

Mineralogyfrom Churkolni's 1954 Report

A detailed study of the mineralization at Vangorda Creek has been made by V. S. Papezik, whose report follows.

"The study is based on several hand specimens collected at Vangorda Creek from the weathered surface of the outcrop of three drill cores.

The specimens were examined by hand-lens and under binocular microscope, a number of polished sections under reflecting microscope, and two thin-sections under petrographic microscope. In addition, a number of micro-chemical and flame tests were made on different minerals, and selected parts of the ore were analyzed by Dr. R. M. Thomson by spectrographic methods.

Summary

The main ore minerals are iron-rich sphalerite and galena with minor chalcopyrite. Other minerals are pyrite, which is very abundant, arsenopyrite, magnetite, pyrrhotite, marcassite, and very small amounts of tennantite, covellite and three undetermined minerals, two of which resemble polybasite and cobaltite. High-temperature iron minerals were deposited first, followed by zinc, copper and lead minerals, in that order. Temperature range of the sequence is from about 500 to 300°C. Evidence of pyrrhotite-sphalerite and sphalerite-chalcopyrite exsolution has been found.

Gangue minerals are quartz, actinolite, barite, witherite strontianite or celestite, with calcite and possibly other carbonates.

Spectrographic analysis has shown that gold is contained in pyrite or arsenopyrite and silver occurs with the galena, probably in solid solution. The sphalerite contains small amounts of cadmium. The ore is fine-grained, and crushing to -100 mesh size is necessary to achieve a fairly clean separation.

Hand Specimens

The ore is fine-grained, brown to black in color, with prominent, small crystals of pyrite mostly disseminated through the specimen, but sometimes concentrated in broad bands. It is fairly massive and coherent; only one specimen from the outcrop breaks in roughly parallel slabs.

Weathered surfaces of the specimens are coated with brown limonite. One of them, strongly weathered, shows encrusting masses of a yellow botryoidal, friable mineral, identified as sulphur. A crust of a dark green botryoidal mineral was observed in an isolated spot. This is probably an oxidation product of copper.

Other minerals identified by hand-lens are:

Pyrite	40%	
Sphalerite	30%	(dark brown to black)
Galena	10%	(in small, cubic crystals with an excellent cleavage)
Chalcopyrite		(disseminated in small amounts)
Gangue	20%	

Besides the main ore specimens, metallic minerals can be seen in stringers and lenses in the wallrock cores. These are mainly pyrrhotite with smaller amounts of chalcopyrite and galena, and very little sphalerite.

Microscopic Examination

Polished sections Nos. 1, 2, 3 and 4 were made from the specimens collected at the outcrop; sections Nos. 5-1, 5-2A and B, 5-3 and 9-4 from the drill-cores.

Metallic minerals identified are listed below. Their percentages represent an average based on all sections. Their proportions in individual sections may vary considerably from the average.

Pyrite	35%	
Sphalerite	25%	Covellite (small amount)
Galena	15%	
Pyrrhotite	10%	Unknown 1)
Chalcopyrite	6%	" 2) --- (negligible amounts)
Arsenopyrite	5%	" 3)
Magnetite	3%	
Marcassite	1%	
Tennantite (or tetrahedrite) small amount.		

Description of Minerals

Pyrite is the most abundant mineral in the deposit. It occurs in a variety of forms, from anhedral, broken-up grains to perfect cubes, sometimes with slightly corroded edges. In size it ranges from 0.01 millimeters to several millimeters across. Some grains show slight anomalous anisotropism. It is usually closely associated with minor amounts of arsenopyrite. In sections from the outcrop, euhedral to rounded grains of arsenopyrite are occasionally enclosed in pyrite; in one of the drill-cores a larger grain of arsenopyrite has been found containing a rounded nucleus of pyrite. These two minerals are considered to be contemporaneous.

Pyrite is often surrounded, veined and locally slightly replaced by sphalerite, pyrrhotite, galena and chalcopyrite, which shows that it was one of the earliest minerals deposited. Though the present accompanying gangue minerals are quite varied, it seems probable that pyrite originally replaced siliceous members in a succession of metamorphosed sedimentary beds. Though it cannot be proved from the material available that this happened on a large scale, its preference for replacing quartz may be observed in some of the drill-cores.

Arsenopyrite occurs in euhedral, sometimes slightly broken or rounded crystals, accompanying pyrite. Often it shows coarse zoning, in places interrupted, with furrows between zones apparently filled with a gangue mineral. The zones probably represent successive stages of interrupted growth of crystals, which have later been invaded by a carbonate along the growth planes. The furrows are due to plucking out of the soft carbonate during polishing.

Besides alternately enclosing and being enclosed in pyrite, a rounded grain of arsenopyrite was found enclosed in pyrrhotite in the mineralized part of chlorite schist (section 5-3). From this, it can be deduced that the deposition of arsenopyrite started somewhat earlier than that of pyrite, and both continued side by side for some time. Pyrrhotite is definitely a later mineral. The evidence for overlapping deposition, however, is not conclusive.

There is a marked difference between the arsenopyrite content of the sections from the outcrop and from the drill-core. In the outcrop sections, arsenopyrite may account for as much as 8 - 10% of the metallic minerals, (pyrite forming about 40-50%), while in the drill-cores it is present in small amounts or entirely missing. The opposite relation was observed for pyrrhotite and magnetite. Though at this stage no coherent theory can be formulated, the possibility of zoning should be kept in mind.

Both pyrite and arsenopyrite were closely examined for gold, but no trace of it was found under the microscope.

Magnetite was found in one section only, the massive sulphide core No. 5-1, but there it forms about 15% of the metallic minerals. It appears in anhedral grains with rounded boundaries, only rarely showing straight edges. The grains are mostly broken up and highly irregular locally coalescing in larger groups. The largest, at the edge of the section, is over 5 millimeters across. Magnetite is usually surrounded and sometimes veined by sphalerite, pyrrhotite and other ore and gangue minerals. As it has not been observed in contact with pyrite or arsenopyrite, its position in the paragenetic sequence cannot be reliably determined, but it is assumed to be one of the earlier, high-temperature minerals. It is conspicuously absent from the outcrop sections, but its presence in the drill-core is sufficient to render it strongly magnetic. This might justify an attempt to outline this type of ore by magnetometric survey.

Pyrrhotite: While the minerals described thus far are considered to be early and hypothermal, and the subsequent ones will be later and probably mesothermal, pyrrhotite is a somewhat ill-defined border case. It is largely absent from the outcrop sections, but appears in all drill-cores, forming about 10% of the metallics in section 5-1 (massive ore), and being the main sulphide in the mineralized part of the hangingwall schist.

Where it forms the minor part of the ore, it occurs in irregular masses between pyrite grains and in close association with magnetite, but mainly with sphalerite. Rarely it occurs as straight rods close to the border of sphalerite masses. More often, irregular grains of pyrrhotite adjoin sphalerite and, in a few instances, they form a distinct border around part of the sphalerite grains. Some of these features suggest an exsolution origin for at least part of the pyrrhotite. In other sections, however, especially in the mineralized siliceous bands in the chlorite schist (Section 5-3), pyrrhotite accounts for about 95% of the metallics, the rest being small amounts of galena, chalcopyrite, and, very rarely, sphalerite in tiny grains within the pyrrhotite, which here replaces quartz along the grain boundaries. While galena is definitely, and chalcopyrite probably, later than pyrrhotite, its relations with sphalerite in this type of mineralization could not be determined.

One possible explanation regards pyrrhotite as a transition between the iron-rich phase and the zinc-phase of mineralization. Towards the end or after the deposition of pyrite, pyrrhotite began to form. This migrated beyond the quartzitic bed into the hanging-wall and footwall schist possibly due to a widening of formerly restricted fractures which had permitted only a limited penetration of earlier-formed arsenopyrite and pyrite. When the iron-content of the solutions was lowered and they became enriched in zinc, deposition of iron-rich sphalerite began, with the excess iron unmixing later as rods and rims in and around the zinc sulphide, and the rest remaining in the lattice. This theory, however, is based on limited material only, and is to be regarded as a suggestion rather than the final answer.

No nickel was found in the pyrrhotite. In one section, it is frequently altered to marcasite, which will be discussed later. In Section 5-3, it contains numerous microscopic inclusions of Unknown C.

Sphalerite occurs in all sections from the ore-zone, forming about 20-25% of the metallic minerals, and occasionally in small amounts in the mineralized stringers in the wall-rock sections. It is the iron-rich variety of zinc sulphide, marmatite; dark brown to black in hand specimens, it appears brownish-red in thin-sections, and in polished sections it exhibits, besides its usual grey color, a deep red internal reflection. According to one classification, these properties suggest that it contains 10% or more iron. It forms mostly irregular masses, grains and bands through the gangue, but an isolated, perfect crystal was found in a soft gangue mineral in section 5-2. Sphalerite encloses and veins earlier-formed minerals, mainly pyrite; occasionally, it corrodes and rounds edges of pyrite crystals, and in isolated cases it penetrates into pyrite in deep embayments. Rounded nuclei of sphalerite in pyrite, observed in some sections, are probably such "tongues" cut transverse to their direction rather than central replacement cores.

Sphalerite is then younger than the early iron minerals, and since it is replaced by galena, it is older than this mineral. As suggested above, it is considered to be younger than pyrrhotite. Its relation to chalcopyrite, however, offers another problem.

In section 5-2, a larger (4mm) grain of sphalerite contains numerous microscopic inclusions of chalcopyrite, arranged in roughly parallel chains, locally intersecting almost at right angles. (Emulsion textured?) In Section No. 4, a grain of sphalerite is deeply interfingered with a chalcopyrite grain, and in other sections carries texture suggests possible replacement of sphalerite by chalcopyrite.

This may mean that deposition of chalcopyrite began towards the end of the zinc phase of mineralization, the copper sulphide at first entering into a solid solution with sphalerite and unmixing later as chains of blebs along its crystal planes. As the zinc sulphide content of the mineralizing fluids became exhausted, or as the temperature dropped below the minimum necessary for solid solution, chalcopyrite was precipitated directly, the last portions partly replacing earlier sphalerite. This may be another example of overlapping deposition.

An alternative explanation may be that all chalcopyrite is younger than sphalerite, the parallel blebs being replacement nuclei, penetrating into ZnS along its crystal planes. The writer favors the first hypothesis.

Chalcopyrite is a minor but widely distributed constituent of the ore. It appears in small quantities in all sections, as irregular grains, veinlets, and stringers, filling fractures in brecciated pyrite grains, locally veining arsenopyrite and partly replacing pyrrhotite, especially in the mineralized stringers in the hanging-wall schist, where it occurs in somewhat greater, though still small amounts than in the ore zone proper. Its relation to sphalerite was discussed above. There is not sufficient evidence to determine its relation to galena, but since galena always seems to be later than sphalerite, while chalcopyrite appears in part simultaneous with it, the copper sulphide is considered at least partly older than galena.

In one outcrop section, it is partly altered to covellite, but this is a very minor and insignificant case.

Galena is, after sphalerite, the most important ore mineral in the deposit. It occurs in irregular grains and stringers in almost all sections, being most common in the ore horizon, but also present in the mineralized parts of the chlorite schist. Locally, it veins and partly replaces pyrite, but in most cases it shows a preference for sphalerite and pyrrhotite. In sphalerite, it shows the inverted caries texture typical for this association. This suggests either replacement or later crystallization in the interstices of sphalerite. But since it often contains rounded residual nuclei of sphalerite, which here usually occurs in solid masses and not in isolated grains, replacement seems more likely. A similar relation (veinlets, elongated nuclei with inverted caries texture, residual grains enclosed in galena) exists between galena and pyrrhotite. The relation to chalcopyrite is not clear. In Section 5-2, it occurs as veinlets in a soft gangue mineral, showing that some gangue was introduced before galena.

Though galena and sphalerite occur in fairly large quantities in the ore horizon, while pyrrhotite is of minor importance there, they appear only in insignificant amounts in the mineralized stringers of the hangingwall schist, where pyrrhotite predominates. One explanation for this marked difference may be that the interstices between quartz grains there have been plugged by earlier pyrrhotite, so that the only way to those horizons was by slow diffusion through the pyrrhotite. This allowed only a minor part of the lead and zinc to penetrate outside the ore horizon, where deposition was easier. However, this remains only a speculation. The writer feels that more investigation will be necessary before this problem will be adequately solved.

Marcasite - FeS_2 ; In section 5-1 (Drill-core sulphides), pyrrhotite is often partly or completely altered to lamellar masses of a light yellow, hard, aniso-tropic mineral with rough, pitted surface, which has been identified as marcasite. This is in contrast with the fresh, unaltered pyrrhotite in the chlorite schist. A reliable explanation of this difference would probably require more material for study, but it should be pointed out that section 5-1, where this alteration appears, is also the only section containing magnetite. A possible connection between these minerals cannot be excluded.

Tennantite (?) - $5 \text{Cu}_2\text{S} \cdot 2(\text{Cu}, \text{Fe}) \text{S} \cdot 2\text{As}_2\text{S}_3$; In section 5-2 five grains of galena 0.1 to 0.4 millimeters long were observed having a rim of a different mineral, 10 to 20 microns wide. This mineral is

grey, darker than galena, with a greenish-brown tint. It is isotropic, harder than galena, negative to KCN, HCl and HNO₃, and without internal reflection. This may be tennantite or tetrahedrite. It extends into the galena grains along microscopic fractures, in places separating it into corroded nuclei. This has been taken as an evidence that this mineral replaces galena. It has not been found in any other section. Owing to the minute size of the rim, no pure material could be obtained for a microchemical test for silver. For the same reason, it was impossible to decide chemically between tetrahedrite and tennantite. But, since this mineral was formed later than the last hypogene sulphide (galena), and since the formation of the tetrahedrite would require a new phase of mineralization with the introduction of Sb, while all the elements in tennantite are already present in the ore, it seems more logical to assume that the mineral is tennantite, in which case it may be supergene, formed by solution and re-combination of the constituents of chalcopyrite and arsenopyrite.

Covellite - CuS: In section 3, taken from the outcrop, there are a few scattered grains of microscopic size, with indistinct boundaries, of a deep blue, pleochroic mineral with red to orange anisotropism identified as covellite. Its occurrence is restricted to this section. It was probably produced by supergene alteration of chalcopyrite.

Unknown A:¹ In section No. 1 (outcrop ore) an irregular grain of galena about 0.1 by 0.3 mm. in size, contains a single grain of an unknown mineral, approximately 10 microns in diameter. This mineral is light grey, only slightly darker than galena, with a faint bluish tint, weakly pleochroic (almost white to light grey), anisotropic (white to dark grey), and with a hardness of about B plus or C (it stands out in relief). Since this is the only grain of this mineral in all the sections, no etching was attempted, and no microchemical tests were possible, due to its extremely small dimensions. Its optical properties are similar to those of polybasite, $8(\text{Ag,Cu})_2\text{S}$. $(\text{Sb,As})_2\text{S}_3$ but its identification remains doubtful.

Unknown B: In Section No. 3, a grain of arsenopyrite contains a rounded grain of an unknown mineral, about 5 by 5 microns in size. This mineral is white, with a slight pinkish cast against the arsenopyrite, apparently isotropic, and possibly harder than arsenopyrite, standing out in relief. No tests were attempted due to its extremely small size. Its color, isotropism and association are similar to those of cobaltite $(\text{Co,Fe})\text{AsS}$, but its identity cannot be proven. It has no apparent significance.

Unknown C: In section 5-2, pyrrhotite contains rectangular to irregular grains of an unknown mineral, in the average of 10 microns across. It is pinkish, paler than pyrrhotite, with a yellowish cast. Some grains appear to be anisotropic, and in others it is impossible to distinguish anisotropism because of the strong pyrrhotite colors. It is widely distributed throughout the pyrrhotite in this section, but always in microscopic dimensions. In one spot, it forms a veinlet about 5 microns wide. It is stained by HNO₃ and HgCl₂, but the stain

1. A recent report by Papizek indicates this mineral is the silver mineral maltildite $(\text{Ag}_2\text{Bi}_2\text{S}_3)$ which occurs in minute exsolution blebs in the galena in the 10-100 micron size range. He believes the silver values in the ore may be due to this mineral.

rubs off. It is negative to other reagents. Its identification was not possible due to extremely small size of the grains. It was not found in other sections, and does not appear important.

Gangue Minerals: Gangue minerals were studied in three thin-sections. Thin-section 5-2 is an aggregate of carbonate minerals, with small grains of pyrite and sphalerite disseminated through it. The grains are anhedral, and interlocking. At least three and possibly four minerals are present.

One is a rhombohedral carbonate which has not been determined more closely. Acid tests on polished-section No. 5-2, however, indicate that it may be in part calcite. Optical properties of the other mineral (low birefringence, biaxial (-), small 2V, high relief) suggest strontianite (SrCO_3) and/or witherite (BaCO_3). Presence of barium and strontium has been proven by flame tests on gangue material from section 5-2. No quartz has been observed in this section. Disseminated in shreds and patches in small amounts throughout the section is a mixture of fibrous micaceous minerals, probably sericite and chlorite.

Thin-section No. 9-4 shows a large proportion of metallic minerals, mainly pyrite, with minor galena and sphalerite. There are two gangue minerals. One is a rhombohedral carbonate, possibly calcite, as indicated by acid tests on polished section 9-4. The other mineral has optical properties of barite (low birefringence, high relief, biaxial (+), etc.)

The presence of both barium and strontium has been proven by flame tests, so that both barite and celestite may be present.

In thin-section No. 1, a large amount of ore minerals are disseminated through and replace quartz matrix. Isolated shreds of sericite are present; tourmaline was looked for and not found.



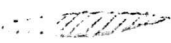
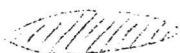


The material available is not sufficient to establish definitely the position of gangue minerals in the paragenetic sequence. But it seems that (a) quartz, where seen in some of the polished sections, represents remnants of the original quartzite.

(b) Barium and strontium minerals were introduced before galena, which seems to vein them and in some spots to replace them

(c) Calcite was introduced with galena. (Contains irregular grains of galena in section No. 1).

Paragenesis and Temperature

Magnetite(?) ...

Arsenopyrite Pyrite Pyrrhotite Sphalerite Chalcopyrite Galena Tennantite(?) Marcasite Covellite 

Evidence for this paragenetic sequence was presented together with the description of the minerals.

The assemblage of high temperature minerals, such as arsenopyrite and magnetite, suggests that mineralization began at Temperature above 500° C. By the time the zinc-copper phase was reached, temperature must have dropped to about 400° C, or less, at which point chalcopyrite unmixes from sphalerite. Deposition of hypogene minerals probably ended above 250 C, as none of the low temperature minerals is present.

The deposit may then be classified as hypothermal replacement type.

Spectrographic Examination

Selected parts of the ore were examined by Dr. Thomson by spectrographic methods to determine which mineral contained gold and silver, and what minor elements were present in sphalerite.

Due to the fine texture of the ore, it was found very difficult to separate a sufficient quantity of clean fragments of different minerals for analysis. Consequently, the results are not decisive, but a few conclusions were reached.

The strongest gold lines appeared in the pyrite fraction, which may have contained some arsenopyrite, beside other impurities. It seems then probable that the small quantity of gold in the ore is in solid solution with pyrite or arsenopyrite or both.

The galena fraction showed the strongest silver lines. It was not possible to determine whether this was due to pure galena or to an associated silver mineral. But since the potential silver-bearing minerals have been found in such insignificant quantities in the sections, the writer believes that such silver as there is in the ore is present in solid solution in the galena.

The germanium content of sphalerite is apparently negligible; the only minor element showing reasonably strong lines was cadmium. An assay for this metal is recommended.

In the process of crushing and separating the ore, it was found that particles above 100 mesh size were mostly composite, and that crushing to at least plus 200 to 100 mesh is necessary to achieve reasonably clean separation.

Conclusions

Though much more geological, mineralogical and petrographic work remains to be done on the property, it seems now certain that it is a high-temperature replacement deposit, which is fairly extensive and may go to a considerable depth. Ore control seems to be lithological but not enough is known about structure of the deposit to determine the degree of structural control."

Metallurgy

Preliminary testing was carried out by the Mines Branch, Ottawa, and Noranda Concentrator Research Department on drill core rejects of representative lead-zinc mineralization. The results will be found in Appendix IV(a) and (b).

The results obtained, though encouraging, are not considered conclusive and further tests will be carried out on larger samples at a later date.

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