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EXPLORATION METHODS ON THE GOGEBIC RANGE

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By W.O.Hotchkiss, State Geologist of Wisconsin, and Consulting Engineer.

An essential mental equipment for planning exploration is the fullest possible knowledge of the way in which the ore bodies occur in the region to be explored. Added to this knowledge there must be the thorough realization that in no mining district is this knowledge complete, and that new facts of importance will be revealed to the explorer in every exploration he undertakes if he is in the proper frame of mind to grasp them.

The geology of the ore deposits of the Gogebic range has for a long time been thought to be relatively simple, but work in recent years by several men has proved that these old ideas of its simplicity do not give us all the facts. We now have a more perfect realization that we are far from knowing all the factors that have resulted in the localization of ore deposits. For example, we have long known that the intersections of the dikes and the footwall were favorable places to look for ore, but only within the last few years have we learned that there are several horizons in the various members, well north of the footwall, that are likely to carry ore. The influence of the numerous cross faults on ore bodies is not known or appreciated at the present time much beyond a general realization that they are important. Just how, in detail, they are favorable or unfavorable to the localization of ore is not known. Such elementary information as the positions of these faults is just beginning to appear on the mine maps.

Such being the condition, one can hardly overestimate the importance to the various operators and fee owners of careful studies of conditions in their properties for the purpose of assuring themselves that they are not missing valuable ore -- that they are doing all the exploration that their situation demands in order to secure maximum returns. Valuable ores have been missed in the past and will be missed in the future. Only with complete knowledge of all the factors which have united to produce ore could anything else be expected. The purpose of this paper is to call attention to these facts briefly and to suggest a few of the principles at present known which should guide effective exploration. The foremost principle, -- which I would emphasize most strongly --, is that the man who starts out with the idea that he knows all about the mine geology of the Gogebic range is starting with a very heavy handicap.

Brief Outline of Gogebic Range Geology

The iron bearing series on this range is similar to that in the other Lake Superior ranges. The important economic feature is the iron formation -- on this range named the Ironwood formation -- with which are associated the footwall quartzite and the slate hanging wall. These formations dip northward at an angle of approximately 60°.

Numerous dikes cut these formations nearly at right angles to the bedding. Most of them pitch 20° to 30° from the horizontal downward toward the east, but some of them pitch at similar angles to the west. All of them make relatively impervious pitching troughs with the footwall and with other impervious beds which occur within the iron formation. It is chiefly in these pitching troughs that ore bodies occur.

The term iron formation in this paper is taken to include all the beds which are known to bear ore, and so includes the basal part of the hanging wall formation as well as the Ironwood formation.

In a recent description of the geology of this range (1) I divided the Ironwood formation into two major divisions and five subdivisions. These are as follows:

Tyler Formation (hanging wall)		Pabst Member (ore bearing)
Ironwood Formation	Upper Ironwood	Anvil Member Pence Member
	Lower Ironwood	Norrie Member Yale Member Plymouth Member
Palms Quartz Slate (Footwall)		

For a detailed description of the various members of the iron formation and their characteristics the reader is referred to the article mentioned.

These six major members are recognizable throughout the main producing part of the range, and are convenient guides for reference. However, when exploration of a single mine is under study, these six divisions are not sufficient. The smaller the recognizable divisions that can be made the more intelligently will the work be done. In one mine the engineers have made over twenty divisions for correlating the geology of the various cross-cuts and drillholes. So definitely can the successive beds be determined, that the duplication or ellipsis of one or more beds

(1) Geol. of the Gogebic Range and Its Relation to Recent Mining Developments - E.& M.J. (1919.) W.O.Hotchkiss

by faulting is oftentimes evident in the drill core, and thus the point where the drill cut the fault, and the direction and amount of throw, is determined and mapped even though the core itself gives no suggestion of a fault.

The iron formation and the dikes are cut by a great fault which is practically parallel to the beds. The north part, or top of the formation has been moved several hundred feet eastward in relation to the part below or south of the fault. There are also numerous faults which are nearly at right angles to the beds. Most of these are vertical, but there are some that have about the same position as the eastward pitching dikes. There are also a few faults cutting the formation at other angles, but it is not necessary to describe them for my present purpose.

Origin of Ore Bodies

The ore bodies of the Gogebic range, with only a few unimportant exceptions, are caused by the leaching of the silica from the mixture of chert and iron oxide which makes up the iron formation. This leaching is done by the water which more or less slowly finds its way through the formation. Any condition that favors this water circulation is favorable to the formation of ore bodies. Any condition which hinders or prevents the circulation is unfavorable.

If a particular bed of the iron formation were originally high in iron and low in silica, it would require less leaching to produce ore. So if two beds were equally well situated with regard to water circulation and equally porous, the one that had the least silica would be first changed to ore. However, the bed having the least silica might be so extremely dense and non porous that the bed that was more porous and contained a much larger percentage of silica might alter ~~the~~ To ore while the first was not affected.

The ore bearing horizons at present known are as follows -- named in order from the footwall north:

1. The base of the Plymouth Member. This is where most of the ore has been mined.

2. Near the top of the Plymouth Member.

3. In the bedding fault zone. Where this fault has broken the ferruginous cherts, it has favored the circulation of water, and in a number of places ore has resulted. In most places the fault is in an impervious black slaty carbonate, and no ore is found.

4. The top of the Norrie and base of the Pence members.

5. The base of the Anvil Member.

6. About 100 feet north of the base of the Anvil.

7. The Pabst Member.

In a few of the largest ore bodies the ore is continuous from foot to hanging, but even in these bodies the rich porous beds of the formation are altered to ore farther from the dike than the other beds.

Among the known conditions favorable to localizing the leaching effect of the water - and hence favorable to the formation of ore - are: 1. Intersections of dikes and the footwall or of dikes and impervious beds of the formation; 2. the more pervious beds of the iron formation; 3. those parts of the formation which have been broken by faults.

Exploration

In order of time in a well planned exploration there are three general things to be determined. First the positions of the various dikes both north and south of the great bedding fault must be known either from drilling or underground workings. Second the particular beds which are known to bear ore should be located from some definite reference plane such as the footwall, so that the places where these beds are cut by the dikes can be determined with the necessary degree of accuracy. These intersections are the objectives that exploration should aim for. Every drill hole, or exploration drift or crosscut should be planned to cut a favorable part of the formation just above a dike. Third the effect of faults must be considered. Faults can be located in many cases by careful magnetic observations, as pointed out in the paper by Mr.H.R.Aldrich at this meeting. This has been done successfully in both the east and west ends of the range, and doubtless can be done in many places in the central part by working along the Pabst Member of the formation. A careful examination of mine workings has served to identify many small cross faults that have never been observed before because their throw was too small to attract attention. These cross faults apparently die out toward the south so that the throw is often only a very few feet at the footwall, but toward the north side of the formation the throw increases and they are of greater importance in planning both exploration and mining work.

These cross faults have, in many cases, made excellent opportunities for the water to get through and leach the formation, and ore shoots have been followed vertically hundreds of feet along them.

The nature of the influence of cross faults on the localization of ore bodies is little known -- except for the case where the fault zone itself is altered to ore. Between two faults a particular bed may be altered to ore on a dike. In the block next east this same bed on the same dike may be almost wholly unleached and the ore may be found in a different bed, either nearer to or farther from the footwall, or the entire block may be barren. The water has evidently gone through one fault block in one zone on a given dike. When it reached a cross fault, it dropped down that fault and found its way through the next block on some lower dike and perhaps in some other bed which offered a more favorable channel. Sometimes it has gone through several fault blocks on the same dike, and the cross faults are marked mainly by enlargements of the ore body due to the favorable situation created by the breaking up of the formation by the fault.

All these facts should be considered in planning exploration and interpreting the results. Successful work demands close observation of the formation and careful study of all the possibilities for finding ore.

Drilling

The iron formation of the Gogebic range is notoriously difficult drilling. The leaching of the formation attacks favorable beds and leaves more or less untouched the less favorable ones. The result is an alternation of hard dense beds and more or less soft vuggy beds. There is consequently much difficulty in getting a proper return of samples, and also a great deal of trouble in operating the drill. The alternating hard and soft beds make it almost impossible to keep a drill hole straight for more than a few hundred feet. In order to keep the samples from contamination it is necessary to keep casing close to the bit as soon as the drill enters soft ground. If this is not done an ore body may be passed through and the samples be so diluted by the soft leached chert worn off the walls of the hole that the analyses show nothing of value.

The large amount of time and trouble necessary to handle caving holes and to fill open vugs makes diamond drill operation both difficult and expensive. The great expense and the inability to keep the drill straight on its course makes most holes of greater length than 1000 to 1500 feet of doubtful utility if there is any reasonable possibility of reaching the objective in any other way.

In consequence of the foregoing facts the belief has gradually grown upon me that the main function of the drill on this range is to determine general conditions rather than to find ore. Diamond drilling can be used to excellent advantage to show the nature and condition of the formation in advance of and for the purpose of guiding drifting and crosscutting and going to greater depth. But these extensions should not depend wholly on the actual findings of ore by the drill. If the drill shows a well leached formation on a good sized dike, the dike is well worth exploring by mine openings. Oftentimes a hole lost as the result of caving is an excellent indication of ore below. When the drill gets into the broken formation which sometimes overlies an ore body -- broken by the slump of the ore on account of leaching out of the silica -- it is very difficult and sometimes impossible to get through.

The core recovery from about 25,000 feet of diamond drilling was computed and found to average 30.7%. This composite result was made from 26 holes of widely varying depths. The core recovery from the individual holes varied from 6.4% to 58.1%. The lowest recovery was from a short hole practically all in well leached formation, and the highest was from a hole that extended through hanging slates and the full thickness of the formation. This hole happened to go through an almost wholly unleached part of the formation. It probably represents about the maximum core recovery from average drilling.

The foregoing statements indicate strongly that drilling is not satisfactory as the sole method of exploration. This statement must not be misinterpreted to imply that drilling is not a useful method. The statements made have had as their purpose the proper placing of emphasis. Drilling should be done far more extensively than mine operators have done in the past, but even though the drill may not be fortunate enough to find ore, it must be kept in mind that it may show up a condition of the formation which warrants extending exploratory mine workings to determine what really exists in favorable situations that the drill may find.

Exploratory Drifts and Cross Cuts.

These constitute the most satisfactory method of exploring, but such work is too expensive to carry on without having the definite objective that should be shown up in advance by drilling. In the past, before it was known so definitely as at present just what are the beds most likely to carry ore, many long crosscuts were driven north to the hanging wall. A few of them found ore but most of them did not. Most of them were driven with little or no knowledge in advance of where the dikes lay north of the great bedding fault, and more often than not when they did penetrate dikes they were in beds that were unlikely to contain ore. Some of these old barren crosscuts could be used to great advantage at present by driving drifts or raises from them to explore the good ore bearing horizons just above the dikes.

Every exploratory drift or crosscut should be planned to give the maximum possible information with regard to one or more of the seven known ore bearing horizons where they are cut by fair sized dikes. If the pitch of the dike is sufficiently great to make its strike cut the strike of the beds at a fairly large angle the best results are obtainable by driving along the top of the dike --northeast, with an east pitching dike, and northwest with one pitching west.

The cross faults should also be given careful consideration in planning an exploratory crosscut or drift. A crosscut that strikes a favorable ore horizon on a good dike where the formation is faulted has probably the best chance of finding ore. These cross faults cut the formation up into blocks that are seldom more than one fourth mile long east and west and are often only a few hundred feet long. In order to test the formation thoroughly every fault block should have every favorable ore horizon tested on every fair sized dike. This statement is made with full realization that it is not always advisable to explore a property thoroughly. The object of exploration must always be to find ore -- not to prove that no ore is there. General indications of the character of a certain block on a certain dike may make such a territory a good one to neglect. But if one bed on a dike is well leached or carries ore, the other favorable beds also should be tested on this dike. I examined a mine in which failure to do this resulted in the loss of a very large tonnage of ore.

Exploration on the Gogebic range offers great possibilities of reward. Even the footwall has been only partly explored down to the depth of present operations. When to this unexplored footwall are added the parts of the formation -- little known but well worth exploring -- north of the footwall; the greater and unknown depths below to which ore may go; and the neglected parts of the range east and west of the producing mines it is obvious that this range has a long and profitable future before it. The subject of exploration methods must continue to be a live one for many years and much good can come from a full discussion which it is hoped this present brief paper may start.