the Alpha-Balkan area on the east and consists primarily of the N½ SE¼ and the S½ NE¼ sec. 13, T42N, R33W and an adjoining part of sec. 18, T42N, R32W (see figure 2). It is not covered by a separate "data sheet" (see U. S. Geological Survey Prof. Paper 570, James, Dutton, Pettijohn and Wier, 1968). Although this area contains a scattering of outcrops, including several conspicuous ones, it is in the main drift covered. The area is underlain wholly by the footwall Dunn Creek Slate and the Riverton Iron-Formation.

Geology

The Mastodon and Manhattan mines are in iron-formation that occurs in an isolated northward-trending syncline. The Nighthawk mine appears to be located at the extreme south tip of the Book syncline. The Dunn Creek Slate is exposed in several places in the anticlinal belt that is between iron-formation of the Mastodon-Manhattan syncline and that in the eastern part of the Alpha-Balkan area. Strata comprising the upper part of the Dunn Creek Slate are well exposed in old railroad grades in the SW¼ NE¼ sec. 13. Most of the rock is black slate. The uppermost pyritic graphitic unit (Wauseca Pyritic Member), with its diagnostic slate breccia, was reached in several test pits southwest of the Manhattan shaft. The pyritic slate is in exposed sharp contact with the overlying Riverton Iron-Formation in a road ditch a short distance west of the Mastodon shaft.

Mines

Mastodon

The Mastodon mine is one of the oldest, if not the oldest, of the mines in the Crystal Falls area. It is said to have been the site of one of the only two outcrops of iron ore known in this part of the district. The other was the Paint River falls or rapids, now known as Crystal Falls. The Mastodon property consists of the S½ NE¼ sec. 13, T42N, R33W. The mine proper was in the SE¼ NE¼ sec. 13.

The mine was originally held under lease by the Mastodon Mining Company in 1881. Open-pit mining began on an ore outcropping that protruded above the surface of the surrounding swamp. Ore was stockpiled until the railroad was completed in 1882 when 3,477 tons was shipped. Except for 1894, shipments continued through 1896.

A shaft was sunk north of the pit from which the ore from the bottom of the pit was raised. The shaft reached a depth of 300 feet in 1891. By 1893 the bulk of the ore

had been mined, the last being taken out in 1895. At the time the mine closed, 3 levels spaced 50 feet apart had been developed. On the 3rd level the ore was said to have been "cut out by graphite that stands vertically in the mine". Shipments totaled 425,708 tons. The property was leased to the Balkan Mining Company in 1912 and ore found in the westernmost part of the Mastodon holdings was mined and shipped as a part of the Balkan-Judson operations. The old Mastodon mine was apparently never reopened after it was closed in 1895.

The ore-bearing zone runs north-south and dips westward. It appears to have plunged northwestward. The ore was said to be capped with a "thick deposit of sandstone, horizontally bedded".

Manhattan (South Mastodon)

The Manhattan property consists of the NE¼ SE¼ sec. 13, T42N, R33W. This property was explored in 1881 by the Manhattan Iron Company. The early work was apparently unsuccessful although a shaft was put down. By 1888, interest in the property was renewed and some success was achieved because 2,722 tons of ore was shipped that year. The property was then known as the South Mastodon and was operated by a Marquette County syndicate. Production in 1889 was 4,005 tons. In 1890 1,476 tons were shipped which brought the total to 8,203 tons. No shipments are recorded for later years.

The Manhattan mine is located near the south end of the syncline of iron-formation that contained the Mastodon ore body.

Explorations

Section 18, Town 42 North, Range 32 West

The Nighthawk exploration is located in the NW¼ NW¼ sec. 18, T42N, R32W. A shaft, begun in 1890, was sunk to a depth of 87 feet and showed 37 feet of ore. Another 16 feet of ore was reported in a crosscut from the bottom. No shipments were recorded nor has the author succeeded in identifying the operators of the property.

The most reasonable interpretation of the occurrence of iron-formation at the Nighthawk is that it lies on the south end of a long attenuated northward-plunging syncline of iron-formation which is an extension of that found in sec. 7, T42N, R32W. Any further extension southward or any appreciable continuation in depth would be, therefore, improbable.

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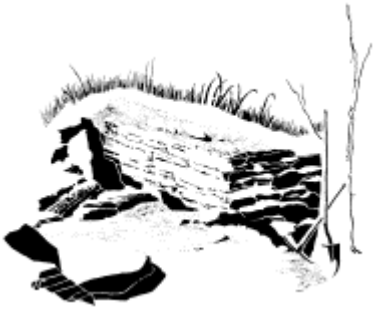

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	Stratigraphic unit	Description	Thickness (feet)	Best exposures	Remarks
Fortune Lakes Slate	Banded slate	Rhythmical alternation of gray slate and sideritic slate; a little chert.	Several hundred	SW¼ NE¼ and SE¼ NW¼ sec. 25, T43N, R33W.	Resembles banded sideritic slates of footwall.
	Slate (?)	Character unknown.	Several hundred	Not exposed	
	Upper graywacke and slate	Gray slates interbedded with heavy beds of coarse massive graywacke; graywackes locally up to 30 feet thick.	1,000	Numerous outcrops NW¼ and N½ SW¼ sec. 30, T43N, R32W; NE¼ NW¼ and NE¼ SW¼ sec. 1, T42N, R33W, SE¼ NW¼ sec. 29, T43N, R32W.	Locally coarse grit or fine conglomerate. Resembles basal graywacke. Slate outcrops rare; heavy graywacke forms conspicuous outcrops cut by transverse feldspar-bearing quartz veins.
	Gray slate	Fissile laminated gray slates; some pyritic slate; thin seams of porcelanite and pyrite; a few thin massive, coarse black graywacke beds.	200-300	Near center sec. 29, T43N, R32W, in city of Crystal Falls	Nonmagnetic.
Stambaugh Formation	Chlorite mudstone	Mudstones with irregular to blocky fracture; weather greenish black with blackened submetallic tarnish; contains porcelanite interbeds. Porcelanite flintlike, gray to white; dense limonite crust in outcrop.	30-40	East end of road, in north part of SW¼ SE¼ sec. 30, T43N, R32W.	Forms long pieces of core; porcelanite commonly logged as "chert"; may be magnetic.
	Magnetic slate	Hard flinty slate; platy cleavage parallel to bedding; thinly laminated. Highly magnetic.	40-50	Road outcrop south side SE¼ SE¼ sec. 25, T43N, R33W.	Splits into "poker chips" when cored; the cause of the chief magnetic anomalies of this area.
	Green slate	Fissile, laminated gray slate; weathers brownish green to yellow; oxidizes near ore to soft pink and yellow slate.	20-70	Outcrops along Paint River; SE¼ sec. 20, T43N, R32W.	Poor core recovery. Nonmagnetic.
Hiawatha Graywacke	Graywacke and chert breccia	Coarse, massive, black graywacke; grades downward into coarse to fine breccia -- angular chert in dark graywacke matrix.	0-70	Same as above.	Massive graywacke forms the longest pieces of core; may be oxidized to red color; oxidized breccia resembles iron-formation core.

Table 2. Stratigraphic section of upper part of Paint River Group in southern Crystal Falls area.