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RECENT DEVELOPMENTS IN THE GEOLOGY OF THE GOGEBIC RANGE

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By W. O. Hotchkiss, 1923.

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With the vast demands for ore made upon the mines of the Lake Superior Iron District the question of the continuation of the supply becomes one of vital importance to one of the leading industries of the country. It is the function of geologists and mining engineers to study this question most intensively, as on their conclusions must be based the investment of many millions of dollars in exploration, new shafts and equipment and mine development work. Insofar as their conclusions are correct this money will be well invested, and insofar as they are incorrect it will be spent wastefully. Consequently they must give the fullest possible consideration to every fact of observation, to every scientific theory, and to every detail of practical mine operation and finance.

There are three important geologic questions relating to the occurrence of ore on this range, concerning which much information is needed, and to which much study should be given. One is the relation of ore deposits to the various horizons of the iron formation. The second is the depth to which ore forming processes have been active. The third question is the relation of ore to the small cross faults.

With regard to the first - the relation of ore bodies to specific horizons - much information has been obtained. With regard to the depth to which ore will be found, relatively little is known. With regard to the third much remains to be learned.

RELATION OF ORE BODIES TO DEFINITE HORIZONS

In the mines from Bessemer to Wakefield 22 different recognizable beds in the iron formation have been identified so clearly that in some mines both miners and mine management use them in describing the location of exploration work. In five of these ore bodies have been found. In my series of articles in the Engineering and Mining Journal I described six major divisions of the formation which are readily identifiable in most mines. From the foot northward these are:

1. Plymouth wavy bedded granular cherty formation.
2. Yale slaty iron formation with beds of cherty formation.
3. Norrie wavy bedded granular cherty formation.
4. Pence slaty iron formation.
5. Anvil wavy bedded granular cherty and red jaspery formation.
6. Pabst conglomeratic, cherty and slaty formation.

Of these 1, 3, 5, and 6 carry important ore bodies, and in exceptionally favorable situations ore may make in all six as in the Norrie and Newport ore bodies. What is needed is closer subdivision of these members of the formation in each mine and careful observation of the conditions favorable for the formation of ore in each one.

RELATION OF ORE BODIES TO CROSS FAULTS.

The relation of ore bodies to the cross faults needs a great amount of study. We know that these faults favor the formation of ore bodies in some places, and yet we find no concentration in similar situations where all the factors we know are just as favorable. We find one ore body lying on the west side of a fault. At the next fault the ore may lie east of the fault. In a third case the ore may lie on both sides of the fault. Why this is we cannot say, and consequently prudent exploration demands that both sides of the fault be investigated.

One thing that handicaps us in this study is that these cross faults have not been mapped with sufficient care. They are not easily identified in many instances, as the throw is usually very slight. In many cases the footwall may not be offset at all, and the only way the fault can be identified is by offsets in dikes or by a broken rubbly condition of the beds. This rubbly condition is also produced by slump in the vicinity of ore bodies so it requires close observation, in many cases, to identify the faults. Again many faults that slightly offset the footwall are mapped as minor "rolls" of the foot. In following the quartzite with a footwall drift it often happens that the footwall is lost, so the drift is turned gently to the south until the foot is encountered again, and the presence of a fault may not be detected. It is important that careful study of the bedding of the formation be made in all such cases to determine whether it is really a fault or actually only a gentle roll in the formation, as so many cases are mapped. The identification of these cross faults should be made as workings are being driven, as they may furnish important guides to exploration on other levels of the mine.

ULTIMATE DEPTH OF ORE

The question of most acute interest at the present time is probably that of the depth to which ore bodies may be found in sufficient abundance to warrant the expense of mining. Shafts are being sunk and others are under consideration that are designed to go ultimately to depths of 4000 feet. The cost of such a shaft and its equipment is in the neighborhood of one and a half million dollars, so it is very important to use every bit of knowledge we possess that has any bearing on the probability of the occurrence of ore at this depth. The theories of origin of the ore, and the conditions under which the iron formation was deposited become of vital importance in such a consideration.

Of definite information we have the following:

1. Near both east and west extremes of the productive part of the range - the Castile and Atlantic mines - narrow ore bodies and favorable conditions as to oxidation and leaching of the formation are known at depths of about 2000 feet vertically from surface in drill holes from the bottoms of the mines.

2. Toward the central part of the range ore is known at somewhat greater depths - about 2400 to 2600 feet below the surface in the Montreal, Pabst, Newport and Geneva mines. Favorable conditions for ore - well oxidized and leached iron formation are known at the Eureka mine nearly 3000 feet below the surface.

<u>Origin of the Ore.</u> Recent studies of the ore bodies have disclosed nothing to change the original idea of Van Hise that the ore bodies were produced by the oxidation and leaching of the iron formation by the circulation of oxygen bearing waters, which were localized in their course through the formation by the impervious dikes and the footwall. However, considerable advance in the detailed application of this theory has been made. It has been recognized that those beds of the iron formation which were originally more porous and richer in iron are more favorable for the localization of ore deposits; the richer beds because it took less leaching of silica to make an ore body, and the more porous beds because they favored an abundant circulation of the water. Conversely it has been recognized that several of the less porous beds often times serve as secondary footwalls and in conjunction with the dikes make the same sort of conditions that produced ore on the quartzite footwall.

As already described, it has been recognized that the fracturing of the formation by faults has greatly increased the possibilities for water circulation, and in many cases has favored the formation of ore. With this, however, must be considered the possibility that the formation may have been made so poroue along some of the faults that the circulating water was too widely diffused to produce the desired concentration.

<u>The Work of Circulating Water.</u> If we knew all the details of the circulation of the water through the past history of the iron formation we could predict accurately the position, grade, and size of every ore body on the range. Such being the case it is unfortunate that we know so little about this important subject.

In all the early history of the range many mining men and geologists believed that the water circulation was stopped by the uppermost dike, and consequently that little or no ore would be found below the dike by deeper exploration. It was also believed by many that all ore bodies started at ledge and continued down the trough of dike and footwall and when that ore body ended no more ore would be found farther down that trough. These notions were not entirely abandoned until J. R. Thompson went below the bottom of the old Newport ore body through 800 feet of barren formation and found the continuation of the Pabst ore body. Now we know that many large bodies of ore have no connection with the surface, and that water has found its way to great depths leaving ore bodies here and there in its course in situations specially favorable, but going through intervening parts of the formation without doing sufficient leaching to develop ore bodies.

We know beyond question that a vast amount of silica - probably in excess of 100,000,000 tons, enough to cover an 40 acre tract 1600 deep - has been dissolved and removed from the productive part of the range. Just when or how this has been done we do not know, nor can we answer the question as to where it has gone.

Much valuable information that might have been gained has escaped us in the past. If we had complete analyses of the water taken at various depths from the surface in each mine as it was opened, so that we knew the change in mineral content of the water with depth, it would afford us an important clue to the depth we might expect ore to go. Analyses of samples taken from different depths in a mine at present cannot give a true idea of the water composition as it was originally, as the natural circulation has been interfered with by pumping.

Much has been published on the composition of mine waters of the Lake Superior districts, chiefly by A. C. Lane, and any one interested in persuing this study should by all means refer to his publications. I have prepared a table, chiefly of unpublished analyses, which indicates rather clearly that water changes in composition with depth.

WATER ANALYSES. Given in parts per million.

Source of Water	Total Solids	Cl	*%Cl	CO_2	*% CO_2	Na	*%Na
Creek Water. Near Plumer Mine	64	6.4	10	8.9	13.9	4.5	7
Spring " " " "	152	18	11.8	72	47.3	19	12.5
Plumer Mine Water, 13th level. From well leached formation.	426	142	30	78	18.3	30	7.1
Montreal Mine. From flowing drill hole, from below bottom level. In little leached formation.	2507	1076	43	92	3.7	500	20
Germania Mine**	1493	638	43	27	4.2	81	12.7
Ashland Mine***	4500+		60+				

* Percentage is % of total solids made by the constituent named.

** A. C. Lane, J'n'l. Can. Ming. Inst. 1909, Vol. XII, p. 124.

*** Anal. furnished by Emil Kronquist, Water from 24th level near the ore body.

I am informed by Mr. M. C. Lake that he is making a careful study of the water in the Ashland Mine, and hopes to have some conclusions to present at an early date. Other work on water composition is in progress at the Plumer and Montreal Mines.

The above table of analyses shows that the chlorine content increases greatly with depth. In the deeper waters the chlorine occurs chiefly in combination with lime.

Further study and continued observation as mines are worked deeper may eventually give us sufficient information so that we can draw valid inferences from the water composition as to the ultimate depth of ore in a given part of the range. At present, however, we must admit that we do not know enough to make this possible. We cannot even be sure that we can eventually predict this safely from water composition, but the cost of accumulating the information is so slight that this avenue of approach to the solution of such a vital question should not be neglected. As new and deeper levels are opened the water should be analyzed before its composition is altered by the drainage of the workings. Only in this way can we acquire the needed body of facts from which to draw valid deductions.

From our present knowledge of the range we cannot give any figure as the ultimate depth to which merchantable ore will be found. We can say with reasonable assurance that ore will be mined to a depth of 3000 feet in some mines, but how much deeper it will go there is too little evidence for us to say. In general it may be said that so far the largest ore bodies are the deepest, but no one knows how long this will continue to be true.

In many mines, if not all, fairly large sized blocks of the formation are unleached and even unoxidized, but for the most part these are surrounded by formation that is thoroughly oxidized and more or less leached. As the bottom of profitable mining is approached these unoxidized parts should be an increasing percentage of the formation. It may be that a careful quantitative study of the mines with this in mind would reveal facts of great importance. So far as I am aware, however, no such study has been made, so we must comfort ourselves with the statement that at present we do not know of any facts that indicate that the end of the ore bodies with depth is in sight.

THE EAST AND WEST PROVINCES.

The Gogebic iron formation is known to extend from near Namakagon Lake in Wisconsin, nearly to Gogebic Lake in Michigan - a total distance of about 65 miles. Of this length about 25 miles is in Michigan and 40 in Wisconsin. The eastern end, from Ramsay eastward is much broken by faulting and by intrusives - a length of about 17 miles - but in this region the formation is quite well oxidized and leached. On the western end there is a somewhat similar occurrence of faulting and intrusion, but here the formation has been differently altered so that there are high percentages of magnetite and some development of iron silicates. These are the extremes of the range.

Another difference that serves to distinguish the east and west provinces is ore production. Most of the ore has come from Michigan. The shipments from the Wisconsin end have been only a small fraction of the production of the range. The westernmost shipment of ore was from the Tylers Fork Mine, about 16 miles west of the state boundary. But this must be rated as an unsuccessful exploration at present rather than as a case of real mine production. The westernmost real mine was the Iron Belt, which is 9 miles west of the state boundary.

The productive part of the range is about 13 miles long in

Michigan and 9 miles in Wisconsin, a total length of 22 miles, with well oxidized and leached iron formation extending east of it for 12 miles in Michigan, and at least as far west as Tylers Fork in Wisconsin - 8 miles. This gives a total actually productive length of 22 miles with an additional length of 20 miles more on its two ends, known to be worthy of exploration.

We may put the division between the western and eastern provinces of the Gogebic iron formation at about Tylers Fork. There is no hard and fast boundary. It is probable that the formation west of Tylers Fork may be oxidized and leached sufficiently to carry merchantable ore, but present exploration is too meager to disclose this. Placing this dividing line here is done for the purpose of giving a general description of the two provinces, and should not be taken to imply that it should be the western boundary of exploration for merchantable ore nor that it is the eastern boundary of exploration for magnetic concentrating ore. It is merely a conveniently described place, with a commonly known location that serves the purpose. It really lies toward the east end of a gradation zone several miles in length.

The chief distinguishing features of the <u>eastern province</u> of the iron formation may be stated categorically as follows:

1. Produces all the natural merchantable ore.
2. Iron formation characteristically thoroughly oxidized, prevailing red or brown in color, and well leached and porous.
3. Dikes abundant.

4. Faults abundant, folds in frequent and minor.

5. Little or no magnetite or iron silicate present.

6. Keweenawan Trap Range to north a strong topographic feature.

7. Topographic relief in the iron formation 100' to 300'.

In contrast the characteristics of the western province may be stated as follows:

1. Has produced no naturally merchantable ore.

2. Iron formation much less oxidized, and while much is red or black at surface, the drilling shows mostly green and black unoxidized, little leached or unleached, dense, impervious formation.

3. Dikes apparently less abundant than in the east province - although this may be an impression due to lack of exploration.

4. Folds of considerable magnitude present as well as faults.

5. Much of the iron present as magnetite with iron silicates common.

6. Keweenawan Trap Range a much less notable topographic feature - not standing much higher than elevations in the Tyler Slate.

7. Topographic relief in the iron formation 200 to 400'. The highest point of the Gogebic Range country is Mount Whittlesey, where the Berkshire Mining Company is working southeast of Mellen.

From these differences between the two provinces certain economic facts of importance become evident.

1. Exploration by diamond drilling for naturally merchantable ore bodies is warranted in an area extending fully 9 miles west of any modern exploration. Modern exploration has extended the eastern limits of the productive part of the range.

The western limit has not been explored but offers opportunities at least as favorable and is just as promising to the explorer.

2. Exploration in the west province should be limited to the discovery of parts of the iron formation that can be successfully concentrated. The presence of magnetite disseminated through most of the hematite probably offers the readiest means of experimental attack. It is hardly necessary to call to the attention of members of this Institute that commercially successful concentration of iron ore in the Lake Superior region is a matter that is necessarily preceded by much grief. Pioneers in any line of business either go broke or make much. To insure the latter requires a combination of good luck, keen hard analytical study of the problem, and much capital.

In the Western Province of the Gogebic Range there are the same differences between various beds of the iron formation that are so well known to the east. It is practically certain that successful concentration will of necessity confine its activities to particularly favorable beds.

There is little doubt that a relatively few years will see a much keener interest in iron ore concentration, as the reserves of the Mesabi Range are depleted.

In conclusion then let me state that the future of the Gogebic lies along two lines; 1. Deeper and farther east and west extensions of production of naturally merchantable ore, and 2. Concentration, both of magnetic and of hematite ores. With regard to depth we know no factor that indicates that the bottom is near. It may well be that ore bodies can be found as deep as it is practicable to mine and hoist ore.