ISOTRACE LABORATORY

SULPHIDIC ZONED GOLD SKARN MINERALIZATION AT ROSSLAND, BRITISH COLUMBIA

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Abstract

This paper documents the first systematic integration of Accelerator Mass Spectrometry (AMS) within a research program in economic geology. Gold-enriched samples from an area of major gold production are described in regional and local contexts. Mineralogical data are supplemented by in-situ AMS analysis of polished samples, in order to determine the partitioning of gold between the major opaque phases in the ore. Analysing sample areas ≈ 0.5 mm in diameter, arsenopyrite was found to contain high (ppm) levels of gold, while the volumetrically-dominant phase (pyrrhotite) contains a very low level of Au, averaging 32 ppb (ng/g) for 38 analyses.

INTRODUCTION

This letter presents new data, derived from field mapping and subsequent petrographic and analytical work, pertinent to the nature and origin of gold mineralization at Rossland, British Columbia, Canada. The results are relevant to three fields of current research, namely;

(1) Skarn-hosted ore deposits, of increasing interest for their gold potential. The Rossland ores are at least partly derived from gold skarn.

(2) In-situ determination of precious metals in polished mineral grains, at ppb (ng/g) levels, was used to study the partitioning of `invisible´ gold between the major opaque phases in the ore. We document the first systematic integration of ultrasensitive Accelerator Mass Spectrometry (AMS) within a research program in economic geology.

(3) Certain new data concern the recent debate on the role of lamprophyres in the genesis of gold deposits. The available information does not support a causative link between gold and alkalic dyke rocks at Rossland.

The Rossland gold camp is located in southeastern British Columbia, some 360 km due east of Vancouver, a few km north of the border of Washington state (Fig. 1). Predominantly a lode mining district, published sources indicate total production of about 85 tonnes of gold, 107 tonnes of silver and 54,296 tonnes of copper from 6.389 million tonnes of ore, the bulk of this stemming from the mines´ heyday, between 1894 and 1928 (Gilbert, 1948; Barr, 1980; Fyles, 1984; Bache 1987). Good summaries of the regional geology are available (Little, 1982; Fyles, 1984), and the following description is limited to a brief summary of the mining camp, with details of the immediate study area. The bulk of the historical mining occurred in an area on the northwest margin of the Rossland monzonite, an east-west elongate body roughly 8 x 3 km in

plan, intrusive into Lower Jurassic Rossland Group host rocks. The Le Roi and contiguous mines form a so-called `Main Belt´ of mineralization, mirrored (albeit with a much smaller production) along a nearby `North Belt´, and also along the S.W. margin of the (late Jurassic or early Cretaceous) pluton. This study focuses on the latter `South Belt´ area, specifically on the immediate. vicinity of the Crown Point mine, a short-lived gold producer in the 1890´s. It should be added that the western end of the North Belt coincides with a Mesozoic porphyry molybdenum system (the former Red Mountain mine); that a fifth mineralized area (high-grade gold veins of the I.X.L. and Midnight mines) occurs some distance westward of the Main Belt; and that four Main Belt mines accounted for 97.9 percent of documented regional gold production.

THE SETTING OF THE CROWN POINT MINERALIZATION

In the course of detailed mapping, the samples used in this study were collected within 500 m of the south margin of the main monzonite mass. The field area includes a small satellite stock or apophysis, incompletely exposed on wooded hillsides E.S.E. of the town of Rossland and the Main Belt mines. 45 polished sections and offcuts and 42 covered thin sections were examined in order to establish the petrological features of the samples.

The Rossland Group rocks in the Crown Point area are dominated by dark, fine-grained basaltic flows, with lesser andesitic flows and sedimentary units, the latter mostly fine-grained biotite-rich siltstones. Wider studies of these rocks (Beddoe-Stephens and Lambert, 1981; Hoy and Andrew, 1988, 1989) describe massive flows and fragmental lithologies, within which some workers have recognized mafic subvolcanic intrusions. Whole-rock analyses obtained on fresh samples from the Crown Point area are very similar to others obtained for volcanic and subvolcanic units elsewhere (Little, 1982; Hoy and Andrew,

1988). The skarn-hosted nature of mineralization in the Rossland area was indicated as such by Dawson (1984) on a regional map, but the occurrence of skarns around the monzonite has received minimal attention in the past. Since gold is the major economic commodity in the Crown Point rocks, the occurrence may properly be referred to as a gold skarn (Orris et al., 1987; Meinert, 1988). Many gold-bearing skarns are known from British Columbia, some of them (e.g., the Merry Widow Fe skarn and the former gold-producing Dividend-Lakeview mine) partly replacing volcanic units (Ettlinger and Ray, 1988; Meinert, 1984). Au and Cu enrichment also occurs in skarns around porphyry systems (Sillitoe, 1988). The Rossland monzonite has a major-element composition akin to intrusives associated with West Coast Fe skarns (the latter have less K_2O and more Na_2O), and the Rossland Group rocks have their basaltic equivalents, which are lower in K and richer in Ti (Meinert, 1984).

The dominant style of mineralization at the Crown Point is similar to the classic Rossland ores, consisting of a very high tenor of sulfide (often `pure´ pyrrhotite on a hand-specimen scale) accompanied by a calc-silicate gangue. Chalcopyrite and marcasite are consistent minor components, and the gangue is largely species of clinopyroxene, amphibole and epidote. Besides the main stage of sulfide deposition, a volumetrically insignificant fraction of the rock comprises remobilized pyrrhotite and chalcopyrite, in discontinuous, mm-scale veinlets. A minor proportion of the skarn suite is predominantly oxide (magnetite) -rich, and both oxide and sulfide skarns carry locally-abundant zoned garnets. The skarns appear to be localized in zones of structural weakness cross-cutting the stratigraphy of the Rossland Group host rocks. Proceeding W.S.W. away from the monzonite contact, variably Cu-Au-enriched skarns appear to grade into a distal facies with lower Au contents

and relative enrichments in Ag, Pb and Zn. Three mineralization styles were recognized near the Crown Point, namely proximal (Au-Cu-Ag) and distal (Ag-Pb-Zn-Au) skarns in altered volcanics, and arsenical brecciated zones developed within susceptible host rocks (siltstones of the Rossland Group), the latter carrying a range of Au values comparable to the proximal skarns.

ANALYTICAL METHODS

The gold contents of the major sulfide components of the ore were estimated using AMS, an ultrasensitive variant of Secondary Ion Mass Spectrometry (SIMS). Only the most pertinent details are presented here, as a thorough description will be published elsewhere (Wilson et al., in prep.; see also Rucklidge et al 1990). Sawn offcuts of rock, roughly 40x25x5 mm in size, from which polished thin sections had been made for microscopic studies, were in turn polished to a fine finish and inspected in reflected light. Areas of the purest sulfides available were chosen for AMS analysis and removed from the offcuts with a diamond-edged core drill of 4 mm internal diameter. Sets of twelve targets, consisting of the polished cores plus associated standards and blanks, were loaded in turn into a sample-changing system (Wilson et al., 1984) linked to a high-current caesium ion source. The samples were optically aligned, and the negative secondary ions sputtered from the sample surface were extracted from target areas $\approx$0.5-0.8 mm in diameter. The 20 keV ions were energy- and mass-filtered, and introduced to the tandem accelerator. After charge-changing (electron stripping) at the accelerator terminal, electro-static selection of ions of charge state +6 (total energy 10.5 MeV) preceded final high- resolution mass and energy analysis. The filtered beam of $^{197}Au^{+6}$ ions was displayed on energy spectra collected with a silicon surface barrier detector, completely resolving gold from potential interferences (Fig. 2).

The primary reference standard for Au was a nickel sulfide concentrate of the SARM 7 precious-metal standard (Anonymous, 1975), containing 351 ppb Au. Instantaneous count rates for [197]Au on this standard varied with the chosen experimental conditions, averaging 1.76 $cs^{-1}ppb^{-1}$ on the last run. `Blanks´ provided by commercial graphite and natural Au-poor pyrite were equivalent to (at most) ≈1 ppb gold. Spatial cross- checks of data as a function of position in the sample holder addressed cross- contamination of Au-poor samples by richer samples and standards (≤0.1 % of the levels in adjacent samples). Thus the `safe´ dynamic concentration range for a given set of samples is limited to about 1000, and care was taken to avoid standards outside this range.

The analysis of the `background´ levels of gold in sulfides, at the ppb values obtained in this study, forms a continuum with related techniques which (with order-of-magnitude detection limits, L.J. Cabri, pers.commun. 1989) are; normal ion microprobes (0.3 ppm), proton microprobes (30 ppm), and wavelength -dispersive electron microprobes (300 ppm). The closest comparison can be made with conventional (secondary ion energy ≈20 keV) ion microprobes. Detection limits in AMS are often far lower than in other methods, due to the removal of potential interferences. This more than compensates for the fact that the absolute attainable efficiency will be lower than for a conventional ion microprobe, due to the additional losses incurred during charge-changing.

AMS RESULTS AND MINERALOGICAL FINDINGS

Mineralogical Notes on the Skarn:

The proximal skarn at the Crown Point incorporates massive sulfide reported to reach widths of 2.5 m (Carlyle, 1896; Drysdale, 1915) in the underground workings. Following the earlier literature, Little (1960) reported that the Crown Point ore is `a replacement along the contacts of diorite porphyry

intrusive into augite porphyry´, using the old nomenclature for Rossland Group

units. The present work confirms many of the mineralogical observations of

Thorpe (1967). For instance, arsenopyrite geothermometry (Kretschmar and

Scott, 1976) and related electron microprobe analysis of sulfides (Scott et

al., 1977) are consistent with formation temperatures near 400^0C for sample

001 (Table 1), collected about 200 m from the inferred position of the

monzonite contact. More generally, the sulfide appears to be formed during the

same thermal event as the host skarn, at temperatures $>350^0$C. Higher

temperatures, up to 600 ℃ or more, most probably applied immediately adjacent

to the intrusive (Thorpe, 1967; Meinert, 1984).

Prograde skarn mineralogy is dominated by andraditic garnet (often zoned,

with grossular-rich anisotropic rims), clinopyroxene (mostly hedenbergite >

diopside, ± minor johannsenite) and magnetite. The Rossland skarns occur, like

calcic iron skarns, in association with volcanic / volcaniclastic host rocks,

and show mineralogical kinship with the iron skarns, albeit with more Fe-rich

garnet and pyroxene compositions. Six microprobe analyses of magnetite from an

Fe-rich Rossland skarn averaged 0.32 weight percent MnO, with no detectable

Ti. Retrograde alteration (to chlorite and actinolite) is limited, consistent

with the postulated mesothermal origin (Meinert, 1983). Mineralogical

contrasts with iron skarns (Meinert, 1984) and with some gold skarns, such as

Fortitude, Nevada (Myers and Meinert, 1988) are in large measure due to the

absence of carbonate units in the host strata at the Crown Point.

Other minerals obey known mineral- chemical trends. For instance, electron

probe analysis of late tetrahedrite (Johnson et al., 1986) coexisting with

arsenopyrite reveals high Sb (no detectable As), and high Cu (no detectable

Ag). Some Sb resides in small inclusions of stibnite, which like tetrahedrite

postdates the major sulfides. Replacement of pyrrhotite by supergene marcasite (±minor pyrite) is locally extensive, and these secondary phases nucleated within coarse crystals and along grain boundaries, in part forming excellent `birds-eye' textures (Ramdohr, 1980, pp.592-612). The pyrrhotite, formula $Fe_{0.89\pm0.01}S$, tarnishes very rapidly when broken, a feature possibly related to the marcasite alteration. Trace levels of Au, Ag and Sb may exceed both the values in the host sulfide and normal levels for FeS_2 minerals (Fleischer, 1955). Possible mobility of gold and other metals in this transformation remains an unknown quantity, but the altered sulphides are markedly porous, consistent with an origin by iron removal, as suggested by Fleet (1978).

Location of the Gold:

Table 1 summarizes the results of AMS analyses on 86 points in sixteen 4-mm polished rock cores drilled from ten rock samples. Mean values of gold within individual pyrrhotite cores vary from 5 to 70 ppb, apparently unrelated to gold concentrations in the bulk rock. Analyses of coexisting sulfides indicate Au solubility in pyrrhotite $\leq$ chalcopyrite $<<$ arsenopyrite. The latter carries high (ppm) levels of gold, while the volumetrically -dominant pyrrhotite contains very little, averaging 32 ppb (ng/g) Au in 38 analyses. This accords with ion microprobe observations of major enrichments of Au in arsenopyrite (Cabri et al., 1989). The massive magnetites have very low ($\approx$10 ppb) Au contents, but show a consistent order-of-magnitude enrichment along thin fractures. This gold was probably introduced late in skarn formation (post-garnet and magnetite), contemporaneous with deposition of late silicates, oxide and trace chalcopyrite into fractures in the massive magnetite.

The AMS results complement the mineralogical data assembled by routine methods of ore microscopy and electron microprobe analysis. Given that the ore

paragenesis developed in one protracted episode of alteration and replacement, pyrrhotite appears to have a minimal capacity for dissolving gold under mesothermal conditions. The known propensity of arsenopyrite to carry higher values was noted earlier. The chalcopyrite analysed here takes the form of discontinuous veinlets in the pyrrhotite matrix. The low Au content, and absence of gold inclusions, does not support Thorpe's (1967) suspicion that Au and Ag were contained in chalcopyrite at the time of sulphide deposition, subsequently exsolving into gold or electrum blebs. Although the data seem to rule out this concept for the Crown Point area, it may be valid in the area of the War Eagle mine, where gold grains have been observed in and adjacent to chalcopyrite concentrations in material from the old mine dumps.

The data are insufficient for a quantitative metal balance of each style of mineralization, but generalized findings can be presented. The bulk of the gold resides in arsenopyrite and native gold, while most Ag in the distal skarns is probably hosted directly or indirectly by galena. Native gold in sample 070 was found by electron microprobe to contain 95.2 ± 0.6 weight percent gold, the balance being silver. The wide diameter of the probing beam suggests that analysed ppm levels of gold in arsenopyrite should be interpreted as minima. Observed gold in the minerals of samples 001 and 070 approximates bulk-rock levels, while deficits in other samples most probably represent a sampling problem, which would be overcome in a metallurgical study by preparation of larger numbers of polished sections. No other gold-bearing phases, such as tellurides, were identified. These, if they exist at all, can have only very minor significance. The mineralogical location of the gold, although not immediately applicable to the discussion of deposit genesis (next section) is relevant to metal recovery, and will be important to any future

attempts to revive gold mining in the Rossland camp. Operating on a spatial

scale intermediate between bulk-rock analysis and routine microprobe work,

this application of AMS compares favourably with the sensitivity of the

former, and provides a bridge to the micron-scale resolution of the latter.

GENESIS OF GOLD AT THE CROWN POINT

The zoning of metal and mineral species as a function of distance from the

Rossland monzonite, clearly observed in the 1988 field season, suggests that

gold mineralization in the Rossland South Belt is genetically related to this

intrusion. This conflicts with the inclusion of Rossland in Rock et al.'s

causative linkage of lamprophyric rocks with gold mineralization (Rock et al.,

1987; Rock and Groves, 1988a,b). A suite of alkalic minor intrusions is

prominent around the Crown Point and elsewhere in the area, and these are

apparently related to lamprophyres noted in the old workings of the major

Rossland mines. No significant mineralization was found in these felsic

alkalic rocks, which are quite abundant, forming low ridged outcrops in the

area. The dykes commonly contain prominent K-feldspar phenocrysts, are mostly

1-10 m thick, strike north-south (at a high angle to the Crown Point sulfide

zones), and are one of the most distinctive lithologies in the area. Drysdale

(1915) reported truncation of ore by these dykes. The dykes appear to be part

of the Coryell alkalic suite, of mid-Eocene age (the Coryell syenite has

yielded a zircon U-Pb age of 51.1±0.5 Ma: Carr and Parkinson, 1989). Drysdale

noted two ages of lamprophyres (Mesozoic and Tertiary) in the area, although

later dating confirmed only the latter (Fyles et al., 1973; Fyles, 1984). K-Ar

and Ar-Ar absolute ages in the area may be clouded by thermal overprinting and

resultant loss of ^{40}Ar (Thorpe and Little, 1973). A sample of fresh feldspar -

phyric pulaskite (pale syenite with ≈90 percent feldspars) assayed 3 ppb gold.

A feldspathic (?)dyke rock with syenitic clasts was found in poor outcrop in Rossland Group volcanics: it has elevated incompatible element contents, strong LREE enrichment, and mineralogic and major-element features consistent with calc-alkaline lamprophyres (Rock, 1987). The chemistry is such as to preclude admixture of 'pulaskite' and basalt, a field hypothesis for its origin. This rock is unmineralized, and assays 2 ppb gold. The only mafic lamprophyre near the Crown Point, found as loose float, assayed 10 ppb gold.

To conclude, this study supports earlier suggestions of a Mesozoic age for the primary gold mineralization (Thorpe, 1967; Emmons, 1937; Carlyle, 1896), developed in a island arc setting (McMillan et al., 1987; Ray and Spence, 1986), independent of the alkalic association of other precious metal deposits in the Cordillera (Mutschler et al., 1985). In the present case the alkalic rocks and gold share a common tectonic setting, but not a genetic origin (Kerrich, 1989). Local remobilization of pre-existing mineralization by dykes is indicated by field data in the Main Belt (Fyles, 1984), but was not observed on surface at the Crown Point. The Crown Point sulfidic rocks have definite similarities to documented Main Belt ore, but the latter display some differences, such as a greater content of pyrite, and association of gold with bismuthinite or molybdenite. Examination of material from the dumps of the War Eagle mine revealed auriferous sulphide veins cutting quartz-biotite hornfels exhibiting late chloritic alteration, suggesting that Main Belt deposits are also skarns. At the least, some Rossland gold is located in gold skarn associated with Mesozoic plutonism, and a direct link between the bulk of Rossland gold production and the Tertiary alkalic suite remains hypothetical.

ACKNOWLEDGEMENTS

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Figure 1. Location Map of the Rossland gold camp, in southeastern British Columbia, Canada.
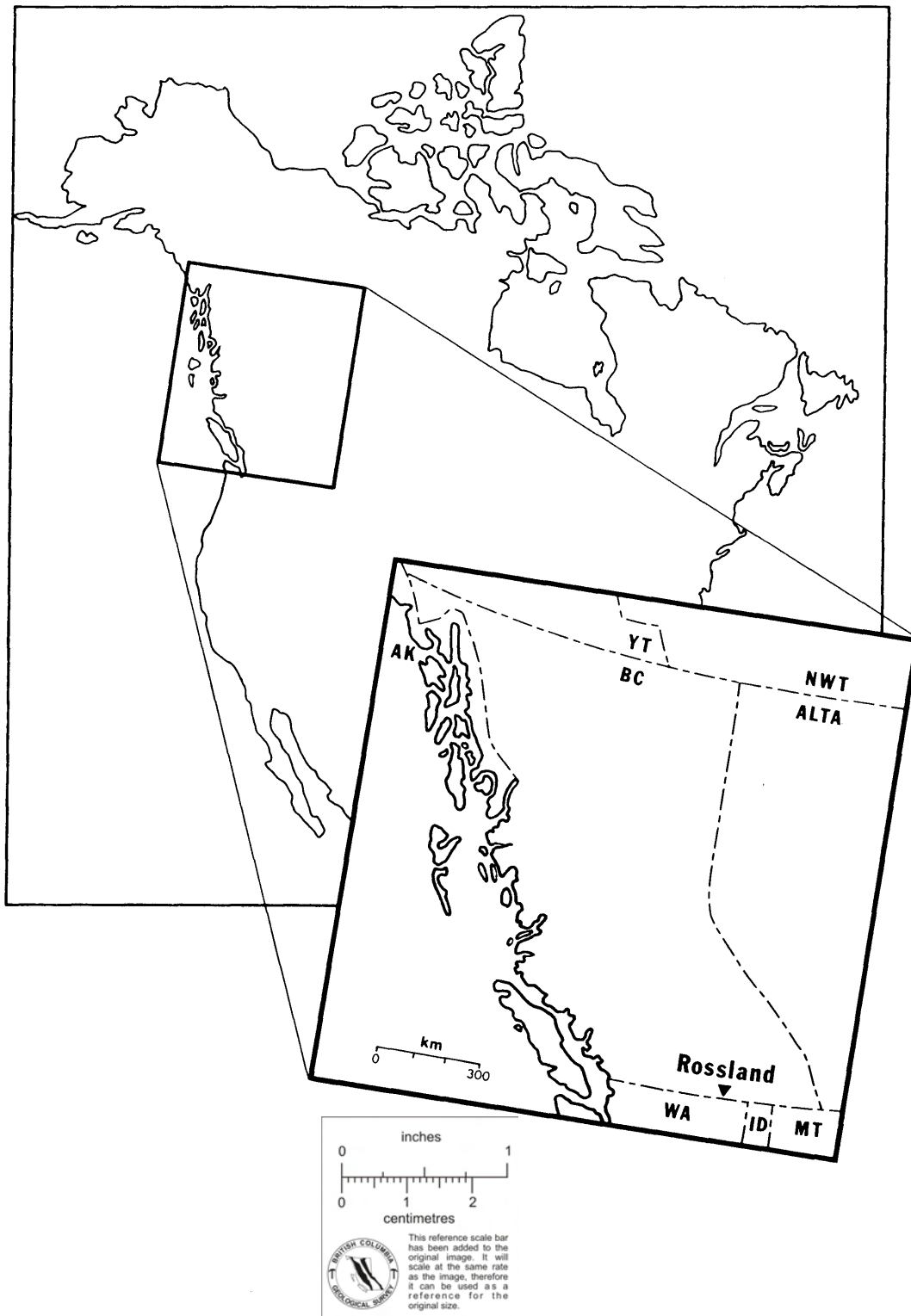
Figure 2. Superposed energy spectra illustrating the widely-differing concentrations of gold in three co-existing sulfides from sample 001. An aliquot of the bulk rock assayed 1800 ppb Au, while the mean concentrations in pyrrhotite, chalcopyrite and arsenopyrite estimated by AMS are $\approx$10, 100 and 3600 ppb respectively. The small, completely resolved peak at lower energy is ^{32}S in the form of ^{32}SH$^+$ derived from breakup of a progenitor cluster ion. These species have similar electric and magnetic rigidity to the gold. Such matrix-specific ions can be predicted and can be useful for preliminary tuning of the mass and energy spectrometers. This sulfur peak is not observed when analysing non-sulfides, such as magnetite, pure copper or graphite.
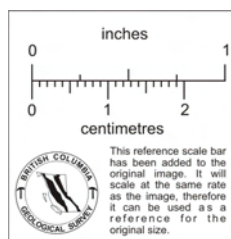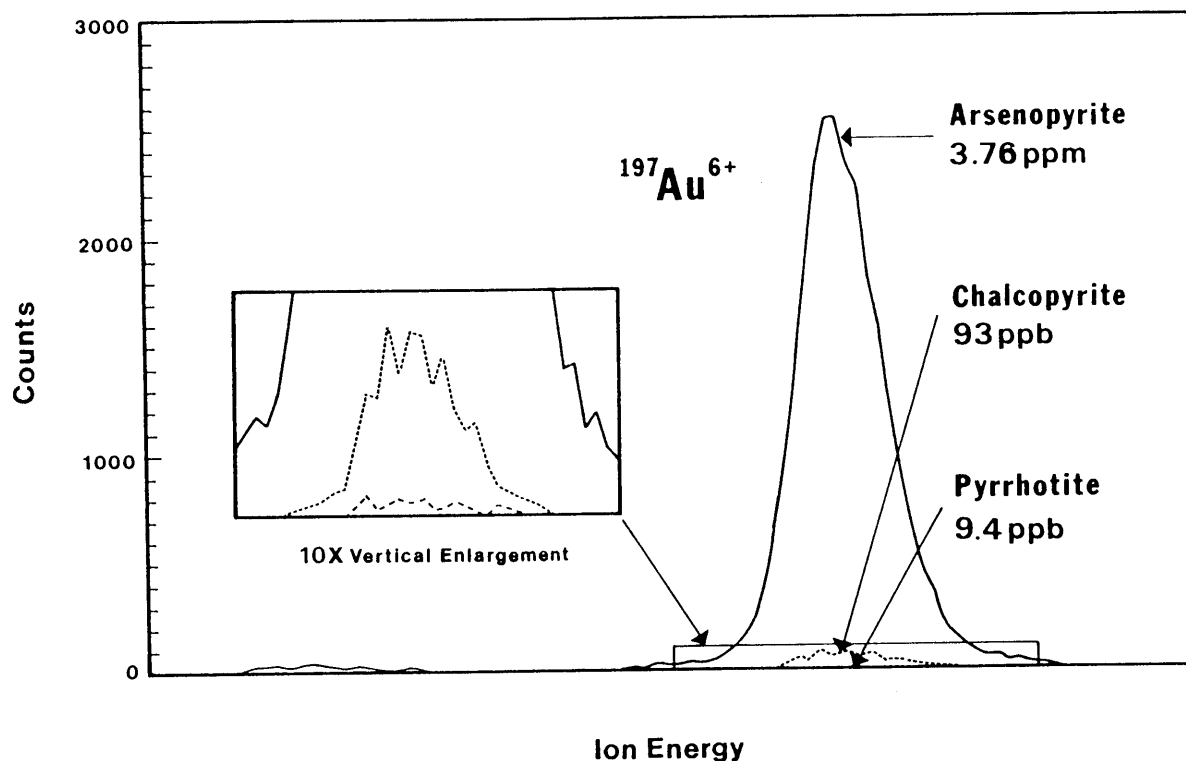
Table 1. Mineral and Whole-Rock Chemistry of Selected Samples.

		Mineral Data			*Whole-Rock Geochemistry*		
Sample	Mineral	------AMS Au(ppb)------			Au(ppb)	Ag	As
		Mean	Range	n			
044-1	Pyrr	8.1	4.3- 13.8	3			
044-2	Chalc	11	7.1- 15.7	4	23500	2.5	57
044-3	Marc	49	34 - 66	3			
050-1	Pyrr	28	24 - 29	3	4320	7.2	43
050-2	Chalc	27	25 - 28	2			
057	Pyrr	35	35 - 35	2	12300	4.4	44
074	Pyrr	42	37 - 43	2	200	0.4	121
087	Pyrr	5.7	2.2- 9.0	6	40	0.8	1000
001-1	Pyrr	9.1	4.5- 18.1	4			
001-2	Chalc	95	76 - 134	4	1800	110.2	8.73%
001-3	Asp	3580	2106 -6328	10			
070	Pyrr	68	36 - 100	10	840	2.8	1.08%
071-1	Pyrr	25	5.7- 41	8	26150	4.9	13.20%
071-1,2	Asp	2010	1498 -2334	3			
053	Mag-crack	170	38 - 247	6			
	Mag-matrix	15	10 - 24	8	2630	2.2	1
1181	Mag-matrix	3.4	1.1- 5.7	4	1760	0.6	17
	Mag-crack	15	9.1- 20.4	4			

A summary of 86 point analyses for gold in pyrrhotite, chalcopyrite, arsenopyrite, marcasite and magnetite samples. Au values in ppb by weight. Other values in ppm unless marked otherwise. The samples are grouped 3-fold into relatively low-arsenic sulfidic skarns, arsenical skarns and breccias, and magnetite skarns. Data on each point were collected over a period of 100 live seconds. See text for experimental details.