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GEOLOGY, ORE OCCURRENCE & MINING PRACTICE OF THE REPLACEMENT ORE BODY OF THE MAGMA MINE

By
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INTRODUCTION

Exploration and stoping of the replacement ore body in the Magma mine is a comparatively recent development. It was during 1950 when the first ore was sent to the mill from the replacement deposits in the eastern part of the mine, the first important deposit of this type thus far found at Magma.

Insofar as this type of deposit had not been encountered byfore at the mine, it brought up new problems both in geology and mining. The extent, copper content and mineability of the mineralized zone were questions foremost in our minds. These questions and many others that came up at that time have been partially answered, but there are still many more with question marks after them. I hope in this paper to give a brief outline of what we have learned since the beginning of ore development in 1950.

HISTORY

The direct history of the east replacement deposit dates back to 1948 when exploration, which the war had curtailed, was revived in the east end of the mine.

The first work consisted of diamond drilling south from the main East Drift to No. 6 Shaft on the 2550 level. This south drilling was done from that section of the drift east of a large fault, N85W, which cut off the main vein. At that time the displacement of this fault was not known, but it was obvious that it was large. The horizontal drilling on 2550 cut, at about 300 feet south, a vein which had first been picked up on the 2000 level in exploration prior to the war. Further drilling of down holes from 2550 determined the general attitude of the vein and proved mineralization down to the 3000 level. This down hole drilling also intersected replacement mineralization in the Martin limestone just above its contact with Troy quartzite on the footwall side of the vein. Replacement at this horizon had been encountered adjacent to the main vein in the zinc country on the upper levels, but the mineralization there never extended out very far from the vein. Although some mineralization of this horizon, adjacent to the vein, was expected, the drilling was done primarily to prove ore on the vein. However, when the replacement zone was cut by the drill holes, it was surprising in that appreciable mineralization was found much further in the footwall of the vein than previous development in the zinc country would have led one to expect.

These drilling results were favorable enough to justify exploration on the 3000 level, so in 1949 a crosscut was driven southeasterly through NS5W fault to the vein. A drift was then driven east along the vein to the replacement horizon where a relatively wide zone of good ore was crosscut. The vein was found to be very weak on the hanging wall side of the replacement ore so, for further exploration, drifts were driven on the North and South beds. E 58-1/5 raise was driven through on the vein to 2550 level, and North 1 and South 1-3/5 incline raises were driven westward up the footwall of the replacement ore zone. By this time an appreciable tonnage of ore was indicated, so a more or less experimental mining method was devised, and development started in earnest.

At the present time we have reached and developed the upper limits of the ore body above 2675 where it is cut off by the NS5W fault, and stoping has been started.

GEOLOGY

Structure and Limits of Ore Body: The sediments in the east part of the mine strike approximately N-S and dip about 30° to the east; just as they do where they outcrop east of Superior.

In relation to the surface, the East Replacement deposits are located about a mile east of Superior, and have been explored from a point just about under the new tunnel on Highway 60-70 down the dip to the east. They occur as bedded replacements in the Martin limestone which is Devonian in age.

Perhaps I should refer to the replacement zones in the singular for they occur in the same horizon in the Martin limestone, and are connected by the vein which presumably acted as the mineralizer. However, the north beds, which are about 30 feet vertically above the south ones due to pre-mineral movement on the vein, are of a slightly different type of mineralization. There is also a good possibility, we hope, of other similar limestone replacement deposits of this same type occurring along other feeder veins in this area.

May not be, Magma Vein?
Koerner Vein, possible

The main feeder, I have been referring to, strikes about N80°E and dips about 60° to the south. It is not too strongly mineralized except in that 30 foot portion between the beds where it is much wider and of better grade than elsewhere. Actually, I believe this widening of the vein is due to the dragging effect on the south beds along the fault before it was mineralized. In other words, at this wide zone, the mineralization is probably chiefly replacement of drag limestone from the south beds instead of vein. Stratigraphically, just above the beds, the vein is little more than a fault zone with virtually no mineralization.

Immediately below the mineralized beds there is usually stronger vein mineralization, mostly pyrite with some chalcopyrite, making, in north-south section, a pendant-like portion of mineable vein. This ore rarely extends over 30 feet below the south replacement zone. The vein sometimes loses its identity in the Troy quartzite and is hard to follow, due to the fact that in the quartzite it branches and is offset by numerous small faults. Also, the quartzite in this area, especially along the contact, is rather weakly mineralized throughout.

The footwall of the ore zone occurs in the Martin limestone anywhere from 10 to 25 feet above the contact of this limestone with the underlying Troy quartzite. The thickness of ore in the beds varies from 5 feet up to about 50 feet with 12 feet probably a good average.

The south beds, insofar as our present development and exploration work has been carried, have proven to be quite a bit more extensive than the north beds. The ore limits on the various levels of the north beds developed at this time extends a maximum of about 150 feet north to where the copper mineralization dies out; whereas, in the south beds, the ore on the 2800 level extends 500 feet south of the vein before it weakens. The north ore zone, however, is a little thicker than the south ore zone.

As you go west or up dip along the replacement ore zone from the 3000 level to 2800 level, the ore limits on the south beds extend farther south from the vein. On 3000 level the south limit of ore is approximately 100 feet south of the vein; 2856 sub-level was in ore for about 325 feet south of the vein. On 2800 level we have just reached the ore limit at about 500 feet south of the vein but on 2700 level the ore extended 250 feet south. In general, exploration to date has indicated the south replacement ore horizon in plan to have a sort of one-sided hourglass shape with the narrow neck around 3000 or 3100 level. Diamond drilling on 3400 level, where the lower part of the hourglass would be, indicates good ore for quite some distance south of the vein.

There is not as much variation in the limits of the north replacement ore. The maximum known strike length is about 150 feet on 2900 level. Above this level the strike length wedges to zero at the upper limit which is the NS5W fault, and below the level it curves back in to the vein below 2950 level.

Down dip exploration has been carried on only as far as 3400 level. The work on this level to date is confined to drifting the vein out to the replacement horizon and some diamond drilling from this drift.

I would like to point out that due to the dip of the beds and the fact that most of the exploration and development is carried on in the replacement zone, it is not feasible to do much diamond drilling to ascertain the limits of the ore body to the north or south along the strike, or down dip. Rock temperatures are such that we cannot drive many crosscuts or drifts for exploratory purposes because as more openings are driven, more hot air is forced into the working places.

The beds and vein are cut off between the 2675 and 2550 levels by a N-S fault dipping west. This fault, known as the NS5W fault, has about 300 feet of vertical displacement with the east side up relative to the west side. The horizontal displacement is not easy to determine, but is thought to be north on the east side relative to the west side.

Post-mineral faulting encountered in the ore zone hasn't been too extensive except for the NS5W fault. The sediments and included ore horizon flatten from a 30° dip below 2675 level to almost horizontal adjacent to the fault. While there are numerous minor faults which do not offset the beds more than a foot or so, only two faults which seriously affect the mining have been encountered. They cut the south ore zone and strike about east-west. The displacement on each of these faults is 10 to 15 feet.

Most of the small faults, which are usually marked by slickensides and red hematite stain, are very hard to follow from one level to another, or even from one sub-level to another. Sometimes they seem to die out or their dip will change so that they are striking and dipping parallel to and within the ore zone. Where one of these small faults crosses the footwall there is usually no noticeable abrupt offset from one side of the fault to the other, although the footwall may roll up or down a short distance forming what looks like a small monocline with the fault in the middle.

It is apparent that not all of the minor faulting in this area is post-mineral. Many of these breaks seem to be pre-mineral with slight post-mineral adjustment and acted as small feeder veins. Similar mineralized breaks are responsible for the replacement deposits at this same horizon in the L. S. & A. mine, back of the

Superior High School. This also helps explain why the south replacement ore is more extensive than the north ore zone, for it has been in the south beds that we have found these small veins.

Mineralogy and Mineralization: Specular hematite and pyrite are the two most abundant minerals occurring in the East replacement beds; pyrite being the principal gangue mineral in the north beds, and hematite being the principal one in the south beds. Red hematite is also common; but the specular variety is by far the most abundant. Altered limestone and some quartz are the next most abundant gangue minerals. The quartz seems to be mostly in the south beds associated with the specular hematite.

The only two copper minerals found, or rather observed so far, are bornite and chalcopyrite. There may be, and probably are, other copper minerals; but megascopically they cannot be seen.

Some sphalerite occurs in a few places, and a very minor amount of galena has been observed. The percentage of gold and silver average about the same as in the rest of the mine; except that the silver assays drop off in the hematite ore zone in the south beds. The best values in gold and silver occur along with bornite.

The mineralization almost always shows a rough banding or stratification of minerals parallel to the strike and dip of the beds; although, I have observed, in some places, a breccia type of ore which looked as if the limestone had been brecciated before the ore solutions were introduced.

There doesn't seem to have been too much alteration in connection with the beds. Some rock which we call altered limestone is still essentially limestone, but has a bleached appearance and contains some hematite or sulphide minerals. In the hanging wall of the beds some of the limestone has a baked appearance, and joints and fractures are stained with red hematite for quite some distance above the ore. The limestone between the footwall and the Troy quartzite is usually fresh and unaltered. (In some places there are thin shale partings or seams on the foot or hanging walls, or on both, which look a lot like phyllite.)

The beds are by no means completely mineralized throughout. Altered, lightly mineralized, limestone streaks, anywhere from a half inch wide up to the full thickness of the beds are encountered, usually but not always, toward the outer limits of the ore. This altered gray limestone carries, on an average, 10-15% iron, 0.2 to 0.5% copper, and often some zinc.

From just above the 2800 level and extending west up to the upper limits of the ore body, there is a horst of this altered limestone in the south replacement ore zone. It is about 50 feet wide at the widest, and, surprisingly, occurs right next to the vein.

In the north replacement zone where this altered limestone is found it seems to contain more zinc and red hematite than it does when encountered in the south replacement zone. This material marks the northern limits of the ore body.

In the south zone, instead of a gradational change as is usual in the north beds, this altered limestone is often encountered abruptly after drifting in good ore and through a small fault which shows little or no offset. This suggests a damming effect of a premineral fault.

MINING METHODS

Because of the flat dip and relatively small thickness of the replacement beds, the type of square set mining employed in the rest of the mine is not used in the East replacement orebody except in the vein between the beds. A more or less new system has had to be devised, and in fact, is still being developed and modified.

The ground is very heavy and all drifts, raises, and development headings have to be timbered. Roof bolts are also used to give additional support along with the timber in those places which have to be kept open for some time or where the ground is extra heavy.

The level interval in this portion of the mine is 100 feet and on each level drifts are driven on the footwall of both the North and South replacement ore to the ore limits. Incline raises are then driven up dip from one level to another. These raises are driven on the footwall of the ore on 50-foot centers and, as nearly as possible, perpendicular to the strike of the beds. At 25-foot intervals these raises are connected by sub-level drifts again driven along the strike of the beds. This blocks out a rectangular stope approximately 20 feet wide by 40 feet long. Starting at the upper end of the ore body and working down dip, these stopes, or blocks of ore, are mined quickly as open stopes, with such temporary support as is necessary for safety. Roof bolting is used extensively and timber cribbing when required.

Since the beds only dip 30° at the most, slushers are employed in all stoping and development work except that on the main levels.

The mining or stoping retreats down dip and from the outer ore limit in toward the vein. The completed stopes cave and fill themselves as mining progresses.

SUMMARY AND CONCLUSIONS

This year we have just started stoping a bedded limestone replacement deposit which was not known to exist six years ago. This body of ore averages about 12 feet thick, 300 feet strike length, and extends down dip at least 1600 feet to 3400 level, which is as far as it has been explored. Copper, for which this deposit is being mined, averages about 7% overall.

We don't know just why this particular horizon in the Martin limestone has been mineralized. Ransom observed brecciation along strike faulting at this horizon in the L. S. & A. mine and thought maybe this afforded channelways for mineral bearing solutions to come in and replace the limestone. Although not common, I have noticed, at various places, along with the brecciated type ore mentioned before, slickensides on the hanging and sometimes the footwalls of the beds. I, more or less, tend to guess that, together with strike faulting and brecciation in this area, there may have been a particular chemical constituent or constituents in the ore horizon which caused, or may have acted as a catalyst to cause the replacement to take place at this point in the beds.

April 23, 1954

GENERAL GEOLOGY OF THE MAGMA MINE & ITS APPLICATION TO MINING PRACTICE IN THE VEIN PORTION OF THE MINE

By
Russell Webster

INTRODUCTION

The purpose of this report is to give a general picture of the development of the Magma Mine, with considerations on the operation of the geology department at the present time.

The present geology department is indebted to such men as Ransome, Short, Ettlinger, Gustafson, Michell and others of equal importance who have contributed much to the general understanding of ore deposition, trends and to the complex structural problems found along the Magma Vein.

From a rather poor surface showing the Magma Mine has developed into a major producer and has operated continuously for over 40 years. Because of weak vein mineralization on various levels there have been times when it was thought that Magma had reached its lowest level of mineable ore, but each time, with careful exploration and development, its life was extended by the finding of new productive ore shoots.

Production of copper has steadily increased, except for the war years, as the mine deepened its workings and extended its development. Listed below are five sample production years.

Years	Ore Production-Tons
1915	59,219
1925	229,377
1935	259,553
1945	185,712
1952	397,546

During 1938 to 1945 the yearly production of zinc ore was approximately 80,000 tons.

Mining methods used at Magma vary according to the condition and type of wall rock with most of the ore stoped by the standard square-set cut and fill method. A few rill stopes are in operation where conditions permit.

GENERAL GEOLOGY

Age Relationship & Rock Types:

Early Pre-Cambrian	Pinal Schist	Sedimentary origin Basic lava flows
Unconformity Late Pre-Cambrian	Apache Group	Scanian conglomerate Pioneer shale -Disconformity- Barnes conglomerate Dripping Springs Quartzite Mescal Limestone -Disconformity-
Cambrian	Troy Quartzite	
Late Cambrian & Pre-Devonian	Intrusive Diabase Sills	Over 3000' in thickness crossing Pinal schist, Apache group and Troy Quartzite
Devonian	Martin Limestone	
Mississippi	Escabrosa Limestone	
Penn	Naco Limestone	
Tertiary	Dacite	

Structural Movements

Late Cretaceous & Early Tertiary	Thrust Faulting & Folding East-West faulting Dikes of quartz monzonite porphyry Ore Deposition

Structural Movements (Cont'd.)

Early & Middle Tertiary	Oxidation & Enrichment Deposition of the White Tail conglomerate Flows of Dacite (1200' in thickness) Regional Tilting
Late Tertiary	Dacite conglomerate Extensive Faulting Concentrator fault — very heavy in there North-West strike N-S Dips about 70° SW Vertical displacement at least 2000 feet Various postdacite and post ore faults Basalt dikes and flows.

GENERAL CONSIDERATIONS

Magma Vein Mineralization: The Magma Vein is an east-west mineralized fault fissure dipping about 80° south. The south wall or hanging wall has moved down approximately 300 feet and west approximately 375 feet relative to the north or footwall. Zoning of the ore is quite apparent with primary zinc and silver minerals in the upper levels down to the 2550 level in the east-central portion of the vein. Primary chalcocite, bornite and chalcopyrite occurs down to approximately the 4200 level where the high temperature mineral enargite begins to appear along with bornite and chalcopyrite. The ratio of enargite to the other copper minerals increases down to and including 4600 level.

FAULTING

The Magma Vein has been cut and sometimes offset by a series of post-ore faults. Low angled (flat) faults were more evident in the western portion of the mine between the 4000 and 4200 levels, offsetting the vein to the north on the average of 20 feet. Strike faults, locally known as slicers and cross-faulting, are not localized but can be found throughout the mine. Two of the major cross faults in the mine are the Main and the Concentrator Faults. Both faults occur in the extreme western portion of the mine. The Main fault strikes nearly north and has a west dip of about 45°. The Concentrator fault strikes N43°E and dips west at about 60°. The stratigraphic throw of the Main fault is about 1500 feet with horizontal displacement of approximately 1200 feet south. West of the main fault is the larger fault (Concentrator) with an unknown vertical displacement. The Magma Vein is completely cut off and it has never been located on the down-throw side. A sizeable body of mineable ore was located between the Main and Concentrator Faults. This is considered to be a faulted segment of the Magma Vein.

HISTORY

The history of the Magma Mine can be conveniently divided into three periods of time, based, more or less, on the extent of its development.

The First Period: The first period begins with the location of the first claim, "The Hub", in 1875 by W. Tuttle. Soon afterwards, Irene Vail located the "Irene Claim" west of the "Hub". These two claims were located on the surface exposed portion of an east-west north-dipping vein-filled fissure. This vein was named the "Silver Queen".

By 1882, the "Silver Queen" shaft (Magma No. 1) was sunk to 400 feet with short cross-cuts north and south on the 100, 200, 300 and 400 foot levels. During this early period native silver was the most sought-after mineral leaving copper in the form of chalcocite practically unwanted. In 1893, the price of silver dropped and production virtually stopped at the "Silver Queen".

The Second Period: The second period of activity for the "Silver Queen" began approximately in 1906. With the location and development of replacement ore on the Martin Limestone and Troy Quartzite contact in the nearby Lake Superior and Arizona Mine, engineers Andrus, Flindt, Gunn, Thompson and Krumb were of the opinion that this same contact had good possibilities of producing ore. In exploring this contact, it became evident that the "Silver Queen" vein and not the Martin and Troy contact was going to be the chief producer. Rich ore shoots of supergene chalcocite, bornite and chalcopyrite were encountered with the deepening of No. 1 shaft. During this time (1910) Magma Copper Company was formed. By 1912, the operating staff consisted of W. C. Browning, General Manager, E. H. Lundquist, Mine Superintendent, and I. A. Ettlinger, Chief Engineer. With this staff Magma began to explore, develop and produce zinc, copper, gold and silver. When shaft sinking passed the 800 foot level the ore in the Magma Vein (Silver Queen) instead of occurring in lenses and pockets, became more continuous. Because of this, and from thin-section studies by Short and McLaughlin, it was shown that the bornite and chalcopyrite were of a primary nature. Thus exploration and development were advanced.

By 1925, when William Koerner became General Manager, No. 2, 3 and 4 shafts were being sunk and the mine was down to the 2250 level. Improvements in transportation, milling and smelting continued.

In 1940 Ed Dentzer succeeded Mr. Koerner as General Manager. By this time No. 5, 6, 7 and 8 shafts had been collared and the mine was now down to the 4000 foot level.

In drilling for water an ore-producing fault zone, known as the Koerner Vein, was located about 1200 feet south and nearly parallel to the Magma Vein. From drifting and raising on the 3600, 3800 and 4000 levels in this vein, the ore appeared to be of similar character to the Magma Vein. Bornite and chalcopyrite were the major ore minerals with lesser amounts of tennantite and hypogene chalcocite.

Mr. W. P. Goss became General Manager in 1944. With the shortage of manpower during the war, extensive development was lost with a subsequent decline in production.

<u>The Third Period</u>: The third period in Magma's history began with renewed interest in the Troy Quartzite-Martin Limestone Contact to the east and in the possibility of finding replacement ore at the intersection of the Martin Limestone and the Magma Vein. Drifting east was started on the 2550, 3000 and 3400 levels along the Magma Vein to check this intersection. A report on the East Replacement beds will be given by Mr. Ward.

At the present time the deepest producing level is 4600 with explorational drifting on the 4800 level. Because of the demanding requirements of ventilation (161° rock temperature on 4800), ore production and exploration are dependent on an adequate supply of air. Due to the extreme rock temperature, it is necessary to group together stoping and development wherever a working temperature can be maintained.

<u>ORGANIZATION OF GEOLOGY DEPARTMENT</u>

The primary function of any department in a mining organization is to aid in the winning of mineable ore. This is especially true in regard to the geology department. Often, if not carefully supervised, the geology department will assume a more or less passive role in its operation and in time become just a record keeper. It is the ambition of Magma to maintain an active and functional organization which should be a direct aid to the mining department.

There are three main functions of equal importance assumed by the geology department at Magma: geologic mapping, sampling and directing the diamond-drill program.

GEOLOGIC MAPPING

With the use of base maps constructed by the engineering department all drifts and cross-cuts are mapped in detail in regard to faults, type of wall-rock and general grade of ore. Raises are located with the help of preliminary sections showing projected fault-zones, vein position and wall-rock type. Each floor of the raise is mapped as it is driven. Stope geology is undertaken only whenever necessary. If a particular section of the mine becomes quite complicated with vein branching or complex faulting, then a series of floor-plans and sections are constructed to aid in stope planning. Most mapping of the mine is recorded on 10-20-50 and 100 scale. The 10 scale is primarily used for geologic and assay sections of raises. Twenty scale is used for drifts, cross-cuts and east-west sections along the vein. Fifty scale is a convenient scale for an over-all picture of the operation. A complete set of 50-scale level plans are maintained in cooperation with the engineering department. One hundred scale maps were used by Dr. J. K. Gustafson in his very comprehensive geological survey of the Magma Mine. This series of maps has proven to be valuable in the intrepretation of the geology of the mine.

SAMPLING

The question may arise as to why the Geology Department concerns itself with the actual process of sampling. It is believed by this department that there can be a close relationship between sampling and geologic mapping. As a sample is taken, much information about structure and the character of the vein can be determined. All development such as drifts, raises, cross-cuts, etc. are sampled if any mineralization or vein is exposed. Stopes are sampled if the Mining Department requests it. Horizontal channel sampling is used primarily because of the nearly vertical attitude of the vein. In outlining mineable ore in stopes the taking of sludge samples from extension steel drilling has proven effective up to a length of about 30 feet. Assay returns are plotted on assay plans and sections and made available to the mining department as soon as possible.

DIAMOND DRILL PROGRAM

The Diamond Drill Program consists of two phases in its operation. The first phase would be its use in aiding the mining department in solving immediate problems such as drilling from stopes and raises to get detailed information and the drilling for the extension of known ore shoots. The second phase would be long range exploration. This would include location of long scout holes and investigation of problems requiring extensive drilling.

The recovered diamond drill core is logged according to type of rock, mineralization and percent of recovery. All cores showing mineralization is split lengthwise and a half is sent to the assay office and the other half is saved. This saved core and a skeltonized portion of the remaining core is stored in numbered trays for future reference.

1400 T 6%, 5% cut off

Vein 4 – 25 ft.

Rock Temp in DDH from 4600 15%

Costs ± 20.00 per ton (Thomson)

Grade ± 6%, cut off 5%

Bornite ores in vein succeeded by enargite below.