

**ORE MINERALOGY AND FORMATION CONDITIONS OF VEIN
AND REPLACEMENT-TYPE Pb-Zn-Ag-OCCURRENCES,
LOGAN AND YP PROPERTIES, RANCHERIA DISTRICT YUKON, CANADA**

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ABSTRACT

The Logan (MINFILE 105B 099) and YP (MINFILE 105B 001) zinc-lead-silver deposits are located in the Rancheria District, Yukon Territory. These deposits and numerous other occurrences occur in veins and breccia zones which cut clastic sedimentary rocks of Proterozoic and Palaeozoic age, along fracture zones cross-cutting Cretaceous granites and Eocene volcanic dykes of mafic and felsic composition, and form replacement bodies in Palaeozoic carbonates. At the Logan and YP deposits, four phases of mineralization can be distinguished. The main sulphide minerals are sphalerite, galena, pyrrhotite, pyrite, chalcopyrite and arsenopyrite. Silver is mostly confined to galena, but also occurs in tennantite-freibergite group minerals, stannite, Pb-Ag-Bi-sulphosalts of the matildite-galena series and lillianite homologues.

Arsenopyrite geothermometry using the method of Kretschmar and Scott (1976) returned maximum formation temperatures of 465° - 490°C at YP and 335° - 385°C at Logan. Microthermometric investigations of fluid inclusions in quartz associated with the YP mineralization showed formation pressures corresponding to a depth of 2500 m.

Fluid inclusion data from quartz suggest that mineralization at YP and Logan is caused by a mixture of magmatic and metamorphic fluids. The fluid inclusions have low salinities of 3-4 weight per cent NaCl equivalent, an unusually low value for fluids which have separated from acid magmas. The metamorphic fluids may have been derived from metamorphic dewatering of Palaeozoic sediments.

RÉSUMÉ

Les gisements Logan et YP de plomb, zinc et argent sont situés dans le district de Rancheria (territoire du Yukon). Ces gisements et de nombreux autres indices minéralisés prennent la forme de zones de veines et de brèche recoupant des roches sédimentaires clastiques du Protérozoïque et du Paléozoïque le long de zones de fractures recoupant des granites du Crétacé et des dykes mafiques et felsiques de l'Éocène, et forment des masses de remplacement dans des carbonates paléozoïques. Aux gisements Logan et YP, quatre phases de minéralisation peuvent être distinguées. Les principaux minéraux sulfurés sont la sphalérite, la galène, la pyrrhotine, la pyrite, la chalcopyrite et l'arsénopyrite. L'argent n'est pas confiné à la galène, mais est également présent dans les minéraux du groupe tennantite-freibergite, dans la stannite, dans les sulfosels de Pb-Ag-Bi de la série matildite-galène et dans les homologues de la lillianite.

L'étude géothermométrique de l'arsénopyrite par la méthode de Kretschmar et Scott (1976) a indiqué des températures maximales de formation comprises entre 465 et 490 °C au YP et entre 335 et 385 °C au Logan. Les études microthermométriques des inclusions fluides dans le quartz associé à la minéralisation YP ont indiqué des pressions de formation correspondant à une profondeur de 2500 m.

Les données sur les inclusions fluides dans le quartz suggèrent qu'aux gisements YP et Logan la minéralisation a été causée par un mélange de fluides magmatiques et métamorphiques. Les inclusions fluides présentent de faibles salinités de 3 à 4 pourcent d'équivalent de NaCl en poids, des valeurs inhabituellement faibles pour des fluides s'étant séparés de magmas acides. Les fluides métamorphiques peuvent avoir été dérivés de l'assèchement métamorphique des sédiments paléozoïques.

INTRODUCTION

This work follows several studies initiated by Indian and Northern Affairs Canada in the Rancheria area (e.g., Abbott, 1984; Amukun & Lowey, 1987; Lowey & Lowey, 1986). The present study focuses on the mineralogy of the Logan (105B 099) and YP (105B 001) lead-zinc-silver occurrences, and its genetic implications.

GEOLOGICAL SETTING

The Cassiar Platform and the Slide Mountain Terrane are the two main tectonic units in the Rancheria District (Tempelman-Kluit, 1979, 1981; Wheeler, 1987; Fig. 1). The Logan and YP occurrences occur within the Cassiar Platform, which includes slightly metamorphosed and folded Proterozoic and Palaeozoic siliciclastic and carbonate rocks. The sedimentary rocks which host the Pb-Zn-Ag mineralization belong to the Atan Group, deposited during the Cambrian in a continental margin setting (Tempelman-Kluit, 1979). The lower part of the Atan Group consists of quartzite, sandstone and phyllite (Boya Formation), and the upper part consists of massive marble (Rosella Formation; Fritz, 1980). During the Late Jurassic and Early Cretaceous, the Slide Mountain and other terranes, representing ancient island arcs, back-arcs and fore-arcs, drifted against the North American continent from the west, and were obducted over the autochthonous strata of the continental margin.

The subduction and obduction processes resulted in partial melting and the emplacement of widespread granitic and granodioritic plutons. The Cassiar and Marker Lake Batholiths are the most important of these in the study area (Fig. 1).

Continued transpressive subduction caused major northwest-southeast trending dextral strike-slip faults during the late Cretaceous and early Tertiary and led to the development of an east-west joint system (Lowey & Lowey, 1986; Abbott, 1984). Mafic and felsic dykes which intrude Cretaceous plutonic rocks or Proterozoic and Palaeozoic sedimentary rocks are probably related to strike-slip faulting and jointing.

Lowey & Lowey (1986) and Abbott (1984) suggested that the Pb-Zn-Ag mineralization is genetically related to fluorite-bearing felsic porphyry dykes. Sinclair (1987) distinguished two types of porphyries. Type I porphyries are characterized by varying amounts of fluorite and sericite while type II porphyries contain up to 5 vol. % of primary topaz and tourmaline. The chemical composition of these intrusive rocks resembles that of A-type granites which are the product of final magmatism in orogenic belts or of magmatism at rift zones within shield areas (Pitcher, 1982). Abbott (1984) and Sinclair (1987) considered the Tertiary volcanism to be genetically related to deep-reaching Cretaceous and Tertiary shift faults. Quaternary basalts of the Rancheria Valley are younger than the mineralization.

LOGAN PROPERTY (MINFILE 105B 099)

The Logan deposits occur in a fault zone which strike about 060° and dips about 70° NW. Mineralization occurs as massive veins up to several metres thick, as impregnations in tectonic breccias, and as stockworks in highly brecciated zones. Four phases of mineralization have been identified:

Phase I minerals include sphalerite 1, pyrrhotite and arsenopyrite 1 (Figs 2 & 3). The sphalerite 1 contains traces of Sn.

Phase II is characterized by Cu-bearing minerals such as chalcopyrite, stannite, fahlore (tetrahedrite) and galena, Pb-Ag-Bi-sulphosalts and pyrrhotite. Chalcopyrite occurs along fractures in phase I minerals and as minute inclusions in sphalerite 1 ("chalcopyrite disease" after Barton, 1978), which are most abundant near chalcopyrite veinlets.

Phase II galena is significantly enriched in silver and bismuth (up to 4.25 wt. % Ag and 9.18 wt. % Bi); mean values are 1.3 wt. % Ag and 2.74 wt. % Bi. Pb-Ag-Bi-sulphosalts of the matildite-galena solid solution series or lillianite homologues (Fig. 4) occur as exsolutions in galena. They are also found along cracks in other minerals, especially sphalerite (Fig. 5), or along grain boundaries (Fig. 6). Sulphosalt minerals contain up to 9 wt % Ag and are therefore important Ag carriers at Logan. Stannite (0.7 wt. % Ag), chalcopyrite (0.15 wt. % Ag) and minor fahlore of the freibergite-tennantite solid solution series also contain elevated levels of silver. Stannite occurs mainly along cracks within sphalerite 1 (Fig. 5).

Phase III is characterized by Sb-bearing minerals such as jamesonite and galena with maximum Sb-values of 0.8 %. Galena of phase III has average Sb/Bi ratios of 0.235, compared to galena of phase II which has a Sb/Bi ratio of 0.0056. Minor emplectite (CuBiS_2) and sulphosalts are the Bi-bearing minerals. Cubanite exsolved from chalcopyrite during cooling, in the form of lamellae or as xenomorphic crystals. Phase III also saw the continued formation of stannite and fahlore and the onset of precipitation of iron-poor sphalerite, marcasite, second generation pyrite and arsenopyrite.

Phase IV probably reflects mobilization and cataclasis of pre-existing minerals. Pyrrhotite has been altered to pyrite and marcasite as described by Ramdohr (1975) in other localities. Galena formed during phase IV is poor in silver and bismuth, and sphalerite is Fe-poor. Arsenopyrite 2 occurs as idiomorphic crystals which replace the earlier formed ore minerals. Siderite is restricted to phase IV mineralization and occurs mainly near mafic dykes. Minor amounts of chalcocite also formed during phase IV. Chalcocite, limonite, bornite, digenite and covellite are primarily supergene products.

The Logan deposit shows a distinct vertical mineral zonation. In the upper mineralized levels, pyrite 1 occurs instead of pyrrhotite. Chalcopyrite and arsenopyrite increase with depth. These changes reflect a downward increase in the temperature of mineralization.

Amukun & Lowey (1987) mentioned the occurrence of colourless cassiterite in a brecciated felsic dyke. This mineral was not found during our present study.

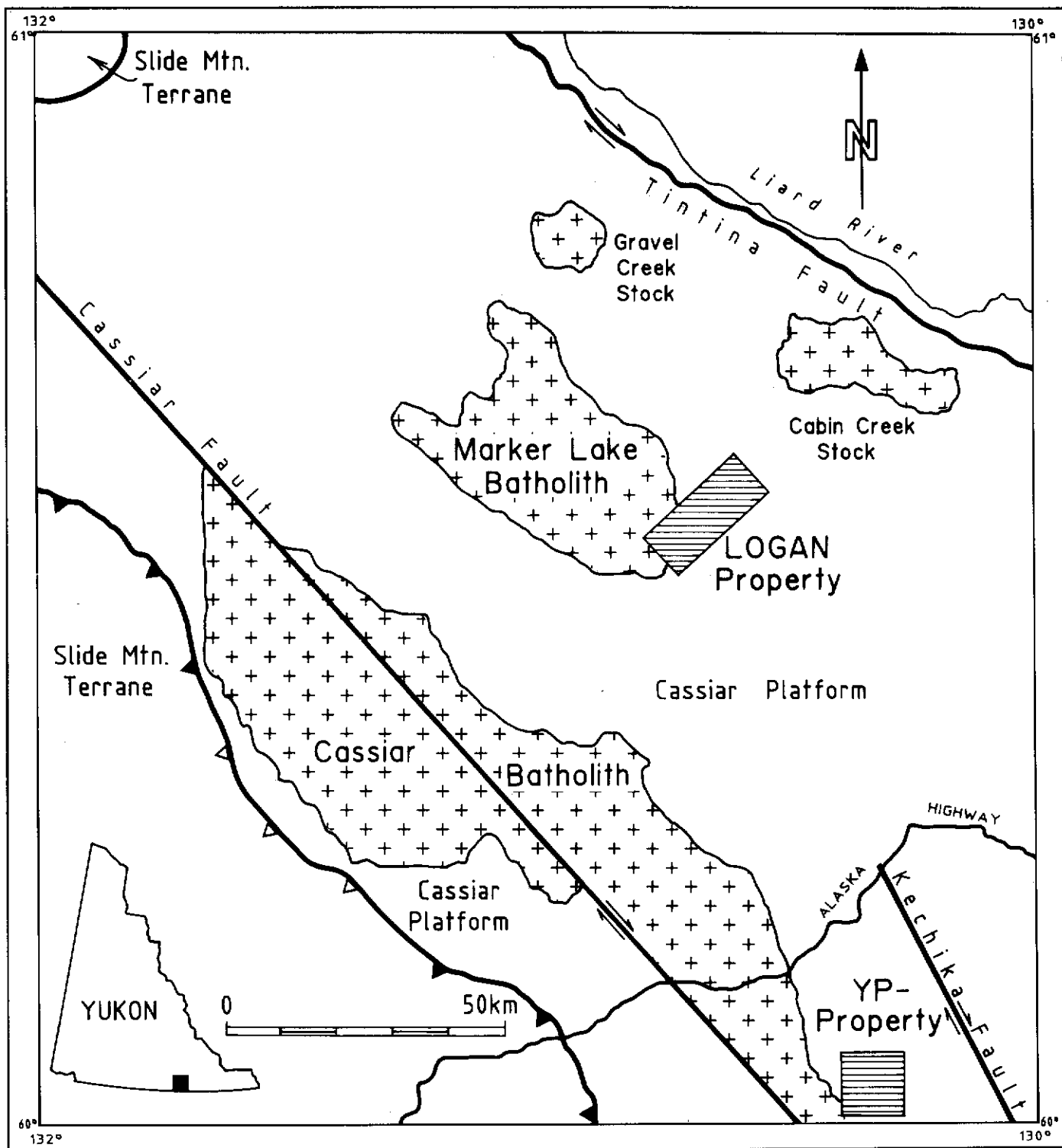


Figure 1. Rancheria District: Location of Logan and YP areas and reconnaissance geology (after Wheeler, 1987).

YP (LORD) PROPERTY (MINFILE 105B 001)

On the YP property, veins, breccia zones and replacement bodies in limestone are associated with a north-trending zone of steeply dipping quartz-feldspar-porphyrries dated at 52 ± 3 Ma (Abbott, 1984; Sinclair, 1987). Mineralization at YP also

consists of four phases:

Phase I is dominated by sphalerite 1 (Fig. 7), arsenopyrite 1 and pyrrhotite. Pyrite 1 is restricted to the upper levels, pyrrhotite to the lower levels.

Phase II is characterized by an increase of copper causing the already described "chalcopyrite disease" (Barton, 1978)

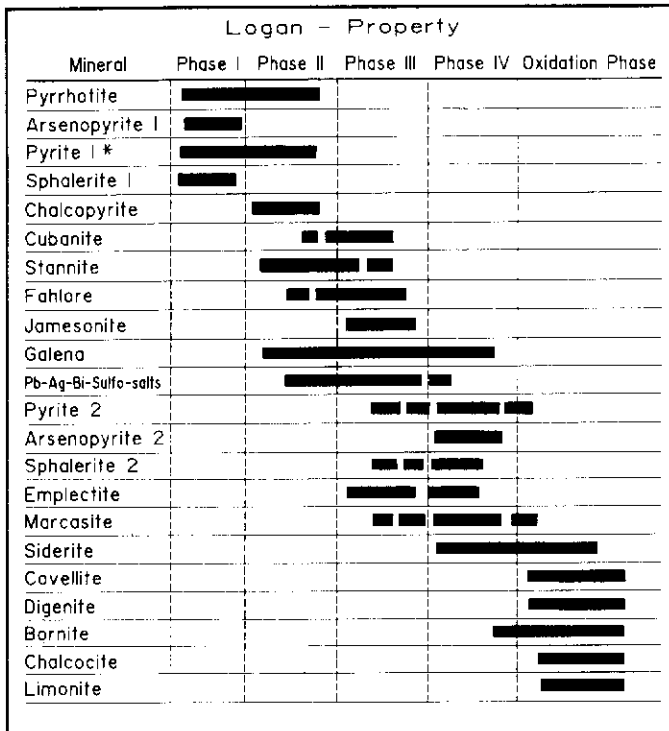


Figure 2. Diagram showing precipitation sequence of ore-minerals at Logan; (* pyrite occurs instead of pyrrhotite in the upper levels).

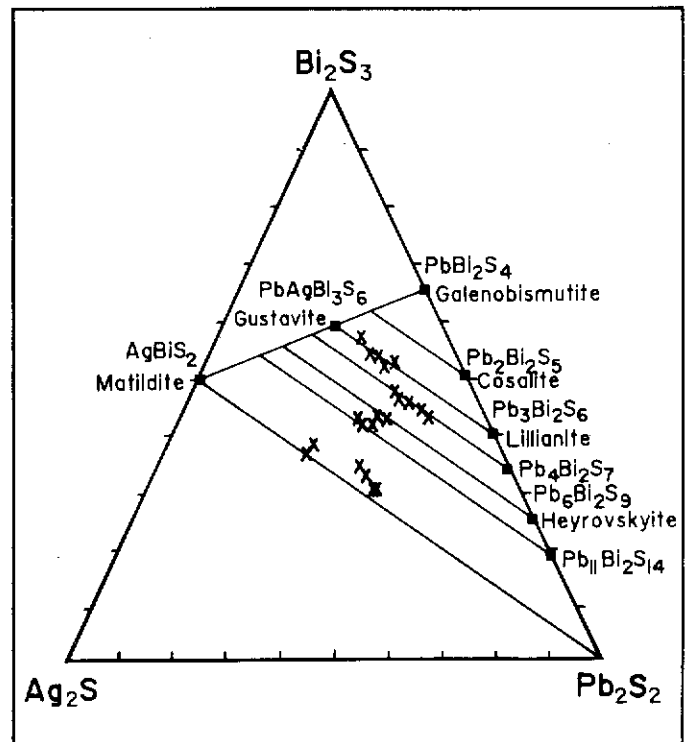


Figure 4. Position of the Logan area sulphosalts of Logan in the system $Ag_2S-Bi_2S_3-Pb_2S_2$ (Craig, 1967).

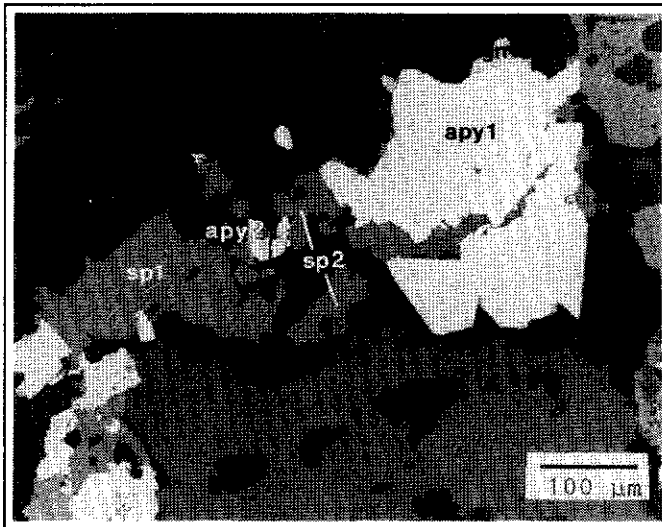


Figure 3. Intergrowth of sphalerite 1 (sp1, with chalcopyrite disease) arsenopyrite 1 (apy1) and galena (gn); sphalerite 2 (sp2) as fissure filling in arsenopyrite 1 (apy1) is partly replaced by arsenopyrite 2 (apy2); (plane polarized light).

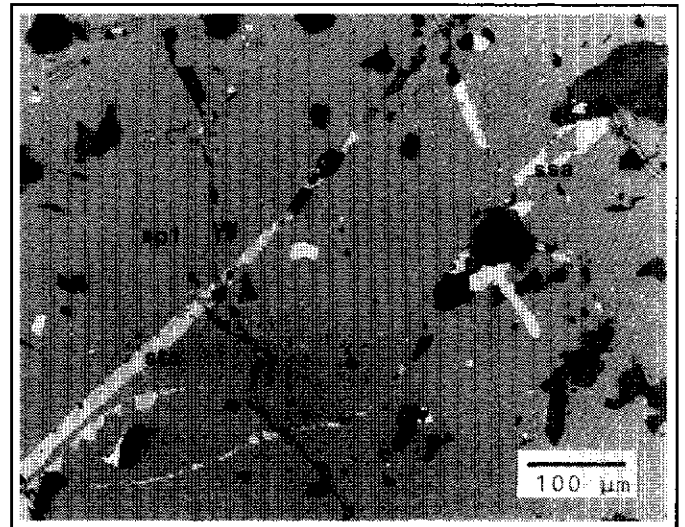


Figure 5. Stannite (sta) and sulphosalts (ssa) as fissure fillings in sphalerite 1; (x nicols).

which grades in the upper levels of the mineralization into a "pyrrhotite disease". Its intensity increases in the vicinity of pyrrhotite veinlets, indicating formation by replacement. Larger chalcopyrite grains of phase 2 contain small star-shaped sphalerite exsolutions (Fig. 8). Stannite, galena,

fahlore of the freibergite-tennantite solid solution series, bismuthinite and native bismuth also crystallized during phase II. Sulphosalts of the matildite-galena solid solution series or lillianite homologues frequently observed in the Logan deposit, were not identified. Silver values in galena of the YP

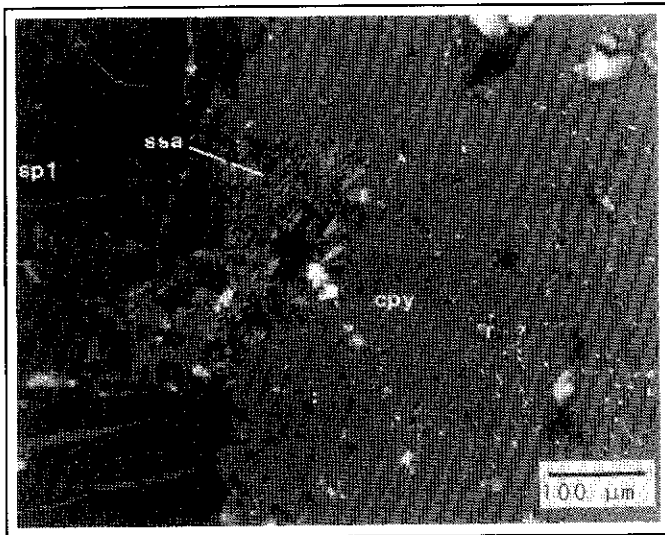


Figure 6. Sulphosalts (ssa) replacing chalcopyrite (cpy) on cracks in sphalerite 1 (sp1) (x nicols).

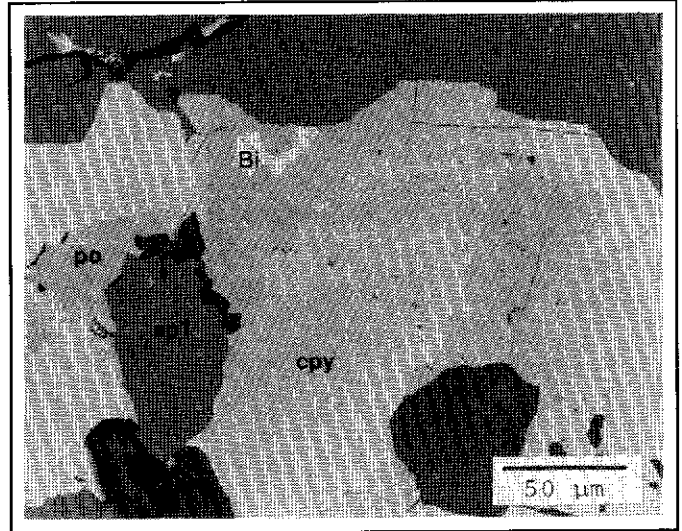


Figure 8. Galena (gn) with inclusions of native bismuth (Bi) intergrown with chalcopyrite (cpy, with star-shaped sphalerite), pyrrhotite (po) and sphalerite 1 (sp1), (plane polarized light).

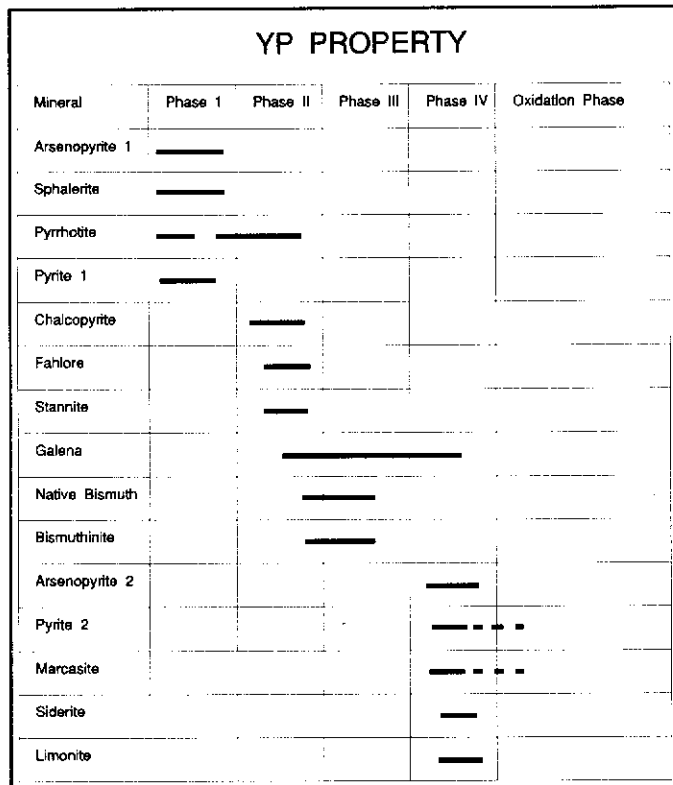


Figure 7. Diagram showing precipitation sequence of ore-minerals in YP; (* pyrite occurs instead of pyrrhotite in the upper levels).

occurrence reach a maximum of 2.8 weight per cent Ag, which is lower than at Logan. The highest Bi content is 15.84 weight per cent. A characteristic feature of phase II mineralization in the YP deposit is the presence of native Bi at grain boundaries or as inclusions in other ore minerals, preferentially in galena and chalcopyrite (Fig. 8).

During Phase III the precipitation of galena and native Bi continued. The existence of different generations of galena is indicated by differing Sb/Bi ratios in galena. While galena crystals of Phase II have Sb/Bi ratios near 0.004, galena of Phase III has ratios of 0.41.

As at Logan, Phase IV resulted from mobilization of pre-existing minerals. Idiomorphic arsenopyrite 2, pyrite 2, marcasite, galena and siderite belong to this phase. Marcasite and pyrite form the fine-grained alteration products of pyrrhotite ("intermediate product" after Ramdohr, 1975), and also occur as larger crystals along fissures. Idiomorphic pyrite 2 sometimes replaces the "intermediate product", and is thus the youngest sulphide mineral.

Limonite was the only weathering product observed. Furneaux & White (1983) reported gold concentrations up to 15.26 ppm in drill core. Native gold and gold-bearing minerals were not found in the present study. Microprobe data obtained from arsenopyrite, pyrrhotite and pyrite were below the detection limit of 0.1-0.15 weight per cent Au. The distribution of gold is assumed to be very erratic.

TEMPERATURE AND PRESSURE CONDITIONS DURING MINERALIZATION AT LOGAN AND YP

Temperature determinations using the arsenopyrite geothermometer (after Kretschmar & Scott (1976)) indicate that formation temperatures at YP differ from those at Logan. At Logan, Phase 1 mineralization formed at temperatures between 385°C and 435°C; at YP, between 465°C and 490°C (Fig. 9). The high temperatures of hydrothermal mineralization at YP reflect the presence of the quartz-feldspar porphyry nearby.

The chalcopyrite disease of sphalerite 1, typical of phase II mineralization at Logan and YP, forms at temperatures of

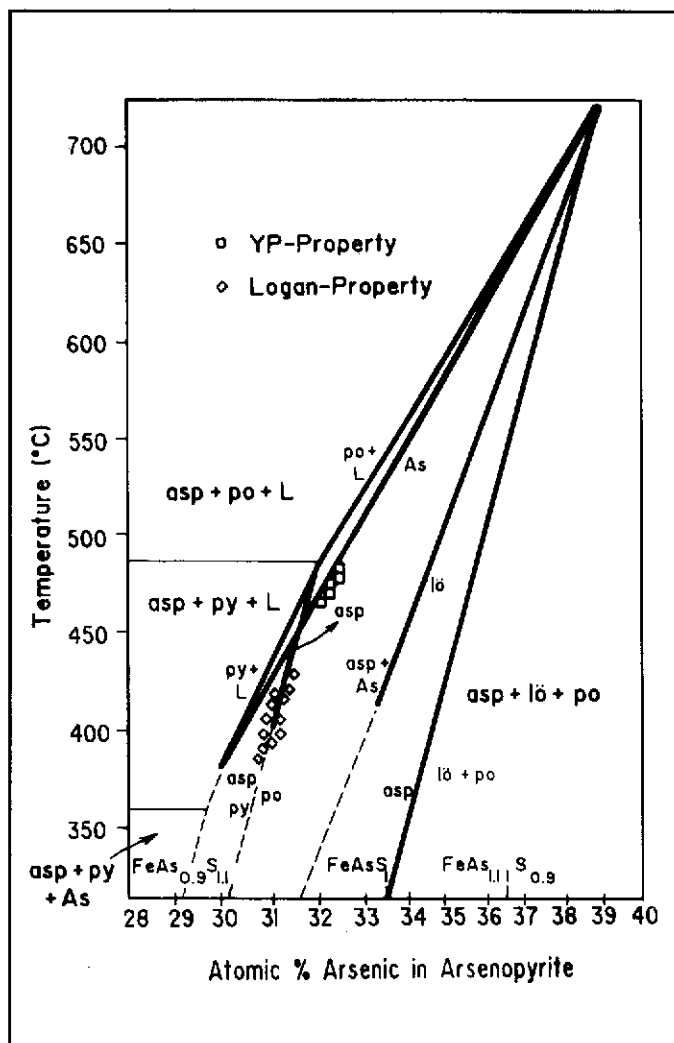


Figure 9. Formation temperature of arsenopyrite 1 from Logan and YP properties, using the arsenopyrite thermometer (after Kretschmar and Scott (1976)).

200° - 400°C (Barton, 1987). The star-shaped sphalerite crystals in chalcopyrite, which have been observed only in samples from the YP deposit, indicate that the chalcopyrite formed at temperatures higher than 400°C (Sugaki, 1985). Chalcopyrite can exsolve such a considerable amount of Zn only at these temperatures. Therefore temperatures in YP appear to have been higher than 400°C during Phase II. Formation temperatures during phase II, obtained from microthermometric investigations of fluid inclusions in quartz, were also higher than 400°C.

Solid solution in the system $PbS-AgBiS_2$ is complete at temperatures above 215°C (Van Hook, 1960; Craig, 1967). The common association of matildite and galena, which is also present at Logan and YP, is believed to represent exsolution at a solvus with a crest of $215 \pm 15^\circ C$ (Craig, 1967). According to Malakhov (1969) the ratio Sb/Bi based on the weight per cent of both elements in galena principally reflects the temperature of crystallization of the galena. Very low

ratios of less than 0.6 Sb/Bi are characteristic of high temperature galena which formed at 200° - 300°C. At Logan the Sb/Bi ratios of Phase II galena are around 0.0056, while at YP they are around 0.0042, indicating that in both study areas, the lower temperature limit of Phase II was between 200° and 215°C.

The Sb/Bi ratio in galena of Phase III and IV indicates a formation temperature between 140° and 220°C (Malakhov, 1969). At Logan, cubanite was found in one Phase III sample. According to Borchert (1938) chalcopyrite exsolves cubanite at temperatures between 250° and 300°. This indicates an upper temperature limit of about 250°C for Phase III mineralization.

Fluid inclusion data from quartz at YP indicate mineral precipitation at pressures of 800 to 1000 bar. This corresponds to a depth of about 2500 m. According to Malakhov (1969) the bismuth content of galena increases with depth. Galena from Logan generally has a lower Bi content than galena from YP, indicating that mineralization at Logan precipitated at a shallower level and/or at lower temperatures.

DISCUSSION AND CONCLUSIONS

The high formation temperatures of the YP and Logan Pb-Zn-Ag occurrences and cataclastic deformation of the ore minerals suggest a close relationship to faulting and magmatism. Tectonic movements opened percolation pathways for hydrothermal fluids. Fractures, joint systems and breccia zones controlled the distribution of the different occurrences, and the size and shape of each deposit depends largely on the composition of the surrounding rocks. At Logan the host rock consists of granite, which deformed in a brittle manner, resulting in the opening of wide vein or breccia structures favorable for ore precipitation. In incompetent phyllite or schist, plastic deformation dominates and fracture zones are too small to contain larger ore bodies of economic value. Fracture-controlled dykes can sometimes act as barriers for the hydrothermal solutions, leading to major ore accumulations adjacent to the dykes.

At the YP deposit, the surrounding rock includes different types of carbonates, which were replaced by acid hydrothermal solutions thus forming sulphide accumulations.

At both YP and Logan, four separate phases of mineralization can be distinguished. The first consists of sphalerite, arsenopyrite and Fe-sulfides, the second of chalcopyrite, fahlore, stannite, galena and Pb-Ag-Bi-sulphosalts, the third includes different Bi-bearing minerals and galena and the fourth includes siderite, galena and other sulfides which formed by remobilization of earlier-formed minerals.

The chalcopyrite disease of sphalerite is common in both deposits. Between 200° and 400°C, iron in sphalerite reacts with the copper ions of percolating hydrothermal fluids and forms chalcopyrite which replaces sphalerite in form of minute inclusions. During this process the iron content in sphalerite decreases. In areas of less intense chalcopyrite disease as at

YP, the iron content of sphalerite may reach 17 weight per cent. At Logan where sphalerite 1 is frequently replaced by chalcopyrite, the iron content of the sphalerite decreases to 5 weight per cent. The fact that the chalcopyrite disease is most intense in the vicinity of chalcopyrite veinlets, indicates it is formed by replacement and not by exsolution.

The antimony content of sulphides from Logan and YP is very low, while bismuth is a major constituent especially in galena and sulphosalts. According to Malakhov (1968), elevated bismuth values in galena are typical of deposits which formed at high temperatures.

Pure galena can contain a maximum of 0.6 mole % Ag_2S at 600°C (Van Hook, 1960). At room temperature the solubility of silver in galena is almost negligible. Nevertheless the Ag-solubility in galena can be strongly increased by the presence of bismuth and/or antimony (Van Hook, 1960; Hoda & Chang, 1975; Amcoff, 1976). According to Van Hook (1960) solubility in the system $PbS-AgBiS_2$ is complete above 215°C. Even at room temperature it is about 8 mole %. The reason for the good solubility of $AgBiS_2$ in PbS is the easily performed six-fold co-ordination of bismuth (Povarennykh, 1971). With decreasing temperature, sulphosalts of the system $Ag-Pb-Bi-(Cu)-S$ can exsolve from galena. This has been observed in galena from the Logan property. At YP where the Ag-content is generally lower, silver appears to be completely dissolved in galena together with bismuth, yielding no sulphosalts on cooling. Excess bismuth has been exsolved as native bismuth.

While the precipitation sequence of the ore minerals and the formation temperature has been determined, the origin of the metals is still uncertain. Sinclair (1987) proposed that the mafic dykes and fluorite and topaz-bearing quartz-feldspar-porphyrries which are contemporaneous with the mineralization at YP are evidence of a magmatic origin. As already mentioned, cassiterite was found in a brecciated felsite dyke on the Logan property. Nevertheless no fluorite has been found in the gangue of the mineral deposits, and low-salinity fluids occur as inclusions in quartz which is cogenetic with the sulphides. These fluid inclusions are not consistent with a

magmatic origin. The increased heat flow related to the intrusion of the dykes may have formed major convective systems extending outward into the Palaeozoic sedimentary rocks, which include black shales rich in sulfides. The extent to which these rocks are involved in mobilization and ore formation is still an open problem. Sulphur isotopic analysis is expected provide further evidence about the mineralization process.

The Rancheria area deposits show significantly higher formation temperatures than those at Keno Hill, 354 km north of Whitehorse, where structurally and mineralogically similar $Pb-Zn-Ag$ occurrences occur (Keno Hill: 250° - 310°C, Lynch, 1989; Logan: 385°-435°C; YP: 465°-490°C). This higher formation temperature led to higher bismuth and lower antimony contents in the Rancheria occurrences. Distinct lateral zonation, which is typical of the Keno Hill area, was not observed at Rancheria. On the other hand vertical zoning, less developed at Keno Hill, is typical for YP and Logan.

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