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DETAIL STRATIGRAPHY OF THE BIWABIK IRON-BEARING FORMATION, EAST MESABI DISTRICT, MINNESOTA.[1]

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INTRODUCTION.

In the various iron ranges of the Lake Superior district the location of new ore bodies is in practically all cases a matter of diamond drilling on the basis of most careful geological study. The ore bodies are parts of sedimentary iron-bearing formations where ground waters have caused a local enrichment of iron oxides, thought to be effected chiefly by solution and removal of the associated silica. On the Mesabi iron range of Minnesota, not only is the location of the ore bodies confined to the Biwabik iron-bearing formation, but the different types and qualities of ore are fairly definitely related to differences in the several horizons of the iron formation from which they are derived. Obviously it is extremely desirable that the explorer know at all times in what part of the iron formation he is working, in order that the search for ore bodies be most intelligently directed. A knowledge of the detailed stratigraphy is therefore important.

In 1916 active interest was awakened in the low grade magnetic ores of the eastern end of the Mesabi range. This led to

[1] Published by permission of W. H. Emmons, director, Minnesota Geological and Natural History Survey. To accompany the following article by Frank F. Grout.

drilling operations on rather a large scale. The willingness of the explorers[2] to coöperate by allowing the members of the Minnesota Geological and Natural History Survey to examine the drill cores and records during the progress of the work, led to the detailed mapping of the iron formation from the town of Mesaba eastward to Birch Lake, a distance of eighteen miles. The results are being published in Bulletin 17 of the State Survey.

The Eastern Mesabi is by far the most favorable area on the range for a study of the stratigraphy of the iron formation. Outcrops are numerous, the various horizon markers in many places showing almost continuously in ridges parallel to the strike for half a mile or more. The character of the rock itself in this part of the range favors detailed study. The iron formation in large part was probably originally a chemical precipitate consisting of various combinations of ferruginous chert, ferrous silicate and perhaps some carbonate. On the eastern Mesabi, regional and contact metamorphism has altered it to a medium to coarse-grained intergrowth of magnetite, quartz and amphibole, with other subordinate minerals. Hematite bodies are small and unimportant. No conspicuous secondary structures have developed, with the exception of small drag folds in certain horizons. Premetamorphic features, such as bedding, conglomerate pebbles, organic structures and septaria cracks, are well preserved, even accentuated by the metamorphism. This quartz amphibole magnetite rock is very resistant to weathering processes. On the other hand, weathering over the central and western parts of the range has had the tendency to obscure original differences in the various horizons. Finally, the great assistance in the geological work rendered by the people conducting exploration by placing at our disposal drill cores and records, made the accurate mapping of the horizon boundaries and the determination of their thicknesses a comparatively easy matter.

It is intended here to take up merely the characteristics of the various parts of the Biwabik formation as it exists in the eastern Mesabi, particularly those characteristics which were of most

[2] Swart, W. G., Duluth, Minn., in charge for Hayden Stone & Co.

value in determining the horizons. Many features of the several beds remain constant over the entire area covered. Others are of local importance only. It is hoped that as the study of the Biwabik formation on the main Mesabi range proceeds, those features which were of most use as horizon markers on the east Mesabi will be found to persist for some distance westward from the limit of the present study, at the town of Mesaba.

The importance of being able to recognize with a fair degree of certainty the various horizons of the iron formation has been emphasized by Wolff in his work on the hematite ores of the Mesabi range.[3] In summary it is found that the character of the hematite ore, whether "blue" and "hard" or "brownish yellow" and "soft," is largely determined by the original horizon.

THE DETAILED STRATIGRAPHY OF THE BIWABIK FORMATION.

The stratigraphic succession in the eastern part of the Mesabi district is as follows:

Quaternary system.
  Pleistocene series—Glacial drift.
Unconformity.
Algonkian system.
  Keweenawan series—Duluth gabbro and associated diabase sills and dikes.
  Unconformity.
  Huronian series.
    Upper Huronian { Virginia slate. / Biwabik formation (iron-bearing). / Pokegama quartzite.
    Unconformity.
    Lower-Middle Huronian { Giants Range granite. / Slate-graywacke-conglomerate formation.

The structure of the upper Huronian sediments on the east Mesabi is simple. The beds rest unconformably upon the eroded

[3] Wolff, J. F., "Recent Geologic Developments on the Mesabi Iron Range, Minnesota," *Trans. Am. Inst. Min. Eng.*, vol. 56, p. 142, 1916.

lower Huronian slates and granite. They strike about N. 50° E., and dip southward at a low angle of 4 to 8 degrees. The thickness of the Biwabik iron formation varies, averaging about 400 feet in the area studied. It is truncated by the Duluth gabbro at the extreme east end of the range.

In the following tabulation of the horizons recognized on the east Mesabi, Wolff's general division of the Biwabik formation into upper and lower slaty and upper and lower cherty beds has been retained.

TABULAR SECTION OF BIWABIK IRON-BEARING FORMATION ON THE EAST MESABI.

Top—Virginia Slate.

Biwabik Iron-bearing Formation.

Upper Slaty Beds.	Thickness.
No. 4—Limestone with silicates. Practically no magnetite..	5– 10 feet.
No. 3—Banded amphibole and white quartz; variable amount of calcite. Less than 5 per cent. magnetite	40– 50 feet.
No. 2—Thin bedded iron formation, quartz, amphibole and magnetite in layers averaging less than one eighth inch in thickness. Magnetite increasing toward bottom to about 30 per cent., in places	25– 35 feet.
No. 1—Like No. 2, but with gray lenticular quartzite beds or concretions in which occur numerous white quartz septaria. Between these quartzite beds, the thin beds are drag folded and brecciated. Scattered garnet occurs near the bottom. About 30 per cent. magnetite	40– 45 feet.

Upper Cherty Beds.	Thickness.
No. 4—Highly ferruginous conglomerate. Pebbles of magnetite and hematite in a matrix of quartz and iron oxides. Layers up to several inches in thickness almost pure magnetite. About 40 per cent. magnetite	10 feet.
No. 3—Jasper and recrystallized chert with algal structure and conglomerate. About 20 per cent. magnetite	1– 10 feet.
No. 2—Like No. 4. About 40 per cent. magnetite	20–30 feet.
No. 1—Greenish gray quartz amphibole magnetite rock with conglomerate and granule texture. Many lenticular seams of magnetite. From 25–40 per cent. magnetite over considerable areas	80–110 feet.

LOWER SLATY BEDS.	
No. 2—Fine massive to slaty quartz amphibolite. Few thin magnetite beds. Fayalite crystals in places. About 10–15 per cent. magnetite	65 feet.
No. 1—Black thin bedded fissile slate. About 5 per cent. magnetite	25 feet.
LOWER CHERTY BEDS.	
No. 3—White to gray recrystallized chert with algal structure. In places highly ferruginous, with magnetite and hematite pebbles	10– 15 feet.
No. 2—Beds of variable character, cherts, breccias, clastic sands, dense magnetite ore, etc. Containing 50 per cent. magnetite over considerables areas	2– 52 feet.
No. 1—Basal beds—conglomerates and green shale commonest phases. Less than 5 per cent. magnetite	0– 15 feet.
	350–470 feet.

Bottom—Giant's Range Granite; or Lower-Middle Huronian slate; or Pokegama quartzite.

LOWER CHERTY BEDS.

Bed No. 1 is the base of the Biwabik formation. It is for the most part a conglomerate of variable thickness which fills in many of the irregularities in the Lower Huronian erosion surface. Many of the boulders are of the immediately underlying rock, especially where it is granite. Between the pebbles and in thin layers overlying them are greenish shaly beds. In most places the contact of the upper and lower Huronian is shown by outcrops of the lower Huronian with a thin plaster of the green shale, or of conglomerate pebbles.

Bed No. 2 is the lowest of the magnetite beds. While considerable variation in the types of rock in this horizon was noted, it increases in thickness and iron content from the eastern end, where it is entirely missing or but a few feet in thickness, to Mesaba, where it is over 50 feet thick. The various phases of rock encountered in this horizon include magnetite conglomerates and breccias, and thick beds consisting of magnetite, with calcite, amphibole and clastic quartz. The horizon is of interest in that it is undoubtedly one of the beds in which processes of concentration have produced high grade hematite ore farther west. It is noteworthy that the two small hematite mines east of Mesaba (which have produced but a few hundred thousand tons of ore in the past), lie in this horizon. While there might be some question as to the identity of the horizon in an isolated outcrop, because of a resemblance to some of the overlying beds, in all cases it could be assigned to its proper place by the character of the neighboring outcrops.

Bed No. 3 outcrops in many places. It was recognized at the extreme end of the iron formation, near Birch Lake and at the western end of the area mapped, in Mesaba. It is a hard recrystallized chert, of fine grain, and is one of two horizons having a peculiar structure ascribed to organic growth. (See description of Bed No. 3 of the Upper Cherty Beds.) The outcrops of the cross sections of these beds show a more or less regular wavy structure such as would be produced by piles of shallow inverted basins 2 to 24 inches in diameter. This structure is emphasized by differential weathering, and color differences of the various layers. In most cases the colors of the parallel basin-shaped layers alternate in grays and whites. In other outcrops, the alternation is white and red of various shades. In the latter case there are many magnetite and hematite pebbles included in the rock. The thickness of these beds is about 15 feet and is fairly constant in the eastern area. Similar forms occur in the iron formations near Hudson's Bay,[4] in the Belt Series of Montana,[5] and in siliceous limestones in the Grand Canyon, Arizona, all of pre-Cambrian age. In these cases the structures are referred to algal growth.

LOWER SLATY BEDS.

Bed No. 1, the bottom of the Lower Slaty Beds, is the most slaty in structure of any part of the iron formation. It is very constant in thickness and character throughout the entire range, and is known as the "intermediate slate." It is thin-bedded and on weathering breaks into thin slabs parallel to the bedding

[4] Moore, E. S., "The Iron Formation on Belcher Islands," *Jour. Geology*, vol. 26, 1918, pp. 425–426.

[5] Walcott, Chas. D., Smithsonian Miscellaneous Collections, vol. 64, No. 2, 1914, p. 111.

planes. Ripple marks were found in places and it is thought to be of clastic origin. The chief minerals are a fine recrystallized mosaic of quartz grains and amphibole needles. Its black color is probably due to graphite, for it contains but little magnetite (Plate XVII., *a*).

Bed No. 1, 25 feet thick, grades upward into bed No. 2 by becoming more granular in texture and by showing less regular bedding. The rock becomes hard and fine-grained and has a conchoidel fracture. Thin sections show it to consist of a mat of fine amphibole needless in recrystallized chert, with a very obscure granule structure. Magnetite occurs in these beds as a few scattered pebbles and in thin lenticular seams, but as a whole is present in small amounts. In places the rocks of this horizon are spotted, due to the presence of metacrysts of fayalite.

Near the top of these beds the transition into the Upper Cherty beds takes place by the texture becoming more granular, magnetite pebbles more numerous and layers of pure magnetite thicker and more abundant.

UPPER CHERTY BEDS.

Bed No. 1 of the Upper Cherty beds is characterized by (1) a granule texture, (2) the presence of conglomerate pebbles, (3) irregular wavy or lenticular character of the bedding, and (4) relatively high magnetite content.

Under the microscope the finer grained parts of the rock show the rounded forms attributed to altered greenalite (hydrous ferrous silicate). Mineralogically the material making up the granules is now the same as the bulk of the formation, namely amphibole, quartz and magnetite.

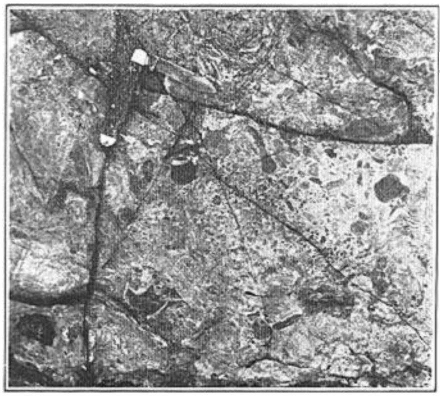
The conglomeratic nature of the beds is evident in many places, especially in the eastern part of the area studied. Many of the pebbles are of magnetite, many are of material resembling the bed below, and many show a core of siliceous granular rock with a zone of magnetite around the border. The shapes are mostly somewhat flattened and fairly well rounded, but a considerable number are angular, and plate-like. The size ranges from one sixteenth of an inch up to six inches in diameter. Inasmuch as it marks no erosional unconformity, this conglomeratic horizon is of the intraformational type (Plate XVII., *b*).

The individual beds pinch and swell, split up and unite, showing in all cases a wavy character, evidently not ripple marks nor caused by folding. There are no signs of cross bedding.

This bed makes up the greater part of the Upper Cherty beds, which as a whole, in the places where the data are most complete, are found to be high in magnetite as compared with any similar thickness of beds elsewhere in the Biwabik formation on the east Mesabi. Over considerable areas, bed No. 1 is found to have an average magnetite content of 30 per cent.

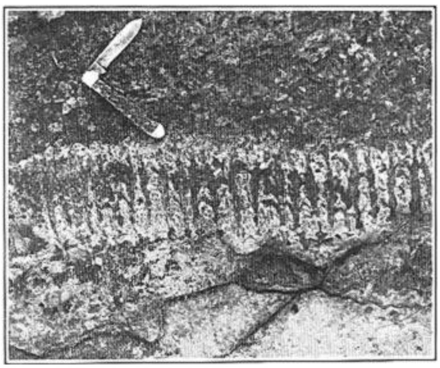
Bed No. 2 differs from No. 1 in having thicker beds of magnetite, many of them two inches in thickness or more. The conglomeratic character is marked in some outcrops. Hematite pebbles may be seen among the magnetite pebbles, and the reddish streak of some of the magnetic layers indicates the presence of some finely intergrown hematite. This bed averages 40 per cent. magnetite in places from which assays are available.

Bed No. 3 is a thin bed of cherty or jaspery material with a characteristic algal structure similar to but smaller than that of bed No. 3 of the Lower Cherty beds. Because of the hardness of this bed and the ones immediately above and below, it outcrops in many places. The color varies from gray to red, with the variation in the content of ferric oxide. In this horizon, the algal bodies resemble little piles of thimbles or inverted bowls one half to three fourths inch in diameter, piled in irregular columns about 6 to 12 inches high. Plate XVII., *c* and *d* show the characteristic forms. The upper and lower parts seem to merge into the granular fragmental material of the conglomerate. Between the finger-like structures, fragmental material also occurs. Horizontal sections of the structures show concentric rings like those of a concretion, but the vertical sections do not. Outcrops in the east Mesabi indicate a continuous bed fifteen miles long, and the structures are recognized in drill cores from thirty miles west of the area maped in this investigation. It is remarkable

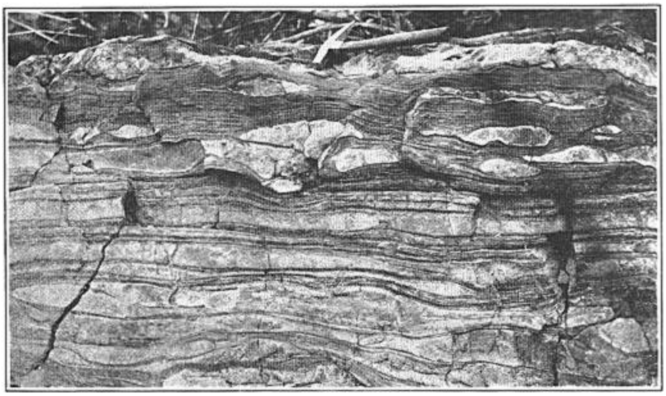
a *b*

FIG. *a*. Thin-bedded "Intermediate slate"; bed No. 1 of lower slaty beds.
FIG. *b*. Conglomerate of bed No. 1, upper cherty beds.

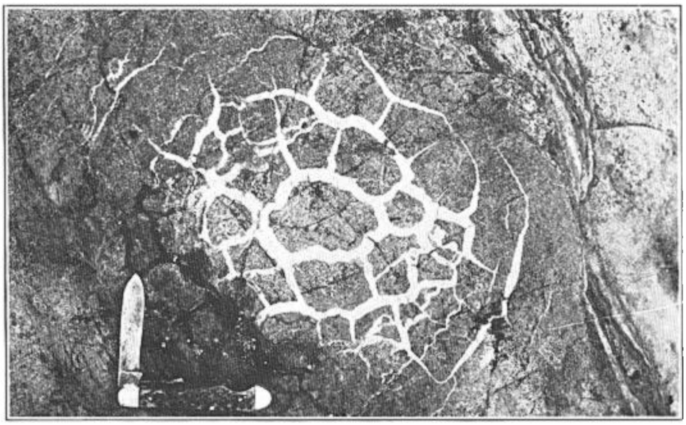
c *d*

FIG. *c*. Horizontal section of algal structures in bed No. 3 of upper cherty beds.
FIG. d. Vertical section of algal structures of bed No. 3, upper cherty beds.



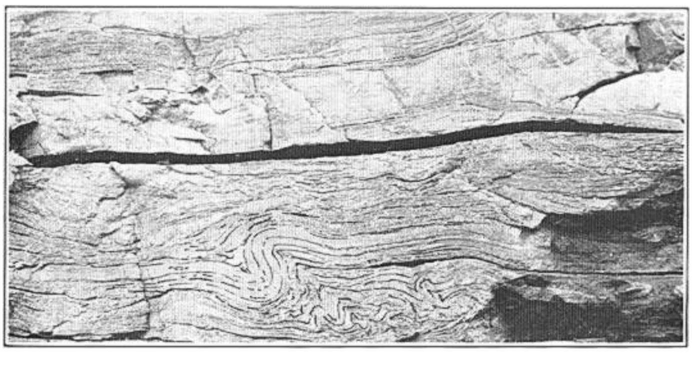
a

FIG. *a*. Nodules in thin beds in upper slaty beds.



b

FIG. *b*. Septarium from bed No. 1, upper slaty beds.



c

FIG. *c*. Drag folds in thin beds between massive chert layers in bed No. 1 of upper slaty beds.

that such small growths, forming but a thin layer, should extend over such a wide territory as to serve as a horizon marker for at least one-half the length of the range. Examination of cores from the rest of the range would probably show that the bed extends over the entire length of the iron formation.

Bed No. 4 is in nearly every respect the same as the magnetite rich bed No. 2, below the algal chert. The algal growth occurred at one stage during the accumulation of the conglomeratic beds.

UPPER SLATY BEDS.

Bed No. 1 of the Upper Slaty Beds is different in several respects from those just described. There is no abrupt change, however. The granule texture is seen in similar lenticular beds and there are even a few pebbles. Two features which distinguish these beds from the preceding are first, the magnetite layers instead of being lenticular and compact, are fine-grained and in many thin layers, a set of thin magnetite beds alternating with the lenticular beds of granule texture; second, the coarser beds contain and may consist of nodules or concretions distinct from the matrix. Plate XVIII., *a* shows these two features.

The nodules are not recognizable in drill cores, but they are very clear in the exposures and grade into the lenticular bedding in such manner as to suggest that the very lenticular beds in the Upper Cherty Beds may have developed by concretionary action. It is noteworthy also that the nodules and matrix have granules and even pebbles in them; so that the growth of a nodule does not apparently mean a replacement of all the material by a uniform precipitate from solution; rather it must have been more like a special cementation of a certain part of the beds.

One of the most striking features noted in the outcrops of the iron formation on the east Mesabi, is the septaria cracks in these beds. Septaria seem to have been described chiefly in carbonate concretions; and there may have been more or less carbonate in the iron formation—some still is to be found. However, the concretions are now mainly quartz and magnetite, while the cracks are filled with white quartz (Plate XVIII., *b*). They serve to identify the horizon of outcrops over practically the entire east Mesabi, and it is believed that they will be found to extend over the whole range.

Other prominent features of these beds are the rather abundant garnets near the bottom, and the drag folding with more or less brecciation of the thin amphibole magnetite beds between the more competent layers of chert (Plate XVIII., *c*).

Bed No. 2 is similar in most respects to the septaria beds below. Drag folding and septaria have not been noted in them, and the magnetite content diminishes upward.

Bed No. 3 is chiefly made up of light green and white bands of amphibole and quartz. Magnetite is almost entirely lacking. Calcite is more abundant than in the lower beds.

Bed No. 4 is a limestone of variable nature, in places amphibolitic. It is soft and outcrops in few places, but all drill cores examined from east Mesabi holes starting in Virginia slate, show a thickness of 5 to 10 feet of limestone just above the iron formation proper. It is, therefore, taken as marking the top of the iron formation. In contrast with the variability of the iron formation below, the slate is very uniform in character for hundreds of feet above the limestone bed, so that the division between the Biwabik iron-bearing formation and the Virginia slate falls naturally at this horizon above the limestone.

As mentioned at the beginning of this article, the working out of the detailed stratigraphy of the central and western parts of the range from outcrops would be almost hopeless. Outcrops are few and the rock is weathered. However, underground workings, the walls of open pits, and the cores of thousands of drill holes would undoubtedly furnish material to continue the study on the main range which has been so well started by Wolff. The writer feels confident that many of the thirteen divisions of the iron formation which are recognized on the east Mesabi could be traced much farther westward. Features of drill cores from holes on the east Mesabi which were of most use in determining the various horizons (see tabulation) were the limestone bed, approximate content of magnetite (tested with ordinary small magnet), thickness of the banding, presence of drag folds, brecciation, separia cracks, garnet, conglomerate pebbles, algal structures, spots of fayalite, black slate, and the basal granite or quartzite.

A brief examination of drill cores from scattered places showed that the magnetite content of the unweathered iron formation over the entire range approaches that of the eastern end. Large bodies of rock on the main Mesabi were found, not heavily overburdened, having 30 per cent. of magnetite. The common practice of discarding drill cores without considering their magnetite content is one which may be regretted, as it may become possible to mine and concentrate such material economically in the not distant future.