PARAGENESIS AND ORE CONTROLS OF THE SHASTA Ag-Au DEPOSIT TOODOGGONE RIVER AREA, BRITISH COLUMBIA

(94E)

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INTRODUCTION

The Shasta deposit is an epithermal multiphase quartz-carbonate stockwork/breccia vein deposit containing significant silver and gold mineralization. Previous exploration work on the property has been hampered by the apparent lack of correlation between economic grades of mineralization and the degree of alteration or stockwork intensity. The current study was initiated to address this problem and to identify other characteristics of the deposit that could be used to guide exploration and development of the property.

This report summarizes fieldwork and preliminary results of the study. Fieldwork during July and August consisted of detailed logging of mineralized intersections in drill core, and sampling of core for petrographic, fluid inclusion, stable isotope and geochemical studies. This work forms part of an M.Sc. thesis underway at McGill University by the senior author.

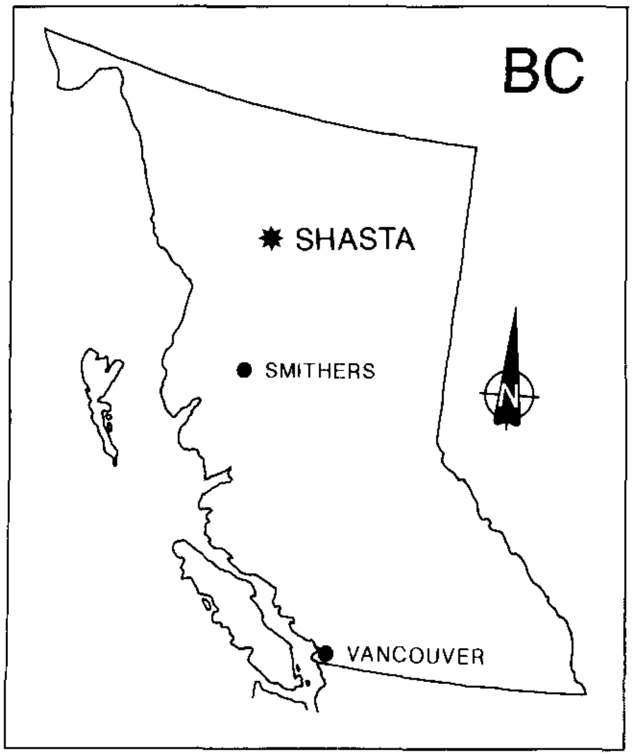

Figure 2-11-1. Location map of the Shasta deposit.

The Shasta property is located in the Toodoggone River area of British Columbia (Figure 2-11-1), on NTS map sheets 94E/2, 3, 6 and 7 at latitude 57°15′ north, longitude 127°00 west. The property is accessible by gravel road from Sturdee airstrip (approximately 300 kilometres by air from Smithers) a distance of 9 kilometres, or from Fort St. James, some 675 kilometres via the Omineca mine road.

The property was first staked in 1972 for Shasta Mines and Oils Limited (now International Shasta Resources Ltd.) Subsequent work led to the discovery of the Main (Rainier) zone gold-silver-bearing quartz-carbonate stockwork. The property was worked intermittently until 1983 when it was optioned by Newmont Exploration of Canada Limited, which mounted the first integrated program of geology, geochemistry, geophysics and diamond drilling. This work led to the discovery of the Creek zone.

In 1987, Esso Minerals Canada optioned the property and conducted a comprehensive program of geological mapping, soil and rock geochemistry, VLF-EM and induced polarization surveys, trenching and about 6000 metres of diamond drilling. This work delineated several new mineralized zones, including the JM zone, which together with the Creek zone comprise the bulk of the deposit. Reserves have been estimated by Holbek (1989) at 1.02 million tonnes of 5.7 grams per tonne gold equivalent with a 3.0 gram per tonne cutoff (using 70 grams silver = 1 gram gold).

Esso Minerals Canada was divested by its parent company, Imperial Oil, in 1989 and the Shasta option was acquired by Homestake Mineral Development Company, which has continued exploration on the property. International Shasta Resources Ltd. is concurrently conducting a small, high grade open-pit mining operation on the Creek and JM zones.

REGIONAL SETTING

The Toodoggone River area lies within the Stikine Terrane on the eastern margin of the Intermontane Belt, in the Cassiar-Omineca Mountains. The regional structure is dominated by major dextral strike-slip faults on the margin of the Intermontane Belt.

The oldest rocks in the area are Permian limestones of the Asitka Group, *which generally occur in thrust contact with* Late Triassic Stuhini Group volcanics and as roof pendants within Omineca intrusions. Stuhini Group rocks are dominantly alkaline to subalkaline, submarine, mafic volcanics. Unconformably overlying the Stuhini are Lower to Middle

Jurassic Hazelton Group rocks representing a probable island arc sequence of volcanics and associated sediments.

The Toodoggone volcanics (Carter, 1972; Gabrielse *et al.*, 1976) represent a distinctive quartz-bearing facies of the Hazelton Group, and comprise dominantly calcalkaline, intermediate to felsic subaerial volcanics (Schroeter, 1982; Panteleyev, 1982, 1983; Diakow, 1984; Diakow *et al.*, 1985). Clark and Williams-Jones (1987, 1988) have proposed that Toodoggone volcanism can be divided into two depositional stages. They point out that all known epithermal gold-silver deposits are restricted to (Stage I) Toodoggone volcanics, underlying the (Stage II) Saunders grey dacite (Diakow *et al.*, 1985), and suggest that regional mineralization occurred during the waning of Stage I or during a hiatus between Stages I and II.

The youngest rocks in the area are Tertiary to Cretaceous Sustut Group sediments, which unconformably overly the Toodoggone volcanics. Late Triassic to Early Jurassic Omineca intrusions of granodiorite and quartz monzonite intrude the Toodoggone and Stuhini Group rocks.

PROPERTY GEOLOGY

Marsden and Moore (1989 and 1990, this volume) provide a detailed treatment of the geology of the area; only a brief summary is presented here.

The Shasta property is underlain by two distinct lithologies within the Toodoggone crystal ash tuffs or Attycelley tuffs (Diakow *et al.*, 1985). They were informally named the pyroclastic series and the "epivolcaniclastic" series by Holbek and Thiersch (1988). The pyroclastic series unconformably overlies pyroxene-feldspar-phyric basalt flows and breccias of the Stuhini Group. In the central part of the property, the pyroclastics consist of dacitic feldspar-quartz crystal tuffs, chloritic and heterolithic lapilli tuffs and an underlying feldspar-quartz-biotite porphyry flow (Marsden and Moore, 1989). These units all contain characteristic orange-weathering plagioclase feldspars. The epivolcaniclastic series consists of green to maroon feldspar-phyric tuffs, heterolithic agglomerates, lahars and ash tuffs. These strata overly the pyroclastic series, but are typically seen in fault contact with them, as explained below.

The structure of the deposit area is dominated by north to northwest-trending normal and/or dextral faults. These are cut by minor east to northeast-trending cross-faults. Strata underlying the area generally dip gently northward to northwestward, coinciding with the regional attitude, except in a central fault-bounded panel of pyroclastic series rocks which dips steeply southwest. The north-trending Shasta fault bounds one side of this rotated fault block (Marsden and Moore, 1989), separating epivolcaniclastic from pyroclastic series rocks. This fault also forms the hangingwall of the Creek zone stockwork.

Mineralization and alteration are essentially restricted to the pyroclastic series and underlying Stuhini Group rocks. The overall lack of alteration and mineralization in the epivolcaniclastics suggests that these rocks were deposited, or displaced by faulting, after the mineralizing event. The absence of alteration at the hangingwall contact with the Creek zone supports this interpretation. However, the recent discovery of small isolated veins and alteration zones in these rocks, some distance into the hangingwall, suggests that the epivolcaniclastic rocks may, after all, have been deposited prior to mineralization.

MINERALIZATION AND ALTERATION

The following sections are based on a detailed study of core from the Creek and JM zones, and limited work on the Rainier, East and O zones. General discussions of mineralization and alteration are presented first, followed by specific treatment of individual zones. Plate 2-11-1 shows the location of these zones. Several other showings are not well defined by drilling and hence are not discussed here.

MINERALIZATION

The Shasta deposit consists of multiple overlapping quartz-calcite stockwork/breccia systems that display generally similar characteristics. They occur as narrow (<1 metre) curvi-planar breccias that pinch and swell within wider (>10 metre) sections of variable alteration and veining intensity. Quartz and calcite gangue occur individually in single-stage veins, as multistage banded veins and breccias, and also intimately mixed in a single stage (Plate 2-11-2). Both gangue minerals display open-space-filling textures in banded veins and rare drusy vugs. Calcite is dominantly late, commonly occurring in the centre of earlier quartz veins and as the matrix in quartz vein and silicified wallrock breccias.

Silver and gold mineralization occurs erratically within quartz and calcite stockworks and breccias. Grades of mineralization appear to be independent of the intensity of alteration or brecciation. However, some of the highest silver values occur in late-stage calcite breccia. Gold to silver ratios vary unsystematically from 1:10 to 1:100, with a deposit average of about 1:45 (Holbek, 1989).

Silver-gold mineralization is associated with finely disseminated grey sulphides and coarser grained pyrite. The main sulphide phases are pyrite, sphalerite, galena and minor chalcopyrite, in decreasing order of abundance. Two distinct types of pyrite are recognized: disseminated euhedral crystals occurring in altered wallrock (PY I); and disseminated subhedral to irregular, fractured grains, with inclusions of galena, occurring in quartz and calcite gangue (PY II). (*see* Plates 2-11-3 and 4). The latter type is commonly associated with other base metal sulphides.

The fine-grained grey sulphide is dominantly sphalerite, which occurs as irregular worm-like grains (SP I) interstitial to quartz and calcite, and also as larger grains in contact with pyrite and/or galena (SP II). Some pyrite grains appear to be corroded and replaced by sphalerite (SP II). Most sphalerite contains abundant fine inclusions of exsolved chalcopyrite.

Galena occurs as subrounded inclusions in pyrite (GL I), or fills fractures in pyrite and forms discrete irregular grains, interstitial to other sulphides, quartz and calcite (GL II). Chalcopyrite occurs as exsolved inclusions in sphalerite (CP I), or interstitially between other sulphides and as free grains (CP II).

Scanning electron microscope analyses by Holbek (1989) identified native gold and silver, electrum and acanthite. The gold and silver minerals occur as inclusions (AG-AU I) in base metal sulphides, as rims (AG-AU II) around sulphide

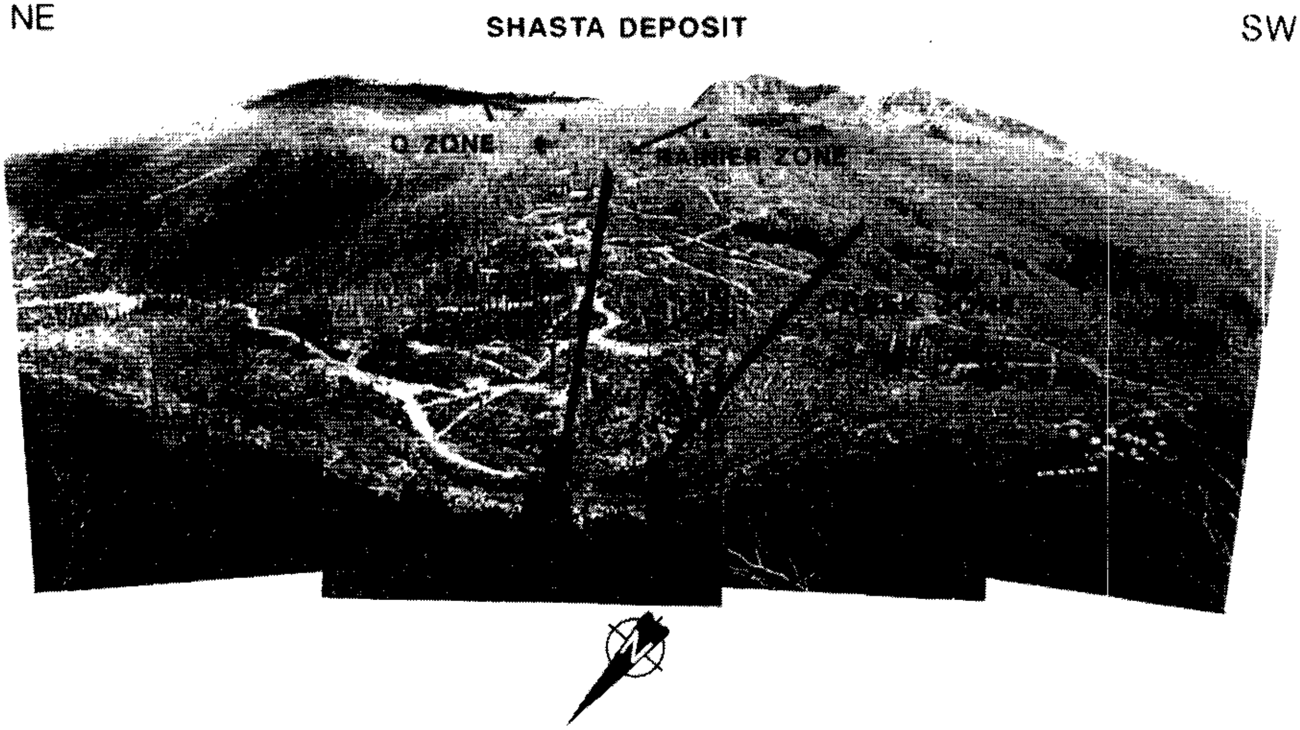

Plate 2-11-1. Panoramic photograph of the Shasta deposit, facing southeast. Solid black lines are traces of ore zones. Approximate vertical extent of zones is 350 metres. Camp in lower right hand corner.

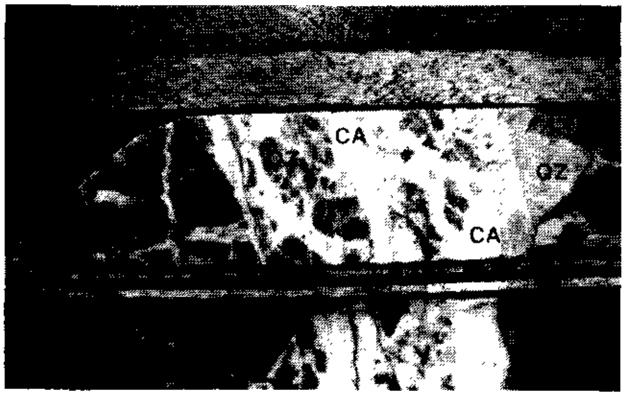

Plate 2-11-2. Drill core (ddh 88-6, 104.5 m) showing multistage quartz and calcite veining. Core diameter 4.5 cm. WR = wallrock, QZ = quartz, CA = calcite.

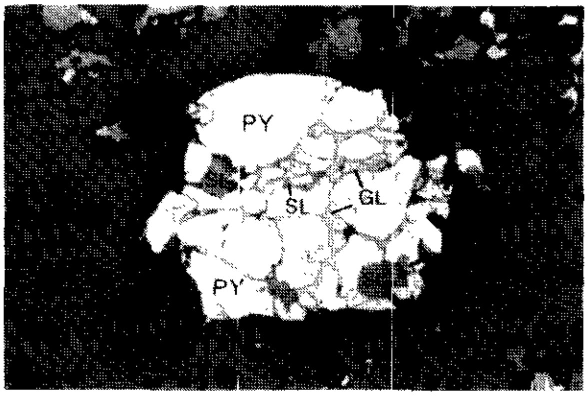

Plate 2-11-3. Photomicrograph of fractured PY II pyrite grain (white), infilled by later GL II galena (light grey) and SP II sphalerite (dark grey).

grains and as minute free grains (AG-AU II). Acanthite coexists with native gold, but not with electrum or native silver. Our precursory SEM analysis reveals that appreciable silver is also contained in galena.

ALTERATION

Wallrock alteration can be divided into four types: potassic, chloritic, phyllic and propylitic. Only potassic and chloritic alteration are directly associated with mineralization.

Propylitic alteration occurs on a regional scale and is characterized by an assemblage of chlorite + pyrite ± carbonate, mainly replacing mafic phenocrysts and lapilli fragments in pyroclastic series rocks.

Potassic alteration is associated with early quartz veins, and characterized by pervasive silicification and potassium metasomatism, resulting in distinctive orange-pink bleaching of stockwork zones, up to tens of metres wide. This alteration may also occur as narrow envelopes, less than centimetre across, around quartz veins. Generally, increasing intensity of potassium metasomatism has resulted in th

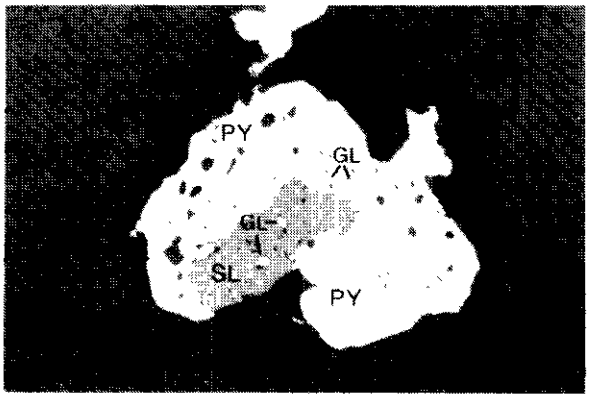

Plate 2-11-4. Photomicrograph of coprecipitated PY II pyrite (white) and SP II sphalerite (dark grey), both containing abundant inclusions of GL I galena (light grey).

progressive replacement of plagioclase phenocrysts, chloritic lapilli fragments and groundmass, in that order, by potassium feldspar and quartz. Minor sericite and clay minerals occur locally in the most intensely altered zones, but this may be a later feature. Whole-rock analyses of wallrock samples indicate K_2O contents of up to 8 weight per cent in the most altered rocks.

Chloritic alteration is dominantly, although not exclusively, associated with late-stage calcite veins and is represented by the assemblage chlorite ± epidote ± hematite. It occurs disseminated within veins and replacing wallrock fragments. Hematite and epidote also occur independently, in early to late fractures. This alteration has a more restricted distribution than potassic alteration.

Phyllic alteration is relatively uncommon, irregular and restricted. It is the latest event, overprinting both potassic and chloritic alteration, and usually destroying primary textures. It consists of pervasive sericite and finely disseminated pyrite, and does not appear to be spatially related to any particular features of the rock.

CREEK AND JM ZONES

The Creek and JM zones host most of the known reserves and outcrop between the 1260 and 1360-metre elevations, over strike lengths of 350 and 500 metres, respectively. The Creek zone strikes 180° and dips moderately westward. The JM zone trends 150° and dips steeply northeastward. These zones thus appear to merge to the north, although their intersection, if any, has not been identified. The Shasta fault forms the hangingwall of the Creek zone at surface, but appears to diverge from the zone as the fault attitude flattens with depth. The Creek and JM zones are hosted by two similar units of feldspar-quartz crystal lapilli tuff (one with heterolithic fragments, the other with dominantly chloritic fragments) which do not appear to exert lithological control on mineralization or alteration. It is notable, however, that silver-gold mineralization decreases sharply between 70 and 100 metres below surface, although stockwork zones may persist to greater depths.

The Creek zone is characterized by a well-defined stockwork system with strong silicification and coeval potassic alteration. Phyllic alteration occurs locally. Late calcite veining, with associated chloritic alteration, is abundant lower in the zone. Calcite veinlets continue through the footwall of the Creek zone and may persist for several tens of metres into relatively unaltered wallrock.

Silver and gold mineralization occur in both quartz and calcite veins, usually intimately associated with blebs of fine-grained pyrite. In calcite veins, pyrite is commonly associated with chloritic alteration of wallrock fragments. At higher levels in the zone, sulphide and silver-gold mineralization in quartz veins is commonly fine grained, and calcite veins are typically barren. At lower elevations, however, mineralization in calcite veins is usually coarse grained and quartz veins are sparsely mineralized.

Quartz and calcite breccias occur irregularly throughout the stockwork zone. Typically, wide (>10 centimetres) single-stage veins of either gangue mineral are barren or poorly mineralized, whereas narrower veins, multistage veins, and particularly mixed quartz-calcite-stage veins tend to carry abundant mineralization. It is also notable that sulphide and silver-gold mineralization tends to precipitate at the margins of veins and at contacts between different stages of gangue.

The JM (Just Missed) zone is generally similar to the Creek zone, but lacks the well-defined structural control of the hangingwall fault of the Creek zone. Potassic alteration and quartz stockworks appear more pervasive and somewhat stronger, while calcite veins and chloritic alteration are more restricted. Hematite and epidote alteration is locally abundant in the wallrock.

Early, narrow (<2 centimetres) quartz veins are commonly grey to green and fine grained. Late calcite breccias are usually wider (10-30 centimetres), and contain a coarse white calcite matrix that is usually barren. Gold and silver mineralization occurs in both quartz and calcite veins, but more commonly in narrow (<1 centimetre) veinlets toward the footwall of the zone. Two isolated occurrences of silver-gold mineralization in intensely silicified and potassically altered wallrock were noted in drill core, suggesting that early stages of quartz may be mineralized.

O ZONE

The O zone, situated 500 metres southeast of the JM zone, between the 1500 and 1550-metre elevations, strikes 130°, dips steeply northeast and is hosted by feldspar-quartz crystal lapilli tuffs and an overlying polymictic agglomerate.

Alteration and mineralization in the O zone is markedly different from that of the Creek and JM zones. Early alteration is characterized by strong, pervasive epidote, chlorite and hematite that is overprinted by moderate potassic alteration and weak silicification. These superimposed assemblages produce striking colour variations in drill core, particularly in the altered polymictic agglomerate.

Intense stockworks and breccias form well-defined zones with sharp boundaries, but are poorly mineralized. However, in rare mineralized sections, gold:silver ratios indicate significant enrichment in gold relative to other zones. Veins are quartz dominant, and although calcite is present, it is not intimately mixed with quartz as in the Creek or JM zones. Late fractures with narrow (<1 centimetre) potassium fel-

dspar and quartz envelopes are commonly filled by calcite with abundant epidote and pyrite.

EAST ZONE

The outlying East zone, 750 metres northeast of the JM zone at the 1250-metre elevation, outcrops in the feldspar-biotite-quartz porphyry unit. The zone strikes approximately northwest.

East zone mineralization and alteration also differ from the Creek and JM zones. Pyrite is more abundant in quartz veins and is locally semimassive. Chalcopyrite is also more common and occurs with galena along hairline fractures in moderately potassically altered wallrock. Silver-gold mineralization occurs in both quartz and calcite veins, but is concentrated in pyrite-rich quartz veins. Late potassic alteration is superimposed on strongly epidote-altered wallrock. A distinctive alteration type confined to the East zone is the conversion of plagioclase to dark green, translucent sericite (?) accompanied by pervasive phyllic alteration.

RAINIER AND JOCK ZONES

The Rainier zone, 300 metres south of the Creek zone at the 1400-metre elevation, is hosted by feldspar-quartz crystal lapilli tuff and trends roughly north with a subvertical dip. The zone has been subjected to extensive faulting and its morphology is unclear. The Jock zone, outcropping immediately northeast of the JM zone above the 1260-metre elevation, is also poorly defined due to complex faulting.

The Rainier and Jock zones were not examined in detail and will not be discussed at length. It is apparent however, that the mineralization and alteration styles of the Rainier and Jock zones are similar to the Creek and JM zones, respectively. This observation suggests that they may be extentions of the Creek and JM zones.

PARAGENESIS

Silver-gold mineralization of the Creek and JM zones can be divided into five stages: Quartz I, II, and III, and Calcite I and II (Figure 2-11-2). Quartz I comprises silicification and associated potassic alteration, and is widespread but only rarely mineralized. Quartz II consists of fine-grained, grey to clear quartz in narrow veins that are frequently well mineralized. Quartz III is fine-grained, dark grey to green, commonly forms wide breccias, and is generally barren. Calcite I is white to green, associated with chloritic alteration, is commonly well mineralized and frequently occurs with Quartz II as a single intimately mixed stage or as breccia matrix. Calcite II is white or cream coloured, very coarse grained and generally forms barren late-stage veins.

Textural relationships indicate a close temporal association between sulphide phases and silver-gold mineralization. All sulphides share mutually interlocking grain boundaries, and silver-gold minerals occur as both rims around and inclusions in various sulphide phases. Sphalerite, galena, chalcopyrite, silver, gold, electrum and argentite (now acanthite) appear to have been precipitated almost contemporaneously; only pyrite exhibits a wider temporal range. Features such as fractures and corroded embayments in pyrite indicate early deposition and subsequent replacement.

Sulphide and silver-gold mineralization occur in severa stages of vein filling, but are particularly abundant in th intimately mixed Quartz II and Calcite I stage. Thi coprecipitation of quartz and calcite indicates that a single common mechanism controlled the deposition of both thes gangue phases and silver-gold mineralization. The occurrence of silver in galena also requires a common parent flui or precipitation control for galena and silver. The observatio that rich silver-gold mineralization commonly occurs i *narrow (<3 centimetres) veins suggests that low fluid:roc* ratios may also have been a significant factor in deposition

CONTROLS OF SILVER-GOLD DEPOSITION

The wide occurrence of hydrothermal breccias in th Shasta deposit is strong evidence for boiling of the mineralizing fluid. Boiling and brecciation could also explain several other features of the deposit. The widespread silicification and fine-grained nature of Quartz I suggest that early hydrothermal fluids were supersaturated with respect to silica. Thi is consistent with the rapid decreases in temperature and pressure that are associated with boiling (Fournier, 1985a). The observation that there were repeated episodes of brecciation *can be explained by sealing of the system with rapidl* deposited silica, and hydraulic fracturing due to the resulting build-up of pressure.

Boiling of the hydrothermal fluid would also have led to loss of dissolved H_2S and CO_2 to the vapour phase. The loss of H_2S was probably responsible for the deposition of gold, as gold solubility is dominantly controlled by complexes

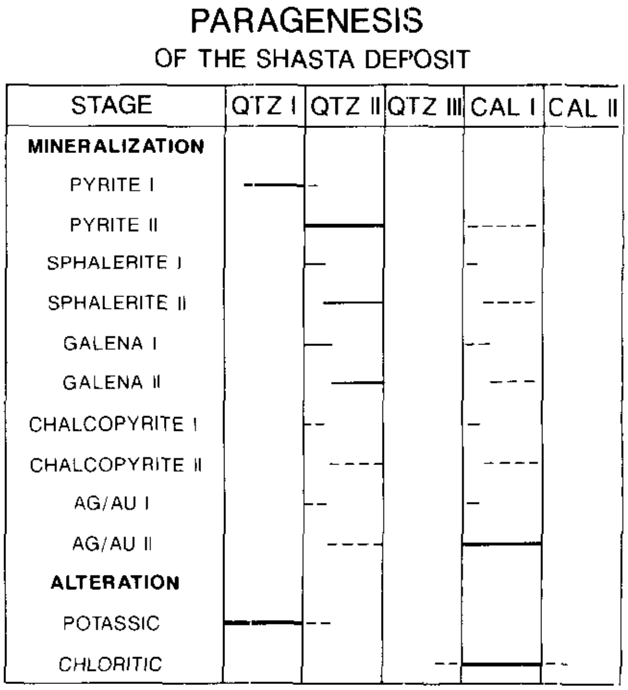

Figure 2-11-2. Paragenesis diagram showing general relationships between vein stages, sulphides and silver-gold mineralization. Solid lines indicate significant mineralization, thick lines up to 5 per cent; thin lines 1 to 2 per cent; dotted lines, trace mineralization.

involving H_2S (Seward, 1984). Partitioning of H_2S and other acid-forming volatiles into the vapour phase would also have increased the pH of the liquid, and led to the precipitation of calcite (Fournier, 1985b). The deposition of silver and base metal sulphides may have occurred in response to either this increase in pH, or the rapid decreases in temperature and pressure that accompanied boiling.

It is thus likely that a boiling process was responsible for the near-contemporaneous deposition of base metal sulphides and silver-gold mineralization, and the intimate mixing of Quartz II and Calcite I. The concentration of silver-gold mineralization at the contacts between different gangue stages and at vein margins is also an expected consequence of boiling and brecciation. The limited vertical extent of mineralization in the Creek and JM zones is likewise a predicted effect of boiling of the mineralizing fluid.

SUMMARY

Detailed examination of drill core from the Shasta silver-gold deposit reveals five stages of quartz and calcite vein filling in the Creek and JM zones. Narrow veins of fine-grained, clear to grey Quartz II, not directly associated with potassic alteration, and white to green Calcite I, associated with chloritic alteration, contain the bulk of silver-gold and sulphide mineralization. Gold, silver, electrum and acanthite were precipitated almost contemporaneously with second stage sphalerite, galena and chalcopyrite, suggesting a common mineralizing fluid and/or precipitation control. The simplest explanation for the observed relationships between gangue, base metal sulphides and precious metals is that of deposition in response to episodic boiling and brecciation.

Future work will involve fluid inclusion, stable isotope and geochemical studies to test the validity of a boiling model for the Shasta deposit, and to determine the physiochemical conditions of silver-gold deposition. These studies should contribute to a better understanding of the genesis of the deposit and provide useful guidelines for the continuing exploration and development of the property.

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NOTES