GOLD-SULPHIDE QUARTZ VEINS IN METAMORPHIC ROCKS AS A POSSIBLE SOURCE FOR PLACER GOLD IN THE LIVINGSTONE CREEK AREA, YUKON TERRITORY, CANADA

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ABSTRACT

The Livingstone Creek area is located 100 km northeast of Whitehorse, Yukon Territory, Canada. Hydrothermal gold-sulphide mineralization (MINFILE 105E 001) occurs in quartz-carbonate veins and veinlets which cut Paleozoic metamorphic rocks of the Teslin Suture Zone. The metamorphic rocks are also cut by Cretaceous(?) feldspar-porphyry dykes with an average thickness of 2 m.

The mineralization appears to be structurally controlled by NNE-striking faults and a set of NNW-trending joints. The vein minerals consist of gold, pyrite, chalcopyrite, galena, hessite/stuetzite, tetradymite, Au-Ag tellurides, tennantite, hematite, pyrrhotite, quartz, and carbonate. Gold occurs as: (1) "free gold" in cracks and interstices of quartz gangue (2) inclusions in galena, usually rimmed by hessite (3) minute grains associated with chalcopyrite and galena in aggregates of coarse grained pyrite (4) individual grains or fracture fillings in iron hydroxides.

The coarse-grained gold in Livingstone Creek appears to be derived from gold-quartz veins in the metamorphic bedrock. This is indicated by: (1) similar silver and mercury contents in primary and placer gold (2) identical trace element composition of galena from gold-quartz veins and galena inclusions in placer gold (3) similar telluride mineral assemblages in both in gold-quartz veins and placer gold grains (4) similar homogenization temperatures and salinities in fluid inclusions from both gold-quartz veins and placer nuggets.

A limited amount of gold appears to have formed by supergene leaching and precipitation. This kind of gold occurs as irregular-shaped grains in the stream placers and in iron hydroxide along fractures in quartz veins. Relative to the primary gold it is enriched in silver and mercury.

RÉSUMÉ

La région du ruisseau Livingstone est située à 100 km au nord-est de Whitehorse (territoire du Yukon) au Canada. Il y a minéralisation hydrothermale en or et en sulfures dans des veines et veinules de quartz et carbonate dans les roches métamorphiques paléozoïques de la zone de suture de Teslin. Les roches métamorphiques sont également recoupées par des dykes de feldspath et porphyre du Crétacé (?) d'une épaisseur moyenne de deux mètres.

La minéralisation semble structuralement définie par une faille d'orientation NNE et un ensemble de diaclases d'orientation NNW. L'assemblage de minéraux des veines consiste en or, pyrite, chalcopyrite, galène, hessite/stuetzite, tétradymite, tellurures d'Au et d'Ag, tennantite, hématite, pyrrhotine, quartz et carbonate. L'or prend la forme : 1) d'«or libre» dans des fissures et interstices de la gangue de quartz, 2) d'inclusions dans la galène, habituellement entourées de hessite, 3) de minuscules grains associés à la chalcopyrite et à la galène dans des agrégats de pyrite de granulométrie grossière et 4) de grains individuels ou de remplissage de fractures dans des hydroxydes de fer.

L'or de granulométrie grossière dans le ruisseau Livingstone semble provenir de veines de quartz aurifère dans le socle rocheux métamorphique, ce qui est indiqué par 1) des teneurs en argent et en mercure similaires dans l'or primaire et dans l'or placérien, 2) des compositions identiques en éléments à l'état de traces dans la galène des veines de quartz et or et dans la galène des inclusions dans l'or placérien, 3) des assemblages de tellurures minéraux similaires dans les veines d'or et quartz et dans les grains d'or placérien et 4) des températures d'homogénéisation et des salinités similaires des inclusions fluides provenant des veines d'or et quartz et des pépites placériennes.

Une quantité limitée d'or semble s'être formée par lixiviation et précipitation secondaires. Ce type d'or prend la forme de grains de formes irrégulières dans les dépôts alluvionnaires des cours d'eau et dans les fractures avec hydroxyde de fer dans les veines de quartz. Il est enrichi en argent et en mercure par raport à l'or primaire.

INTRODUCTION

The Livingstone Creek placer gold camp is located approximately 100 km northeast of Whitehorse at latitude 61°19'N and longitude 134°17'W on N.T.S. map sheet 105 E 8 (Fig. 1). It comprises eight tributaries of the South Big Salmon River. The first discovery of placer gold was in 1898. In the first decade of the following century the Livingstone placer area became a booming camp with an estimated production of about $1,000,000.00 in gold (Bostock, 1938). From an economic standpoint, Livingstone Creek has been the most important creek in the camp, and placer gold deposits are still being mined.

The geology and placer gold deposits of the Livingstone Creek area were first described by McConnell (1901). Regional geological mapping was carried out by Bostock and Lees between 1929 and 1934 (Laberge sheet; Map 372A) and by Tempelman-Kluit (1978,1979). Hansen (1986a,b) described the tectonic setting in detail.

The origin of placer gold of the Livingstone Creek was unknown for a long time. Bostock (1938) supposed quartz veins in the metamorphic bedrock were possible contributors of the gold. A 1983 assay of dump material beside a small mineral occurrence on the north side of Livingstone Creek (MINFILE 105E 001) assayed up to 1.58 opt Au, 16.6 opt Ag and 9.9% Pb (Archer, Cathro & Associates (1981) Ltd internal report, 1986). Visible gold, however, has not previously been reported.

This paper describees the paragenesis of gold-quartz veins in relation to placer deposits in the Livingstone Creek area. It is based on data obtained by chemical and mineralogical investigations of gold-bearing quartz-carbonate veins and placer deposits. Field work was carried out during an eight week period in 1986 as part of the Canada/Germany Science and Technology Exchange program.

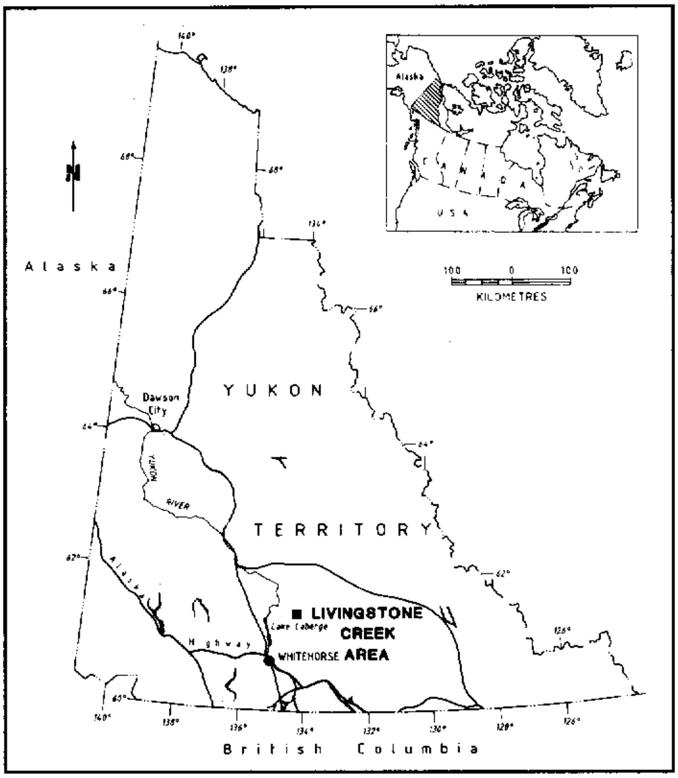

Figure 1. Location of the study area.

REGIONAL GEOLOGY

Cataclastic rocks of the Teslin Suture Zone (TSZ) underlie the area. The TSZ is interpreted as the fundamental boundary between eastern autochthonous rocks of the ancient North American Craton and allochthonous terranes to the west (Tempelman-Kluit, 1979). Cataclastic rocks of the TSZ are divided into three assemblages. The Nisutlin Allochthon, a schist-quartzite assemblage is derived from a protolith of synorogenic clastics with interlayered intermediate volcanics. The Anvil Allochthon is a sheared ophiolite complex consisting of basalt, gabbro and peridotite. The Simpson Allochthon consists of granitic cataclasites (Tempelman-Kluit, 1979). TSZ rocks were metamorphosed to greenschist or amphibolite facies in Late Triassic to Mid-Jurassic time (Tempelman-Kluit, 1979). The silicate mineral assemblage records maximum temperatures of 625°C, and pressures to 8 kbars (Hansen, 1986).

LOCAL GEOLOGY

Bedrock in the study area consists of southwest-dipping metamorphic rocks, intruded by two unmetamorphosed

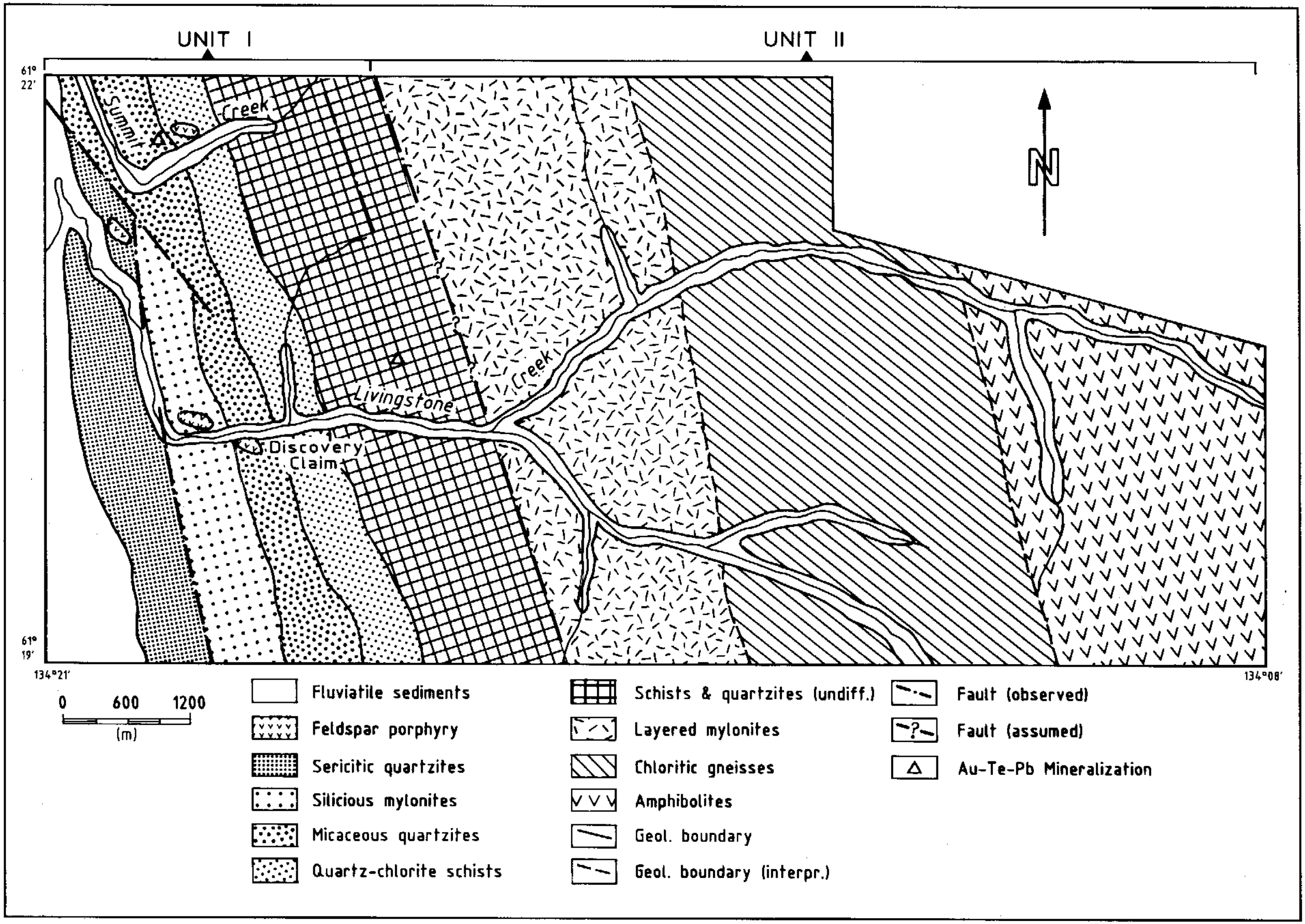

Figure 2. Geological map of the study area.

feldspar-porphyry dykes (Fig. 2). Exposure is poor, with good outcrops confined to the narrow canyon-like valleys of Livingstone Creek and Summit Creek, and to the ridges north,south and west of the two creeks.

Three distinct lithologic units are recognized. Unit 1 consists of siliceous tectonites derived from sedimentary and/or volcanic protoliths, and is assigned to the Nisutlin Allochthon. Unit 1 rocks are subdivided into five subunits. From west to east these are: (1) sericitic quartzite and metagreywacke; (2) siliceous mylonite intercalated with quartz-mica schist and lenses of silica-rich marble; (3) micaceous quartzite; (4) quartz-chlorite schist and (5) undifferentiated quartzite and mica-schist. The Unit 1 schists and quartzites are generally fine grained and consist mostly of quartz and sericite with minor sodic plagioclase, potassium feldspar, chlorite, biotite, epidote, clinozoisite, actinolite and carbonate, and accessory zircon, rutile, pyrite and magnetite.

Unit 2 is a metavolcanic unit of layered mylonite, chloritic gneiss and amphibolite. It is interpreted as part of the Anvil Allochthon, separated from Unit 1 by a NNW-trending fault zone. The layered mylonite consists of Mg-rich chlorite, epidote, clinozoisite, amphibole (barroisite and tschermakite), potassium feldspar, quartz, oligoclase, calcite, biotite and sericite. Amphibole (tschermakite) and plagioclase (oligoclase) are the main components of the dark green, medium-grained amphibolites. Minor components include epidote, iron-rich chlorite, garnet, sphene, clinozoisite and quartz. The Unit 2 amphibolites have a mafic igneous composition, and have been metamorphosed to upper greenschist or lower amphibolite grade. According to Spry's (1969) classification, cataclastic rocks in the study area range from protomylonites to mylonites and ultramylonites.

Unit 3 rocks are northwest-trending hornblende-feldspar porphyry dykes with an average thickness of two metres. The porphyritic texture is produced by phenocrysts of euhedral plagioclase (18 ± 0.4%) up to 2 cm in size, amphibole (hastingsite,(34 ± 1.3%) and biotite (3 ± 0.5%) in a fine-grained groundmass (45%). Their chemical composition suggests that they are banakites. They are most likely subvolcanic equivalents of the Late Cretaceous Carmacks Group volcanics (Glasmacher, 1989).

PRIMARY MINERALIZATION

Gold and sulphide minerals occur in quartz-carbonate veins and veinlets. The veinlets crosscut sheared micaceous quartzite of Unit 1 and are generally confined to NNW-striking joints. They are best exposed in Summit Creek valley. The main sulphide minerals in the veinlets are pyrite, pyrrhotite and chalcopyrite. Galena, gold, Bi-tellurides and hematitite occur to a lesser extent.

The major lode occurrence is a gold-quartz vein on the Horseshoe claim north of Livingstone Creek (MINFILE 105E 001). Average thickness of the vein is about 70 cm. The mineral assemblage consists of gold, pyrite, galena, chalcopyrite, tennantite, Au-Ag tellurides, hessite/stuetzite, quartz and minor carbonate gangue.

Gold forms visible grains in cracks and interstices of quartz gangue (Fig. 3) and inclusions of microscopic scale in galena (Fig. 4). It also occurs as relict particles in iron hydroxide (Fig. 5) and newly formed along microfractures (Fig. 6). Petrologic and electron microprobe studies reveal distinct differences in morphology and composition between gold grains from unoxidized and partly oxidized vein material.

Individual gold grains in quartz gangue and in unoxidized galena (Figs. 3, 4) reach 0.2 cm in diameter and commonly exhibit smooth grain boundaries. The silver and mercury contents in gold of this type of gold range from 13 to 16 weight per cent Ag (modal value 14%) and 0.2 to 0.9 weight per cent Hg (modal value 0.2%)(Figs. 11, 12). The average Au:Ag ratio is 5.9.

Relict gold particles found in iron hydroxides are characterized by corroded grain boundaries (Fig. 5) and similar chemical composition to those gold grains described above. In contrast, gold on fractures in iron hydroxides occurs as irregular shaped particles (Fig. 6). These irregular fracture-hosted particles show significantly higher silver values (16 to 23 weight per cent) and mercury (2 to 4 weight per cent)(Figs. 11, 12). The Au/Ag ratio decreases to an average value of 3.8.

Telluride minerals found in quartz veinlets of lower Summit Creek valley and in the Horseshoe quartz vein include hessite (Ag_2Te), stuetzite ($Ag_{5-x}Te_3$), Au-Ag tellurides of varying composition close to ideal petzite (Au-Ag_3Te_2), and tetradymite (Bi_2Te_2S).

Silver tellurides are restricted to the Horseshoe quartz vein. They usually occur as microscopic inclusions in unweathered galena, occasionally forming small rims around enclosed gold grains (Fig. 4). The silver tellurides contain between 57 and 62 weight per cent silver, and have been identified as hessite and/or stuetzite. Gold is below the detection limit ($<0.2\%$).

Gold-silver tellurides have a restricted distribution and can only be identified by electron microprobe analysis. They occur either as small inclusions ($<3\mu$) in galena and pyrite, or intergrown with Bi-tellurides in quartz gangue. Figure 14 shows the compositions of the Au-Ag tellurides.

Bismuth tellurides have been found in quartz-carbonate veinlets cutting metamorphic rocks of the lower Summit Creek valley, where they are associated with pyrite, chalcopyrite, pyrrhotite and gold. They occur (1) as inclusions in pyrite, partly intergrown with galena and chalcopyrite (2) in quartz gangue intergrown with chalcopyrite or hematite (3) as individual phases in quartz gangue. The bismuth telluride crystals are generally anhedral with a maximum grain sizes of about 0.2 mm. The average composition of the bismuth tellurides (57.5 weight per cent Bi; 34.98 weight per cent Te; 4.48 weight per cent S) corresponds to tetradymite (Bi_2Te_2S).

Pyrite is ubiquitous in quartz-carbonate veins and veinlets.It fotms euhedral crystals in the quartz carbonate veins or is disseminated and intergrown with rutile in highly silicified metamorphic wall rocks. Microprobe analyses indicate that both kinds of pyrite contain less than 0.11 weight per cent gold.

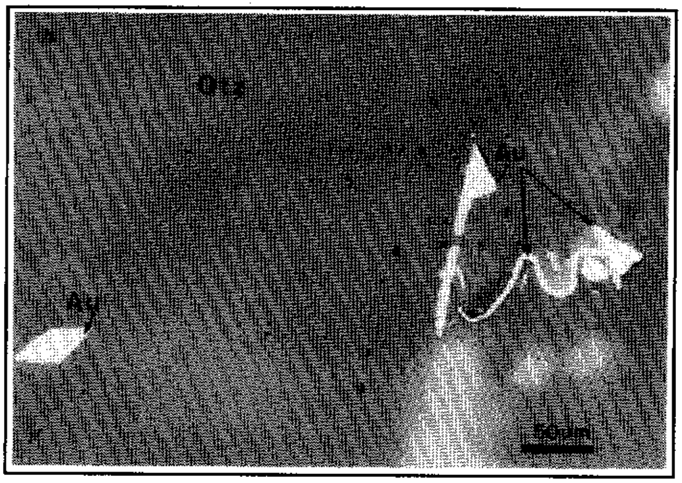

Figure 3. Interstital gold in quartz gangue (Horseshoe claim).

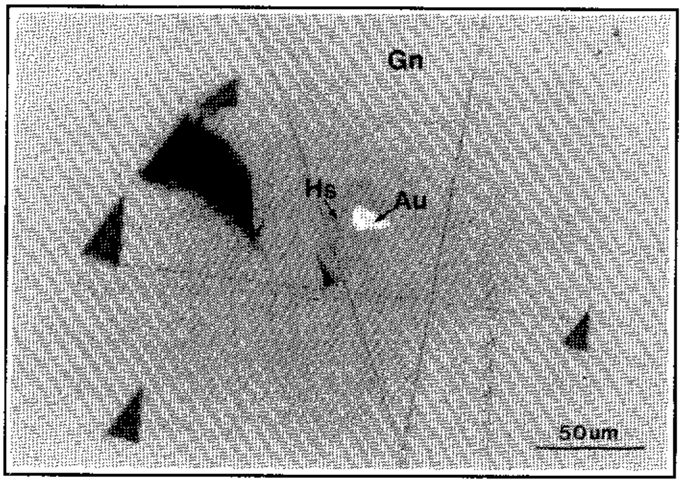

Figure 4. Gold rimmed by hessite, forming inclusions in galena.

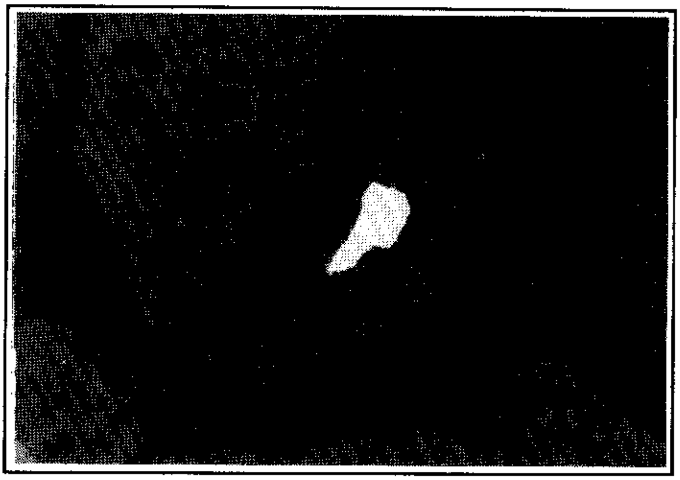

Figure 5. Gold rimmed by hessite, forming inclusions in galena.

Figure 6. Gold along fractures in iron hydroxide, Horseshoe claim.

Galena in gold-quartz veins generally forms coarse aggregates up to 2 cm in size. It often contains inclusions of gold which are usually rimmed by hessite (Fig. 4). Fracturesin galena are healed by tennantite and chalcopyrite. In the veinlets, galena occurs as small inclusions or along microfractures in pyrite. Microprobe analyses reveal traces of silver (average 0.41 weight per cent) and bismuth (average 0.74 weight per cent). Antimony has not been detected.

Chalcopyrite usually occurs as subhedral to anhedral crystals or as coarse grained aggregates intergrown with or cementing pyrite and galena. In minor amounts it is associated with hematite or occurs with galena along small fractures in pyrite.

Tennantite is exclusively intergrown with chalcopyrite in quartz gangue or along cracks in galena. It has an average arsenic content of 17.9 weight per cent. Traces of antimony (0.35 weight per cent), bismuth (1.0 weight per cent), silver (0.13 weight per cent) and mercury (0.08 weight per cent) have also been detected.

Hematite is common in veinlets of Summit Creek valley as needle-like crystals up to 1 mm in size. Hematite also occurs as symplectic intergrowths with chalcopyrite associated with pyrite. It also replaces fine disseminated magnetite in the metamorphic host rocks.

Coarse grained quartz is the main gangue mineral. Fluid inclusion data are presented in Fig. 15. Homogenization temperatures from primary fluid inclusions in quartz from the Horseshoe vein range from 110°C to 200°C with a maximum at 150°C (Blum, 1987). Salinities are about 4.5 weight per cent NaCl equivalent.

Wallrock alteration near mineralized veins includes pyritization, kaolinitization, dolomitization, sericitization, and chloritization. Quantitative studies of element enrichment and depletion in altered metasedimentary and volcanic rocks demonstrate elevated levels of gold and arsenic in altered wallrocks. Close to a NNE-trending fault zone, pyritized,

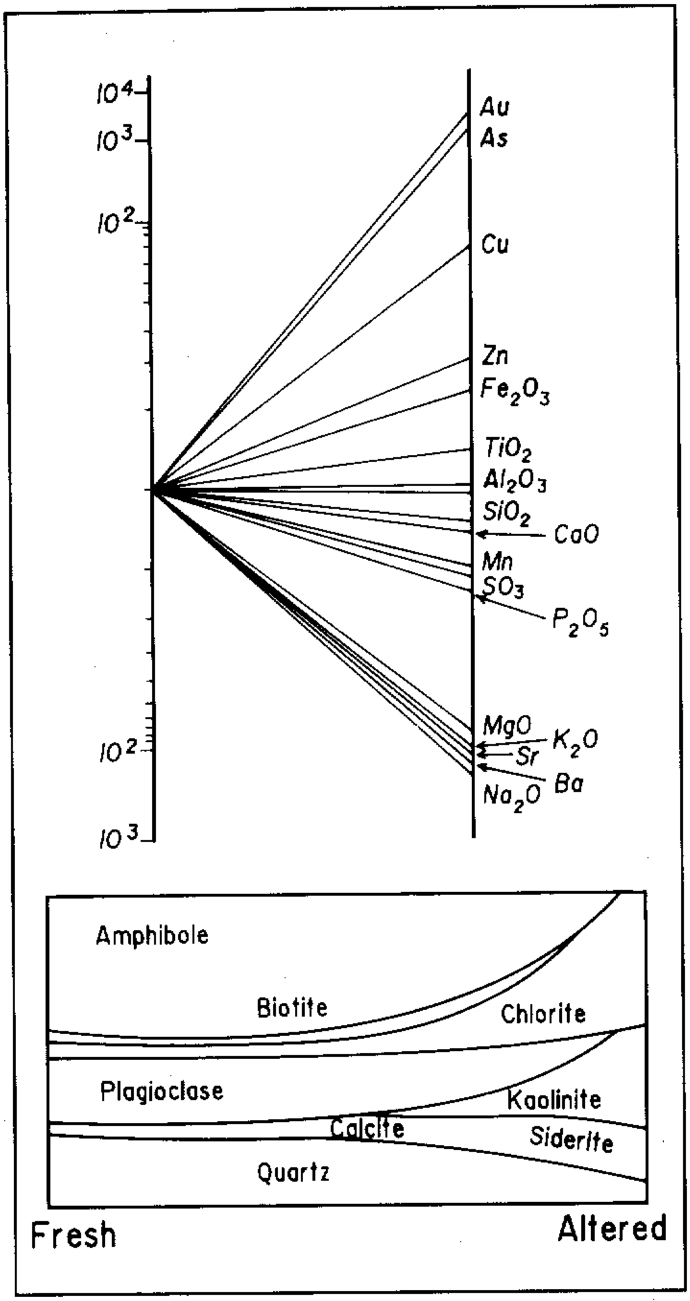

Figure 7. Element enrichment and depletion in altered feldspar porphyry.

kaolinized and sericitized porphyry dykes also show considerably increased levels of gold and arsenic (Fig. 7). The positive correlation between arsenic and gold allows arsenic to be used as a "pathfinder" element in this area. Mercury might also be used as a pathfinder element, as gold-silver alloys in the Horseshoe quartz vein contain up to 4 eight per cent mercury.

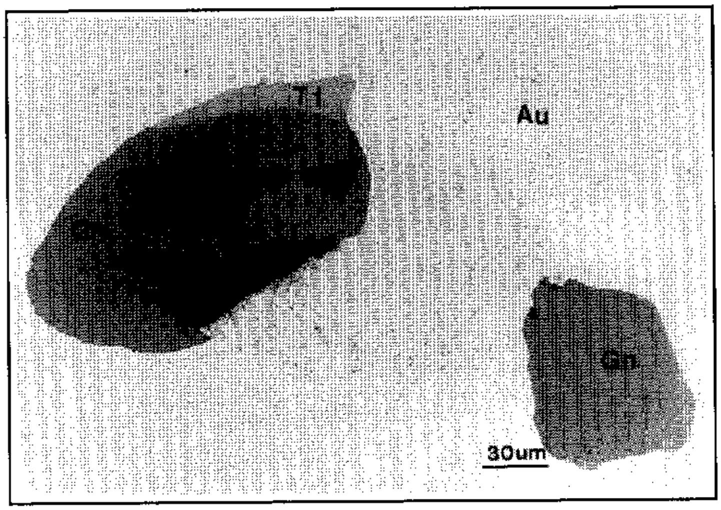

Figure 8. Intergrown galena and tetradymite, enclosed in placer gold grains from Livingstone Creek.

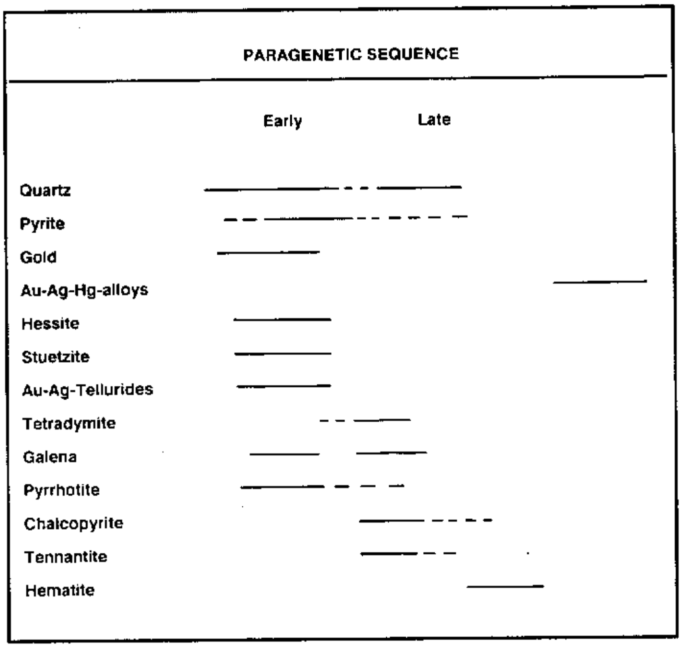

Figure 9. Paragenetic sequence for primary mineralization.

PLACER DEPOSITS

Alluvium in Livingstone Creek contains a heavy mineral assemblage which includes gold, galena, pyrite, arsenopyrite, cassiterite, cinnabar, epidote, garnet, hematite, ilmenite, pyrite, tourmaline, rutile, zircon and magnetite. Free gold particles consist of gold nuggets (grain size from 4.75 to >29 mm), "jewellery gold" (grain size from 1.7 to 3.4 mm) and fine gold (grain size <1.7 mm). Individual gold grains vary considerably in shape and internal structure. Four main types are recognized (Friedrich and Wiechowski, 1987): (1) Rounded gold grains, sometimes flat, with a smooth surface. Limonite is rare, usually confined to embayments in the

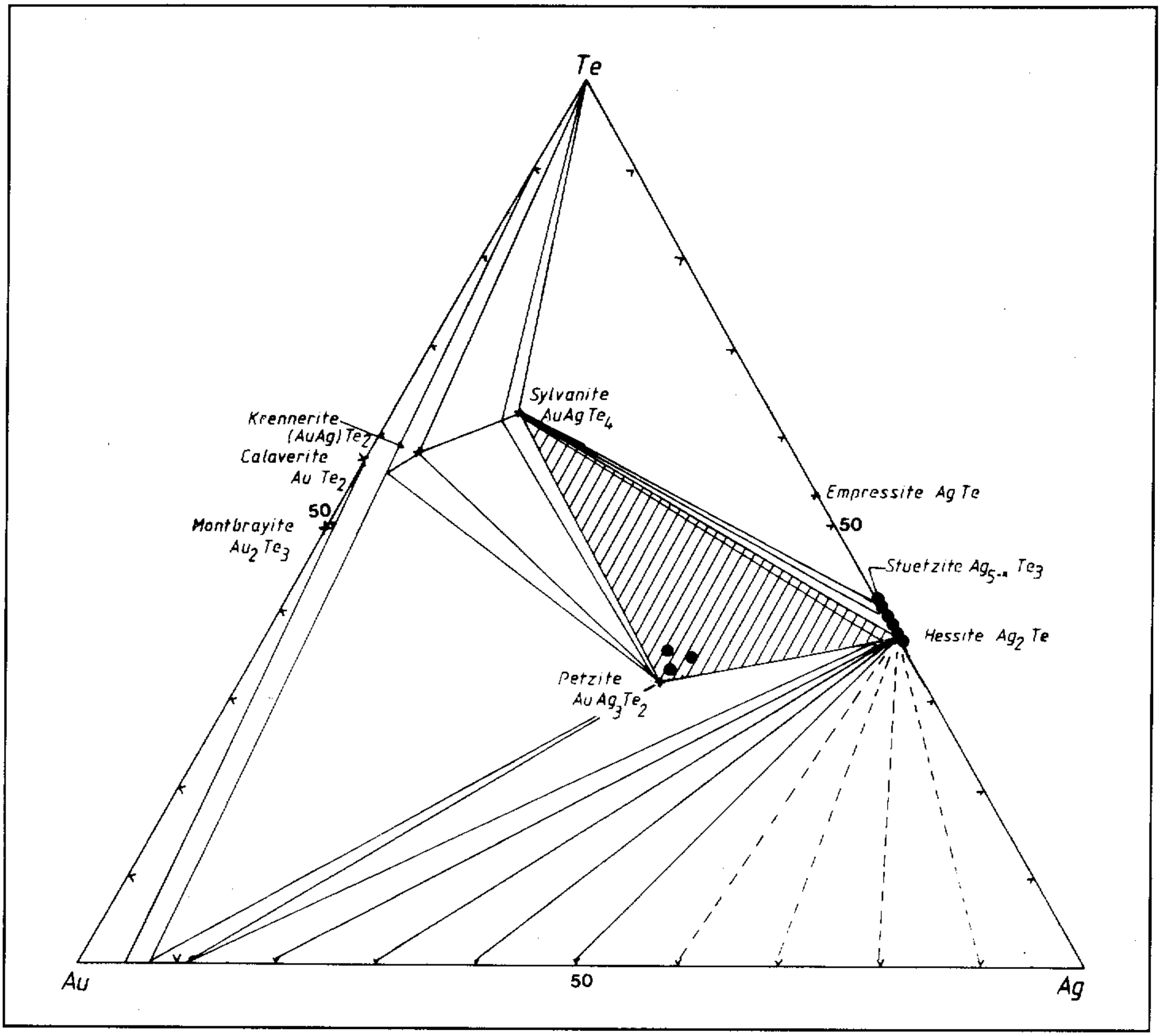

Figure 10. Minerals in the Au-Ag-Te system. Tie lines are indicated by natural mineral assemblages. (After Cabri, 1965). Dots indicate telluride minerals of the Livingstone Creek area.

surface. Larger nuggets often consist of an aggregate of gold leaves which are believed to have accreted during alluvial transport. (2) Flat, frequently elongated gold grains with smooth surfaces and rounded edges, characterized by dendritic growth structure. (3) Irregular gold grains with rugged or partly rounded surfaces, often intergrown with quartz. Irregular grains are rimmed with limonite, especially near embayments. (4) Thin flakes of gold with a smooth to verrucose surface and occasional curved rims.

Many gold nuggets contain inclusions of galena intergrown with tetradymite (Fig. 8), as well as hessite (Ag_2Te) and stuetzite ($Ag_{5-x}Te_3$).

Microprobe data reveal that the chemical composition of individual gold grains does not vary significantly, except for the mercury content. Fig. 11 shows the frequency distribution of silver values in placer gold grains. The outer rims generally return very low silver values due to leaching. The frequency distribution pattern of silver shows a range of values from 4-19 weight per cent, with a maximum at 12 weight per cent. There is no apparent correlation between silver content and grain size or shape of gold. The mercury content varies from <0.2 to 2.92 weight per cent (modal value 0.2 weight per cent) in primary gold grains and within individual gold nuggets (Fig. 12). Considerably higher mercury values (2-4 weight per cent) are found in irregular gold grains which are inferred to have a supergene origin.

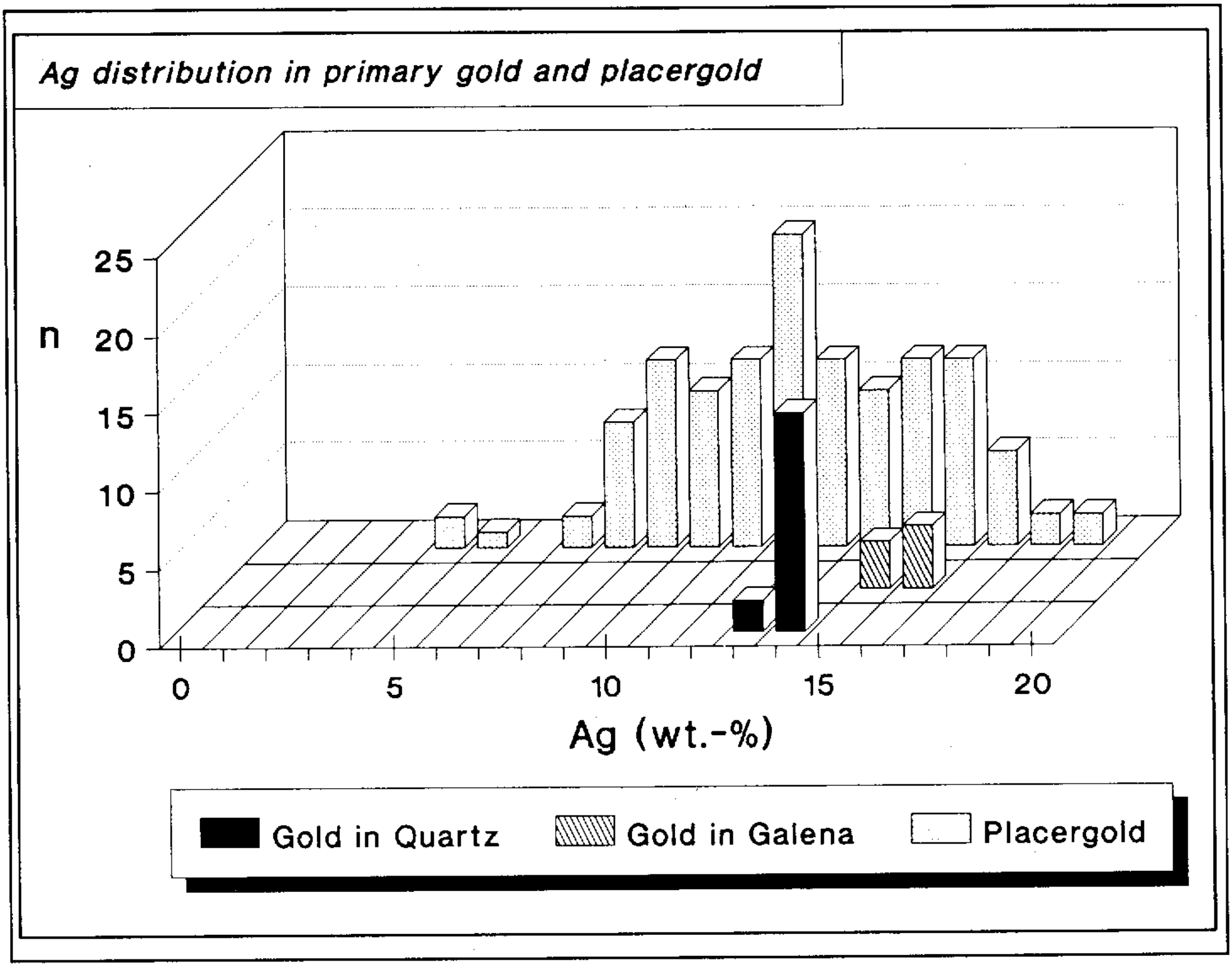

Figure 11 Frequency distribution of silver in placer gold and in vein gold from the Horseshoe claim.

Trace element compositions of galena inclusions in placer gold grains are shown in Fig. 13. Antimony is below detection limit. Average bismuth values range from 0.4 to 0.8 weight per cent and the silver content does not exceed 0.5 weight per cent.

Hessite and stuetzite inclusions in placer gold grains show slightly variable Ag/Te ratios (1.7 to 1.9). The gold content of the inclusions is very low and varies from 0.3 to 2 weight per cent. The composition of the Te-bearing minerals (including Au-Ag-Te inclusions in placer gold grains) is shown in Fig. 14.

Most of the placer gold deposits formed by physical transport and gravity concentration. Minor dissolution, migration, and reprecipitation of gold, however, is suggested by gold grains with silver-depleted rims.

DISCUSSION

The paragenetic sequence shown in Fig. 9 is defined by cross cutting relationships and replacement textures. The first stage of mineralization deposited milky quartz, coarse-grained pyrite, gold hessite, stuetzite, galena (I), and gold-silver tellurides. Later fracturing allowed earlier sulphides like galena and pyrite to be partially replaced or enclosed by chalcopyrite, galena (II), tetradymite, pyrrhotite and tennantite. Hematite formed last, as indicated by its lack of replacement textures, and massive hematite veinlets which crosscut earlier quartz-sulphide veinlets.

Assumptions about the temperature of mineralization are based on the occurrence and stability of Au-Ag-Te minerals. At temperatures above 170°C, compositions within the sylvanite-petzite-hessite field (Fig. 10) form the metastable gamma-phase (Cabri, 1965). The gamma phase breaks down at temperatures below 120°C forming stuetzite associated with hessite and petzite. The coexistence of stuetzite, hessite and other tellurium minerals with end-menber petzite in the Horseshoe vein indicates that the earliest telluride minerals were deposited at temperatures above 170°C.

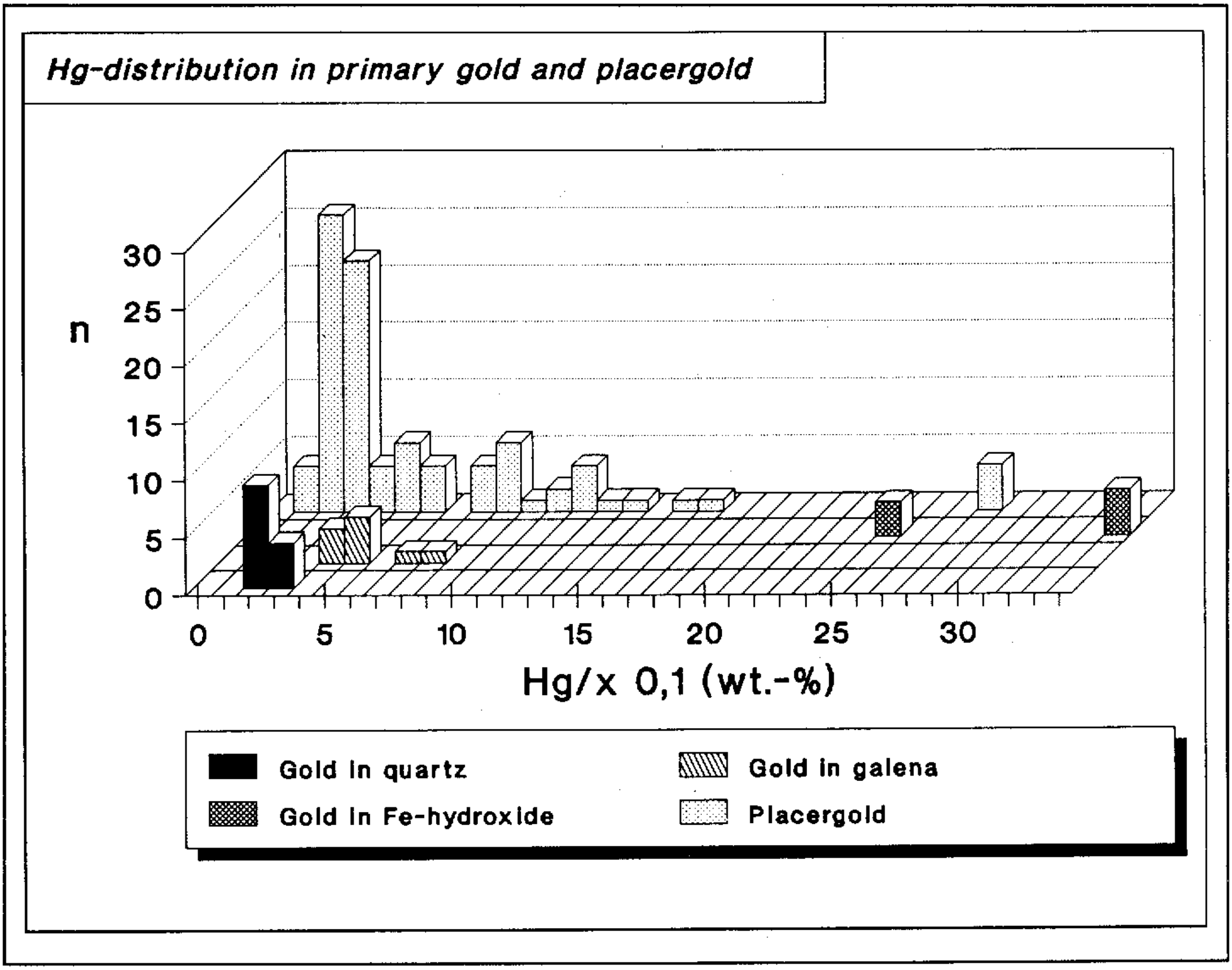

Figure 12 Frequency distribution of mercury in placer gold, and in vein gold from the Horseshoe claim.

Oxidized material from the gold-bearing quartz vein north of Livingstone Creek contains numerous tiny grains of visible gold. Relict gold particles in the iron hydroxide have a similar composition to the gold in unoxidized quartz and galena and show corroded grain boundaries due to partial dissolution. They are inferred to be residual.

Irregular-shaped gold particles in iron hydroxide-filled fractures are believed to have formed entirely as a result of supergene leaching and precipitation. Relative to gold grains in quartz gangue and galena, supergene gold is enriched in silver and mercury.

CONCLUSIONS

Comparison of gold and gold-silver tellurides from placer deposits and the Horseshoe vein suggests that most of the placer gold in Livingstone Creek is derived from gold-bearing quartz veins which crosscut the metamorphic bedrock. The following evidence supports this conclusion: (1) The vein and placer gold have very similar chemical composition (Fig. 11, 12); (2) galena inclusions in placer gold grains and primary galena in the gold quartz vein have identical trace element compositions (Fig. 13); (3) a similar suite of telluride minerals is associated with both the placer and vein occurrences; (4) Fluid inclusions in primary gold-quartz intergrowths in placer nuggets and in gold-quartz veins show similar patterns of homogenization temperatures (Fig. 15). Gold telluride compositions and fluid inclusion evidence shows that the veins were deposited from low-salinity epithermal fluids at a temperature of 170-200°C and a shallow or moderate depth. The age of the veins is unknown but they clearly post-date Late Cretaceous porphyry dykes in the area.

Gold is enriched in altered wallrocks along a NNE-trending fault, and there is a strong correlation between primary gold and arsenic.

Some gold grains in Livingstone Creek and in iron hydroxide-filled fractures in quartz show evidence of supergene leaching and redeposition. Gold grains of inferred

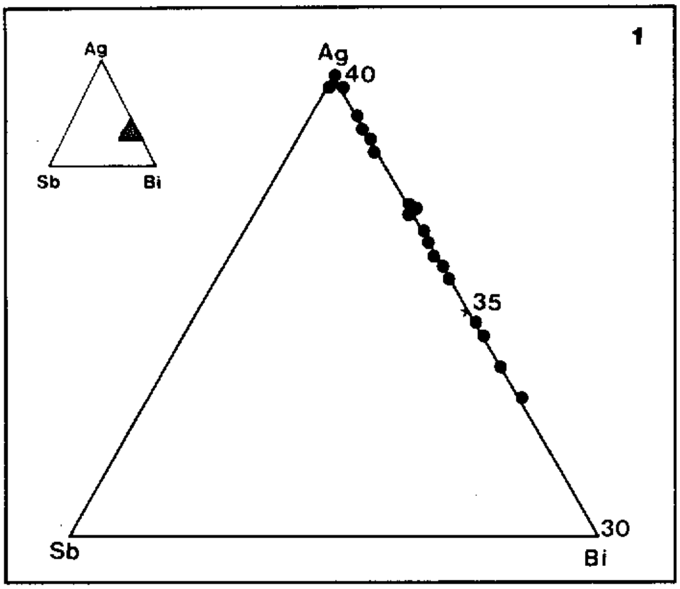

Fig. 13(1) Relative distribution of silver and bismuth in galena from gold-bearing quartz vein on the Horseshoe claim.

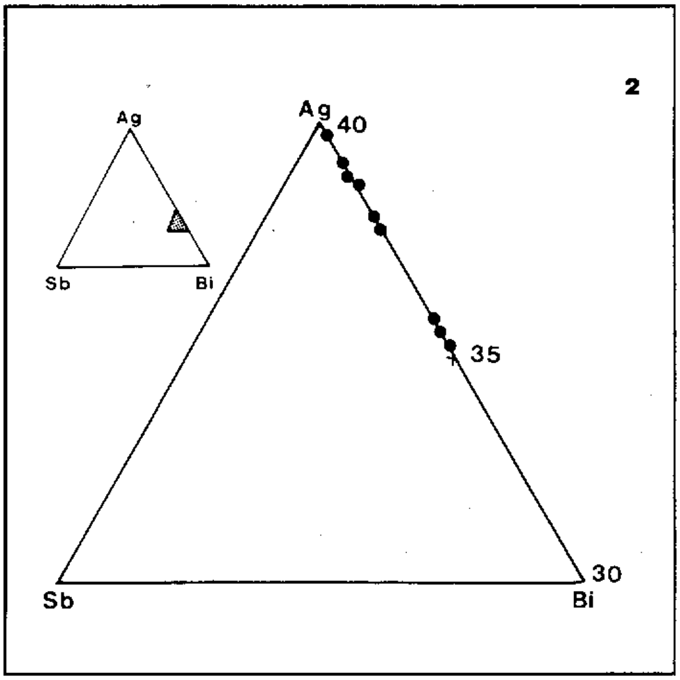

Fig. 13(2) Relative distribution of silver and bismuth in galena inclusions in placer gold.

supergene origin are distinguished by their irregular morphology and considerably higher silver and mercury content.

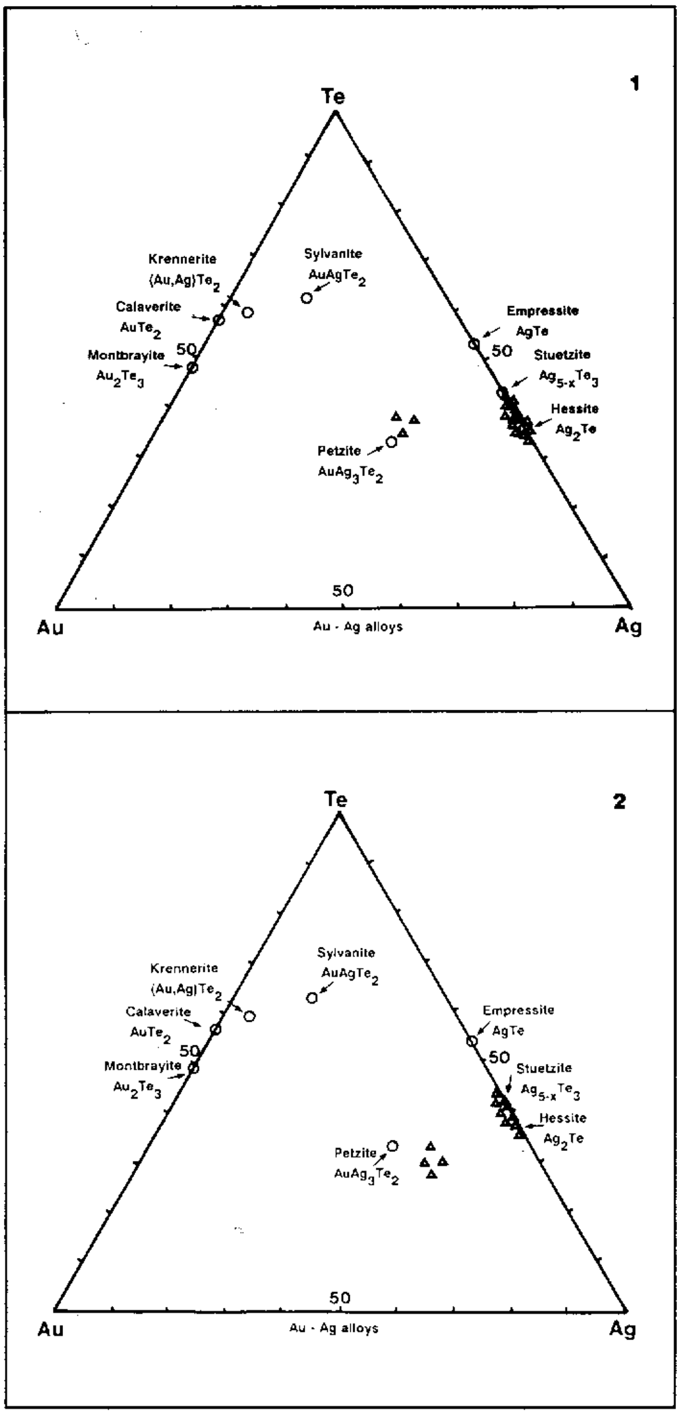

Figure 14. Composition of Ag- and Au-Ag- tellurides (triangles) from (1) gold bearing-quartz vein on the Horseshoe claim, and (2) telluride inclusions in placer gold.

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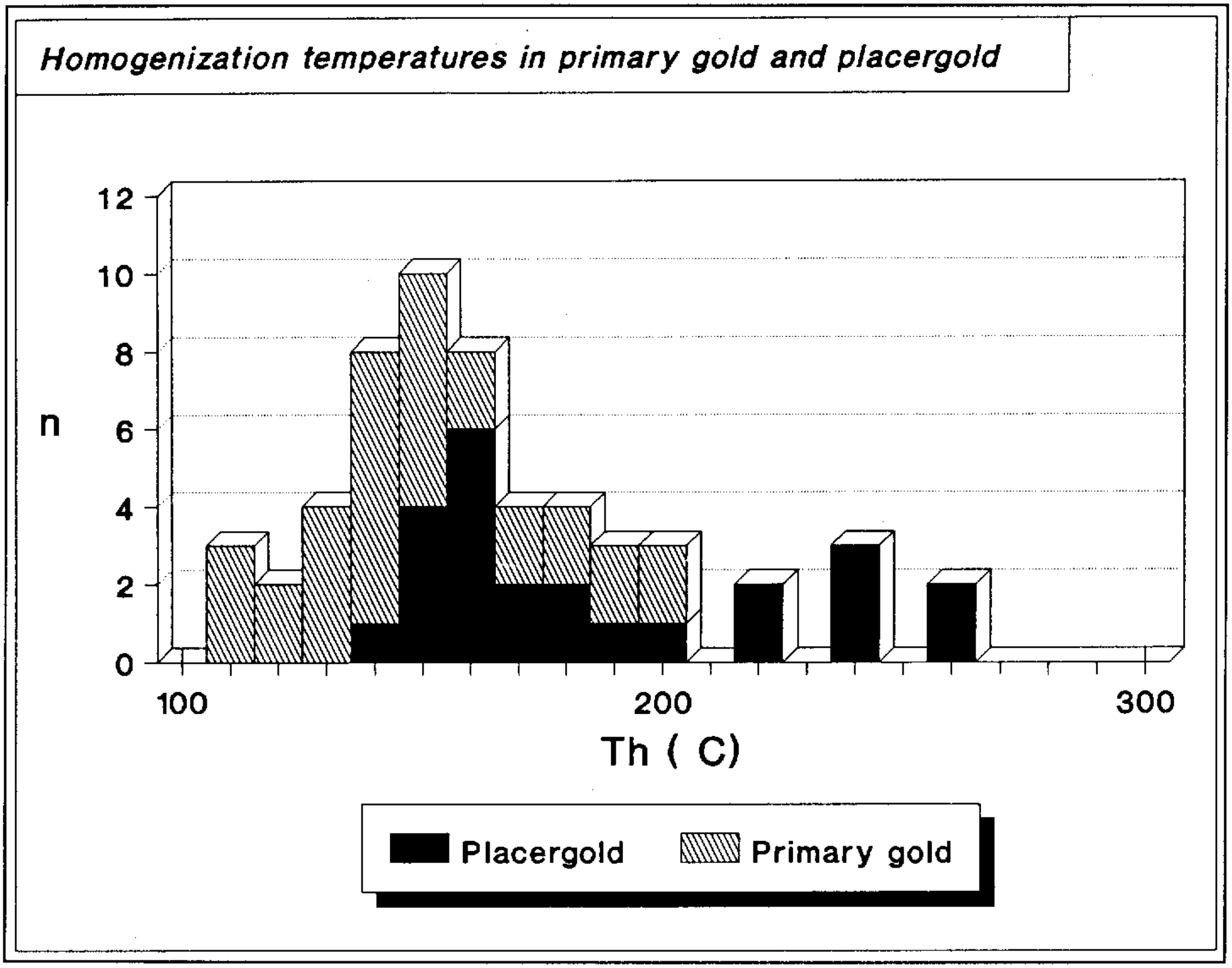

Figure 15. Homogenization temperatures of fluid inclusions in quartz-gold intergrowths from (1) gold-bearing quartz vein on the Horseshoe claim, (2) placer deposits.

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