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GEOLOGICAL SURVEY

The occurrence of gold in siliceous Co-Cu exhalite deposits of the Blackbird mining district, Lemhi County, Idaho

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ABSTRACT

Gold is a significant constituent of a siliceous variety of Co-Cu deposits in the Blackbird mining district where it occurs in close association with cobaltite. The gold-rich lodes are interpreted to be syngenetic exhalative deposits that formed late in a period of submarine mafic volcanism. They differ from other stratabound Co-Cu lodes in the district in their lower content of chalcopyrite and pyrite-pyrrhotite, higher content of metachert, and lack of synsedimentary disruption structures. Gold-rich intercepts up to 20 g/t are in layers less than 1 m thick that are rich in Si-Fe-As-B-Bi-Co-Nb, and rare earth elements (REE). Assay data indicate a significant correlation of gold with Co and As and independence of Cu. Native gold grains ranging in size from <1 to 20 μm have been observed in most samples that assay more than 0.5 g/t; most of the gold is within or on cobaltite grains, and sub-μm grains of probable gold occur in metachert layers. The intimate paragenetic relationship of gold to Co-As-S minerals, distinctive geochemical signature, and association with mafic volcanic rocks and exhalite layers are guides for evaluating sediment-hosted targets for gold-rich zones.

INTRODUCTION

Gold has been an important part of the history of the Blackbird Co-Cu-Au mining district and may be important in its future. Gold first drew prospectors to the area in the 1890's, and from 1938 to 1941, 12,908 g of gold were recovered from 3,291 tonnes of ore (Bennett, 1977). At that time, cobalt drew a smelter penalty. The gold grade inferred from that production, about 3.9 g/t, is attractive today, but the low silver content of the ores (generally less than 2 g/t) is not an incentive. Exploration by Noranda Exploration, Inc. from 1978 to 1982 outlined significant gold values in some siliceous Co-Cu-Au lodes, and more recent investigations by Noranda and by the U.S. Geological Survey have clarified the nature and distribution of gold in the ores.

The Blackbird mine is located in the eastern Salmon River Mountains of Lemhi County, Idaho, about 35 km west of Salmon (fig. 1). Exploration and mining activity in the area have been episodic with most production during war years. Mining ceased in 1960 with the loss of government contracts and increased competition from foreign suppliers. Noranda Exploration, Inc. reevaluated the district from 1978 to 1982 and recognized the stratabound character of the ores and their association with specific styles of sedimentation and with mafic tuffaceous rocks (Hughes, 1983; Hahn & Hughes, 1984). In recent years, additional attention has been given to the occurrence of gold to provide guides for the selective mining and milling of that component. We report here some of the results of the Noranda programs and the results of geochemical and petrologic studies by the U.S. Geological Survey. Hundreds of samples were assayed for gold (detection limit 10 ppb), along with routine assays for Co and Cu. Complete chemical analyses for more than 40 major and minor elements were made by the U.S. Geological Survey on 324 samples, and several hundred polished thin sections have been studied. About 50 polished sections have been studied in detail in reflected light using 40X and 100X oil-immersion objectives to locate gold minerals and determine the paragenesis of gold relative to cobalt and copper sulfarsenide minerals.

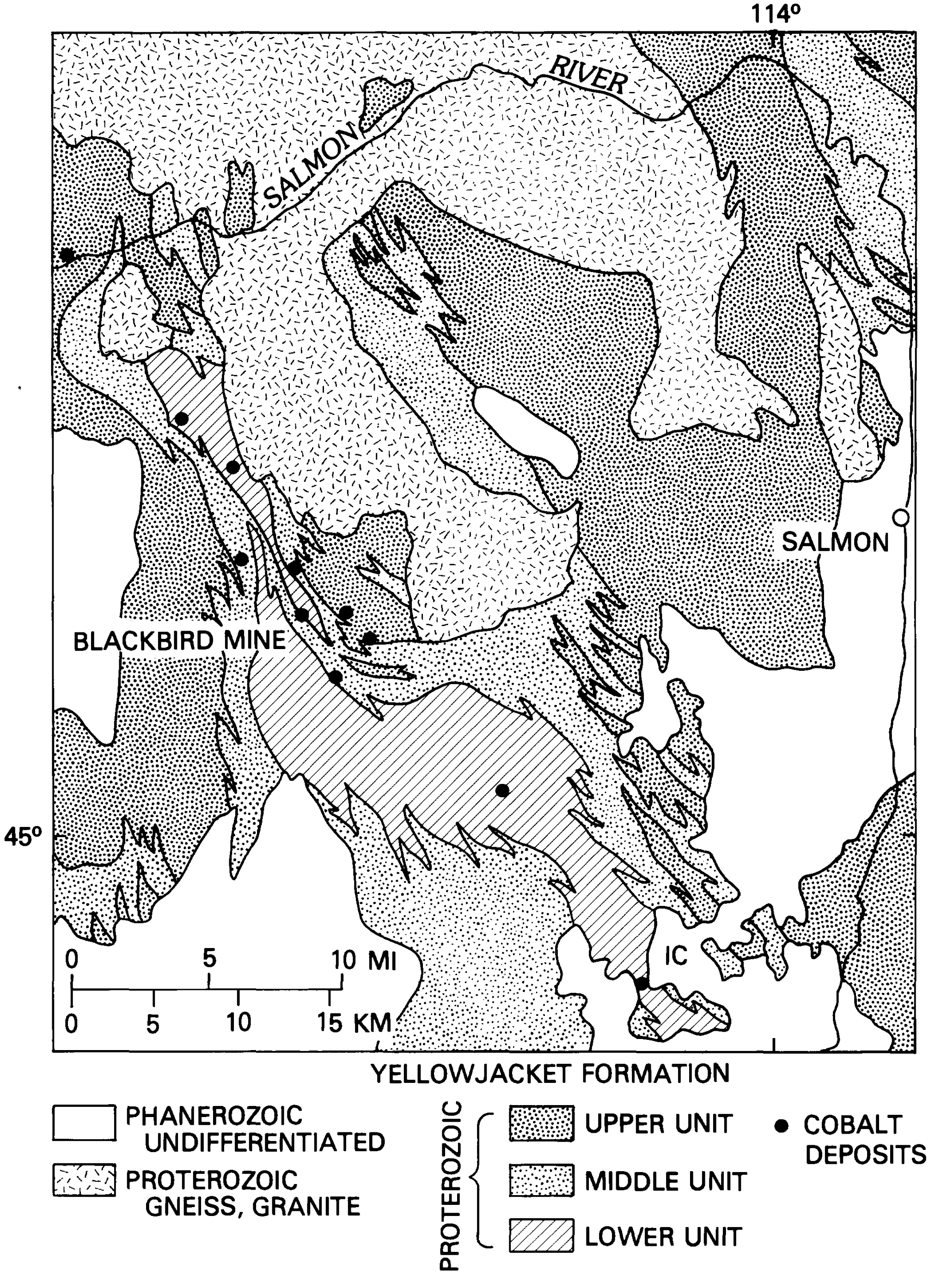

Figure 1. Location of the Blackbird mine, Lemhi County, Idaho. Generalized geology of the region is from Hahn and Hughes (1984).

This research was made possible by the cooperation and support of Noranda Exploration, Inc. Many Noranda geologists contributed to the descriptions and ideas reported here, and we thank especially G. J. Hughes, Jr. and M. D. Daggett for their contributions. Discussions with R. L. Earhart and R. I. Grauch, U.S. Geological Survey, also have been helpful.

GEOLOGIC SETTING

Cobalt-copper-gold deposits of the Blackbird district are stratabound within the middle part of the Middle Proterozoic Yellowjacket Formation (Hughes, 1983). The sequence that hosts ore comprises fine-grained clastic, mafic, volcaniclastic, and exhalative rocks; all are metamorphosed to greenschist grade. The volcanic rocks of alkali basalt composition are abundant only in a 10-km^2 area around the Blackbird mine. Lower Yellowjacket Formation strata, below the mineralized part of the section, are chiefly green-gray phyllite and siltite with some fine quartzite and impure carbonate rock (fig. 1). Sedimentary features (Hughes, 1983) suggest deposition as basin plain and distal turbidite deposits. The middle unit of the Yellowjacket Formation that contains the Co-Cu-Au lodes is about 1,200 m thick, comprised of several coarsening-upward cycles of argillite, siltite, and quartzite with distinctive biotite-rich interbeds interpreted to be aquagene mafic tuffs (Hahn & Hughes, 1984; Nash & Hahn, 1986b). The upper unit of the Yellowjacket is more than 1,000 m of quartzite with thick beds and planar laminations interpreted to have formed in a mid-fan or marine shelf environment. These rocks were metamorphosed at least three times: first by a submarine geothermal system contemporaneous with eruption of mafic volcaniclastic rocks and emplacement of coeval dikes, then by regional metamorphism to biotite grade, and last by contact metamorphism by a 1,370-Ma granitic pluton. All rocks in the mine area contain biotite, and some structural blocks contain garnet and chloritoid.

Recent mapping and exploration drilling indicate that more than 12 Co-Cu-Au lodes occur in the mine area (fig. 2) and that each is associated at meter scale with sequences rich in volcaniclastic rock. The mafic layers and associated lodes are in local subbasins created by a combination of synsedimentary growth faults and clastic wedges (Hughes, 1983). The ore lodes are rich in Fe-Si-Al-K, as well as As-Au-B-Bi-Co-Cu-REE. Diagnostic minerals are Fe-rich silicates (biotite, almandine, and chloritoid), tourmaline, and µm-sized grains of REE-bearing phosphate minerals, as well as ore minerals. Finely laminated and stratiform occurrences are interpreted to have formed as a chemical sediment, but cross-cutting fabrics in other varieties indicate redistribution and infilling during synsedimentary processes or during metamorphism (Nash and Hahn, 1986b). Silicate minerals are recrystallized but most ore components other than chalcopyrite seem to be little changed by metamorphism.

Ore deposits in the Blackbird mine area are mixtures of two varieties of stratabound mineralization, all in or adjacent to mafic volcaniclastic strata (fig. 2). Type one is syngenetic stratiform mineralization, best characterized by siliceous exhalite (metachert) beds interbedded with mafic rocks in the uppermost part of the mine stratigraphy. This finely laminated mineralization contains relatively lower amounts of chalcopyrite and pyrite or pyrrhotite than type two, and is known from six prospects penetrated by drill holes, notably at the Sunshine lode. The siliceous exhalite of the Sunshine, Horseshoe, Chelan, East Chelan, Toronto, and Ridgetop prospects (fig. 2) contains economically significant amounts of gold. Type two mineralization is

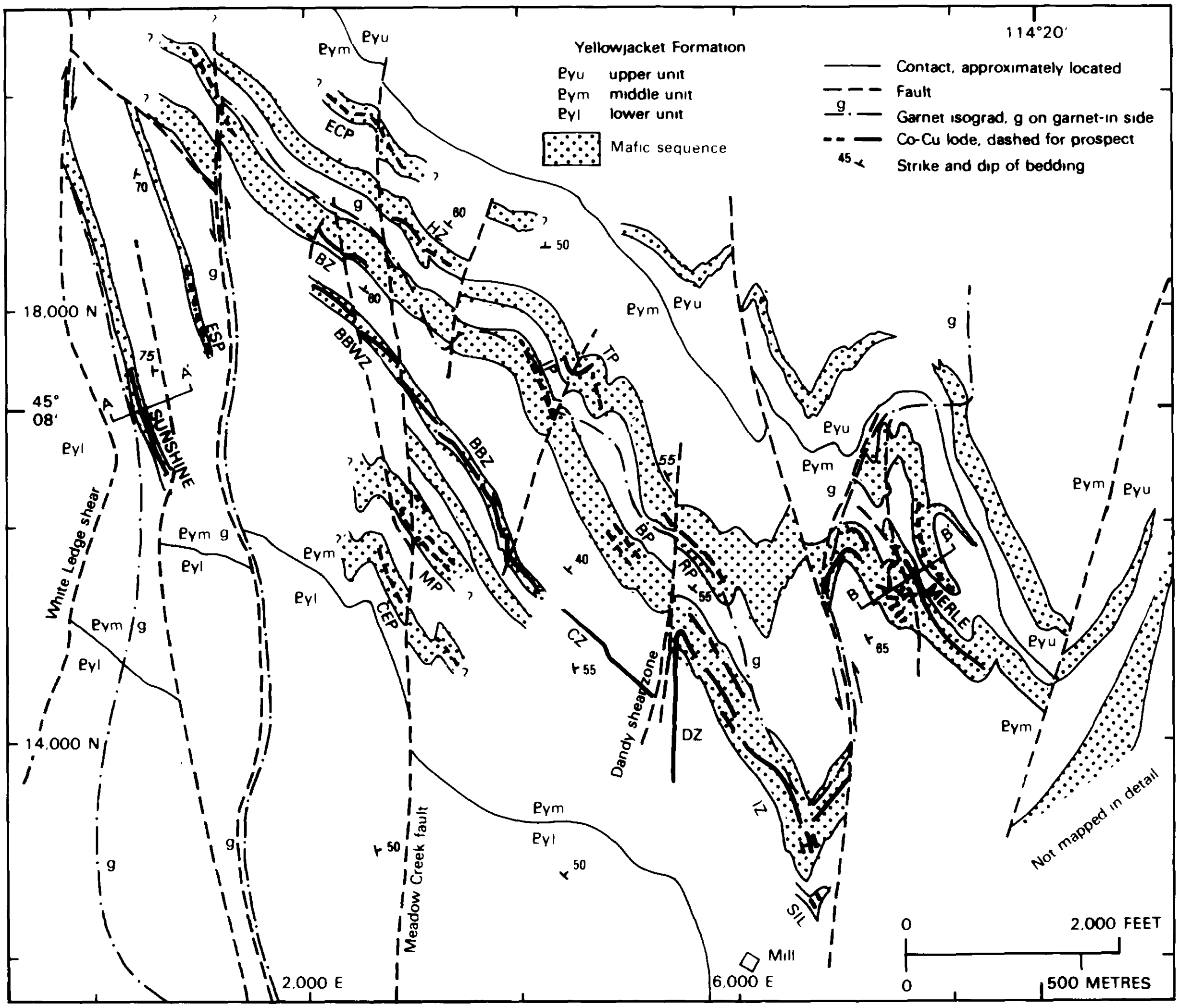

Figure 2. Geology of the Blackbird mine area showing location of CO-Cu-Au lodes and prospects (generalized from unpublished mapping by Noranda Exploration, Inc., 1982). Abbreviations: BL, Blacktail lode; BBL, Brown Bear lode; BBWL, Brown Bear West lode; BP, Buckeye prospect; CL, Chicago lode; CP, Chelan prospect; CEP, Catherine-Ella prospect; DL, Dandy lode; ECP, East Chelan prospect; ESP, East Sunshine prospect; HL, Horseshoe lode; IL, Idaho lode; IP, Iowa prospect; MP, Mushroom prospect; RP, Ridgetop prospect: SIL, South Idaho lode; TP, Toronto prospect.

epigenetic with ore and gangue minerals filling synsedimentary disruption structures (Nash & Hahn, 1986b) and rare veins. This type is most common in the lodes of the Blackbird mine as well as seven prospects that have been drilled; this ore type contains more chalcopyrite than cobaltite, about 3-10 percent pyrite or pyrrhotite, and less gold than type one. Type two ores occur lower in the section and contain significant amounts of siderite and coarse veinlike quartz rather than layered metachert. The Co-Cu-Au deposits of the mine area contain both types of mineralization. The stratigraphically lower deposits, such as in the Blackbird mine or Merle deposit, contain chiefly epigenetic type two mineralization with lesser amounts of laminated type one ore. The Sunshine lode is predominantly laminated type 1 ore, with a smaller amount of epigenetic (type two) ore at the north end.

SUNSHINE LODE

The Sunshine lode, located 1 km west of the Blackbird mine, is the best example of a gold-bearing siliceous exhalite. The lode crops out along a ridge, was tested by a shaft in the 1940's, and more recently has been cut by numerous trenches and diamond drill holes. Rocks in this structural block are of higher metamorphic grade than at the Blackbird mine and are characterized by biotite, garnet, and chloritoid. The metasediments are sheared and foliated in the vicinity of some major north-trending strike-slip faults (fig. 2), but at distances of more than about 30 m from the faults, the metasediments have granoblastic fabric and most sedimentary textures are preserved despite the metamorphism. The lode is a single layer 1-3 m thick that is conformable with enclosing biotite-garnet siltites and quartzites. The strike is N 10° W and dip is 70° E (fig. 3). The measured length of the lode exceeds 550 m; the south end is cut off by a fault and the north end is open down plunge.

The mineralized zone is generally rich in garnet (20-50 percent), biotite, and chloritoid compared with enclosing siltites and quartzites. The lode is highly variable in composition from layer to layer at millimeter or centimeter scale. Prominent chloritoid metacrysts as much as 2 cm long characterize some layers, whereas other layers a few millimeters to 10 cm thick are chiefly fine-grained, sugary quartz (metachert). Cobaltite is the chief constituent of some layers. Chloritoid varies from 0 to 30 percent in adjacent layers, and tourmaline is abundant in rare thin layers, some of which also contain fine grains of a phosphate mineral. Thin sections indicate that clastic quartz generally is not abundant. The layers of metachert are readily identified as chemical sediment, especially by the thin monomineralic layers and interlocked grains seen in thin section. However, the layers rich in biotite, garnet, and chloritoid reflect variable mixtures of volcaniclastic and iron-rich chemical sediment that are not easily distinguished megascopically or microscopically. The mineralogic variability is seen in chemical analyses of 0.3- to 0.6-m-long splits of core that have highly variable concentrations of rock-forming elements (Si-Al-Fe-Mg-K-Ti-B), as well as ore elements. The content of Co drops sharply to less than 0.05 percent at the bedding contact with footwall and hanging-wall metasediments.

Most of the Sunshine lode contains more cobalt than copper. Cobaltite is the dominant ore mineral and occurs as fine euhedral crystals, generally in layers that are conformable with layers of biotite or quartz. Pyrite content generally is less than 2 percent and chalcopyrite content less than one-half percent, although the north end of the lode contains more than 1 percent chalcopyrite and also has abundant coarse pyrite. The chalcopyrite-pyrite-

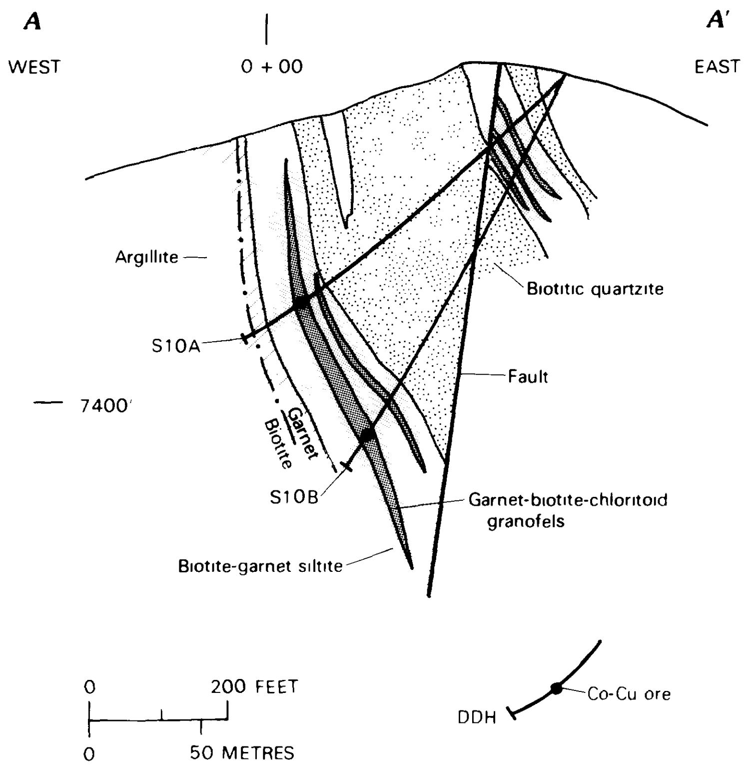

Figure 3. Generalized cross section of the Sunshine lode.

rich zone is on the flank of the main zone of cobaltite (fig. 4), and where chalcopyrite and pyrite occur with cobaltite, they engulf and vein it. The spatial and textural relations suggest that chalcopyrite and pyrite formed later than cobaltite or were remobilized a short distance during metamorphism.

Gold concentrations range from 10 ppb to 20 ppm (20 g/t) for samples of 0.3-0.6 m of core. Large bulk samples taken from trenches for metallurgical testing contain 1-6 g/t. Best gold grades are associated with layers in the lode that have abundant cobaltite (5 to more than 30 percent at centimeter scale) or abundant sugary quartz (metachert). Inspection of scatter plots of assays for Au, Cu, and Co show a strong linear relation between Au and Co and no systematic relation of Au with Cu. The correlation coefficient of Au with Co is 0.59, significant at the 99 percent level of confidence, whereas the correlation of Au with Cu is -0.05. We infer that the geochemical correlation of Au with As is also significant, based on the gold-cobaltite association and district-wide significant correlation of Co and As assays, but we do not have sufficient As assays from the Sunshine lode to compute a meaningful correlation coefficient for Au:As.

The distribution of gold at deposit scale is imperfectly known because drill holes are mostly more than 50 m apart and only a small part of the lode has been exposed by trenches. According to available assays and megascopic features, gold at grades of more than 0.5 g/t is present in layers less than 1 m thick in the middle part of the Fe-Si-rich exhalite layer and in roughly the central and thickest part of the layer with most abundant Si, Co, and As (fig. 4). Lateral zoning of metals does not seem to be systematic in the exhalite layer, but Mg-Cu-S seem to be more abundant (relative to Fe-Co-As) on the fringes of the lode. No footwall stringer zone has been identified below the Sunshine lode, but footwall chalcopyrite veinlets exist and contain very little Co or Au. Very little oxidation occurs in the Sunshine lode and nothing suggests that supergene processes have affected the distribution of gold.

GEOCHEMISTRY OF Co-Cu-Au LODES

Several geochemical features of the gold-bearing lodes are distinctive, although we cannot demonstrate that all of these features developed at the same time that gold was introduced. From both mineralogical and chemical studies (table 1), the lodes clearly are rich in iron, contained in the iron-silicates almandine, black biotite, and chloritoid (all with Fe/Mg of about 0.9) and to a lesser extent in iron sulfides such as pyrite, pyrrhotite, and chalcopyrite. Total iron content (expressed as Fe_2O_3) commonly exceeds 20 percent. Free silica as nonclastic quartz also is abundant at centimeter scale in the form of metachert layers. The enrichment in SiO_2 is not easily seen in the chemical analyses because they are for samples much thicker than beds, and, although clastic and hydrothermal quartz are texturally distinct in thin section, these types of quartz cannot be distinguished chemically. Some millimeter-scale layers contain as much as 30 percent tourmaline with grain size in the range 20-300 μm. Fine-grained phosphate mineral grains are erratically present in some samples of metachert and seem to be the residence of some scattered high concentrations of rare earth elements. The ore zones are notably rich in arsenic (to more than 5 weight percent in assays) and bismuth (to 530 ppm). Although the content of Ni ranges to 3,300 ppm, the Co:Ni ratio generally is in the range 5-100 in ore, and Ni is more abundant than Co only in some pyritic footwall samples. Concentrations of Pb, Zn, and Ag are very low (table 1).

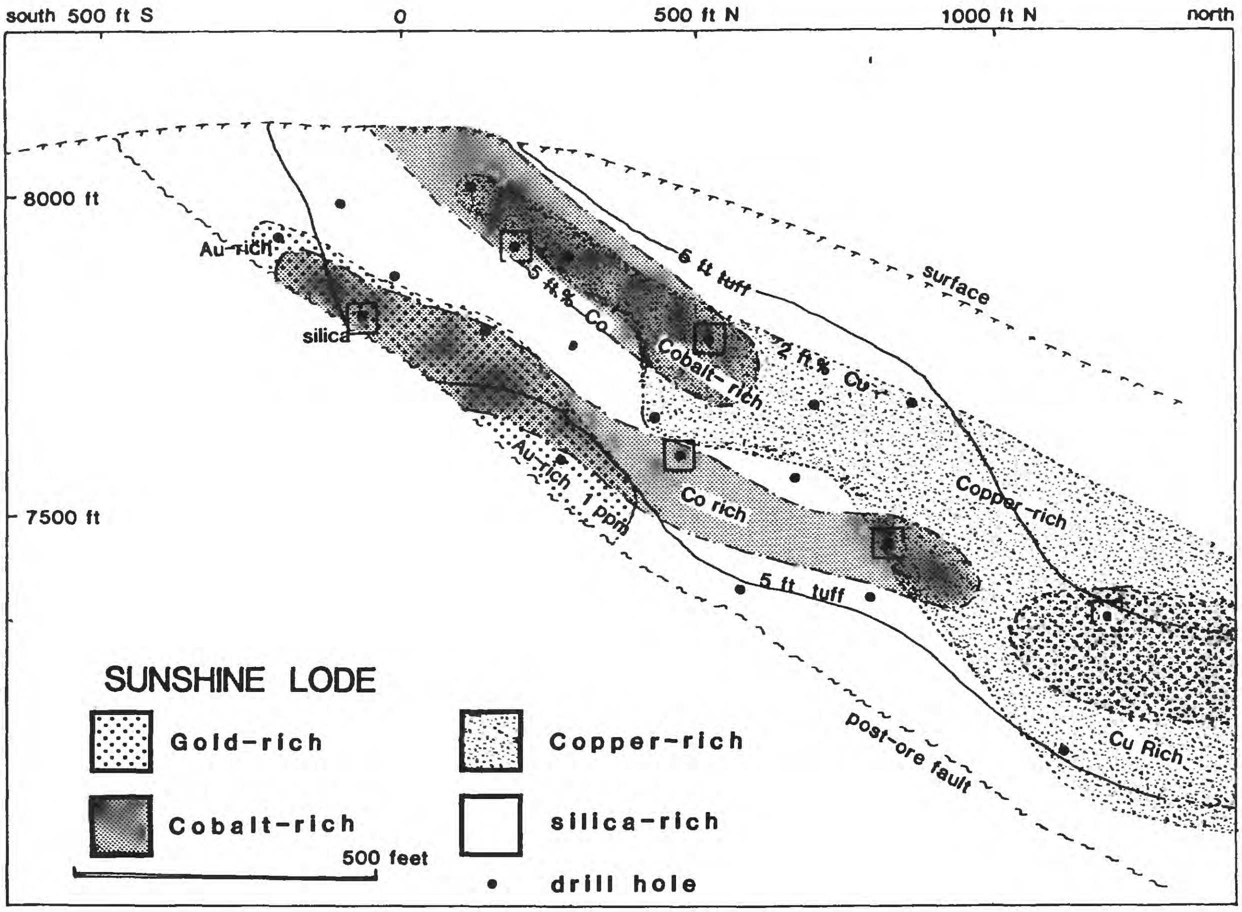

Figure 4. Generalized longitudinal section of the Sunshine lode showing the distribution of Co, Cu, and Au. Because the lode has very steep dip, this section is essentially the same as a plan view of the deposit as originally formed. Zones of richest Co and Cu are defined by the product of grade times thickness (ft %).

PETROGRAPHY OF ORES

We have examined hundreds of polished sections of ores from the Blackbird lodes and here emphasize in particular observations made on sections from parts of deposits known from assays to contain gold. We studied three to six polished samples cut from gold-rich intercepts in an attempt to see a good representation of assayed material. A key to the successful observation of gold grains has been the use of high magnification oil immersion objectives; with these optics, we generally could find gold that was not evident at lower magnification or without oil immersion.

Cobaltite ((Co,Fe)AsS) is the most abundant ore mineral in the siliceous lodes. In many of the samples chosen for study, cobaltite comprises more than 70 percent of the polished surface. It occurs as euhedral to subhedral equant crystals as large as 3 mm but generally less than 0.2 mm and often about 20 μm in size. Cobaltite is strongly ideoblastic and generally free of inclusions, although μm-size inclusions of pyrrhotite, chalcopyrite, and gold are observed. The cobaltite generally occurs in bands or layers that are parallel to compositional layering in the samples. Less commonly, it is present in siliceous veinlike zones, with or without pyrite or chalcopyrite. Cobaltite occurs as poikilitic inclusions in some porphyroblasts of garnet and chloritoid and is displaced by such porphyroblasts in other samples (Nash & Hahn, 1986b). Some loellingite is present with cobaltite. Because of its similarity in appearance to cobaltite, loellingite concentration has probably been underestimated. Loellingite tends to be somewhat elongate or bladed, and some large grains more than 5 mm in size are twinned. Arsenopyrite is present in some lodes but has not been recognized in samples from the Sunshine lode. We believe that loellingite and arsenopyrite are trace constituents of the siliceous lodes.

Chalcopyrite is common but not abundant in most samples other than those from the north end of the Sunshine lode. Most typically, it occurs as isolated crystal aggregates in silicate matrix, but it locally occurs with cobaltite and, in these situations, tends to enclose and embay smaller crystals of cobaltite. Chalcopyrite tends to be coarser than cobaltite, is always anhedral, and commonly contains abundant silicate or sulfide inclusions. Thin rims of chalcocite present around some grains of chalcopyrite are probably a secondary weathering effect.

Pyrite is a minor constituent of the siliceous lode ores, although, at a few localities at the north end of the Sunshine lode, more than 5 percent pyrite is present, generally as subhedral crystals 100-400 μm in diameter. At a few rare sites at the north end of the Sunshine lode, pyrite has prominent banding and consists of a mosaic of finely intergrown crystallites with variable anisotropy, a texture that is common in other deposits in the district and thought to reflect replacement of former coarse-grained pyrrhotite (Nash & Hahn, 1986b). Fine inclusions of pyrrhotite a few μms in size occur in the cores of some cobaltite and chalcopyrite grains.

Native bismuth is present as fine inclusions in cobaltite. Although it is nowhere abundant, it is a common and widespread trace constituent. The largest grain seen is 40 μm in diameter. Native bismuth is most abundant in samples from exploration trenches cut into the Sunshine lode, but has also been seen in drill-core samples.

Native gold has been observed in most polished sections cut from samples assaying more than 0.5 g/t. Gold grains range in size from less than 1 to 20 μm, and most are about 5 μm. About 70 grains were identified with confidence as native gold, and many additional grains resembling gold were seen, but their identification was hampered by their extremely fine grain size or by a lack of color or reflectivity comparison in the field of view. Isolated, highly reflective yellow grains in silicate matrix could be gold, pyrite, or chalcopyrite. The great majority of the reliably identified gold grains are in contact with cobaltite, consistent with the previously described association of Au with Co.

Gold occurs in several textural settings. Most grains are on cobaltite grain boundaries (fig. 5A) or in microveinlets that cut cobaltite (fig. 5B), and some are present as inclusions within cobaltite. A few grains of gold are associated with chalcopyrite grain boundaries and a chalcopyrite-cobaltite mutual grain boundary. Metachert layers contain isolated grains less than 1 μm in diameter that seem to be gold. Judging from petrographic and assay results, one-third to one-half of the gold in the Sunshine deposit may occur in metachert bands.

The amount of gold observed in polished sections is roughly proportional to assays and seems to account for gold in these samples of ore. We have no evidence to suggest the occurrence of any other gold-bearing minerals. Gold grains associated with cobaltite in the Sunshine lode are relatively coarse (1-20 μm) and seem to be coarser than gold with cobaltite from the Horshoe and other exhalite prospects that are in rocks of lower metamorphic grade. Metallurgical bench tests by Noranda Mining Co. indicate better recovery of the coarser gold; thus, the higher metamorphic grade of the Sunshine lode area may be a factor in the economic recovery of gold in milling.

DISCUSSION

Structural, lithologic, and geochemical data for the Sunshine lode and several other Co-Cu-Au deposits suggest formation as a chemical sediment (exhalite) intimately mixed with mafic volcaniclastic sediment and minor siliciclastic sediment. Within these siliceous exhalites, a close spatial and temporal association of cobalt, arsenic, and gold occurs. Gold and copper do not have a significant spatial association at any scale. Multiple stages of metamorphism have affected the lodes and could have modified some textural relations of gold, but we suspect that gold has moved less than a few millimeters in most places. Detailed textural relations of gold at μm scale indicate that most gold precipitated somewhat later than cobaltite or with quartz. Large differences in the proportions of biotite, quartz, cobaltite, tourmaline, and other minerals in individual beds at millimeter scale suggest that the gross composition of the hydrothermal fluids or depositional conditions fluctuated dramatically. Some hydrothermal pulses rich in Co, As, or Si also were rich in Au. The codeposition of these elements may have been caused by periods of rapid cooling or other physical changes on the sea floor. The structural and sedimentary record indicates a dynamic system of turbidite deposition, active growth faults, local clastic wedges, slump folding, volcanic eruptions, and dike intrusion (Hughes, 1983; Hahn & Hughes, 1984). We believe that the combination of these processes created a hydrothermal system that discharged onto the sea floor after leaching metals from both siliciclastic and volcaniclastic sediments in the Yellowjacket section. The siliciclastic rocks would be a likely source for some elements (Si, K, B, As?), whereas mafic volcanic rocks would likely yield the Fe, Bi, Co, Cu, and S seen in the ores. The increased abundance of Au and siliceous exhalite in the youngest tuffaceous sequences in the district might be a reflection of accumulated mafic volcaniclastic material in the basin, of tectonic quiescence favorable for deep hydrothermal circulation, and of chemical sedimentation without dilution by terrigneous clastics.

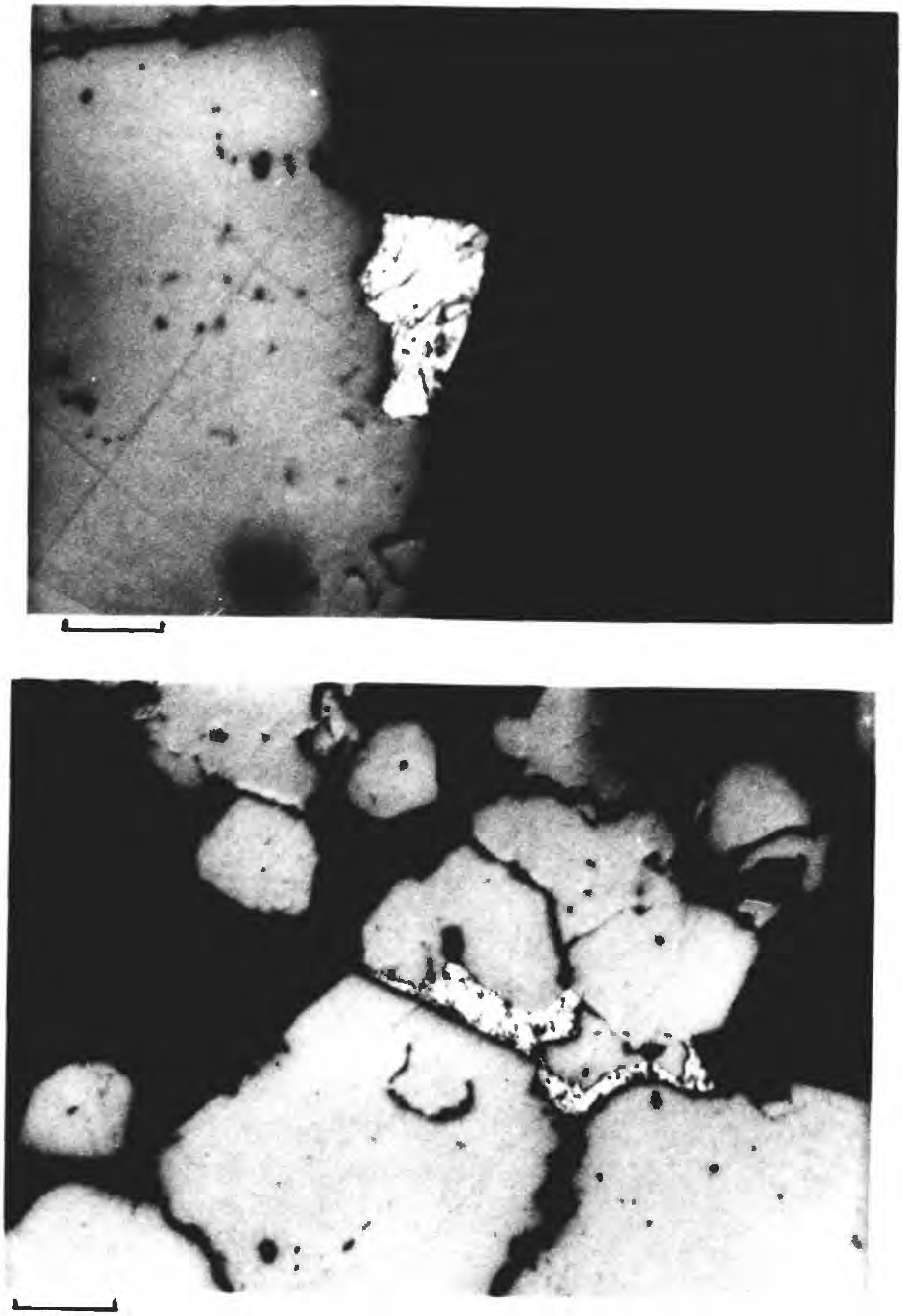

Figure 5. Photomicrographs of gold and cobaltite in the Sunshine lode; reflected light, oil immersion. (A) Coarse grain of gold on boundary of cobaltite crystal, overlain by quartz (black). Bar scale is 10 μms. (B) Fine-grained gold in μm between cobaltite crystals, enclosed in quartz. Bar scale is 10 μm.

The intimate association of several types of Co-Cu-Au lodes with mafic volcanic rocks in the Blackbird district is strong evidence for a genetic link between the two (Nash & Hahn, 1986b). This association at district, deposit, and bed scale is a fundamental exploration guide because the mafic rocks can be mapped in outcrop and logged in drill core. Geochemistry of soils or rocks can confirm the visual estimate. Clastic sequences lacking mafic volcanic rocks are not likely to contain cobalt-gold deposits as known in the Blackbird district.

Gold-rich zones of the Blackbird deposits clearly differ from most stratiform base-metal deposits in clastic rocks, such as in the Belt Supergroup of Montana, Idaho, and British Columbia. The most important diagnostic differences are the mafic volcanic rocks and mafic geochemical suite at Blackbird. Also, the Blackbird gold zones differ from numerous greenstone-hosted gold deposits of the world (Boyle, 1979) in the much smaller amount of vein or layered quartz, and absence of sodic or carbonate alteration. Yet we believe that synvolcanic processes advocated for the leaching, transport, and deposition of gold in some submarine volcanic systems (e.g. Hutchinson, 1982) operated at Blackbird.

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TABLE 1.--Summary of chemistry of rocks from the Sunshine deposit

Element	Sunshine ore zone n	min	max	geom. mean	Footwall + Hanging wall n	min	max	geom. mean
Major elements in weight percent								
SiO_2 %	15	47.9	68.3	58.2	86	40.1	82.8	61.1
Al_2O_3 %	15	10.0	17.6	12.6	86	4.5	19.1	12.9
$FeTO_3$ %	37	6.8	37.2	18.5	86	8.0	27.3	14.6
FeO %	37	3.7	25.8	13.8	90	6.2	27.3	11.6
MgO %	37	0.61	5.9	2.1	86	0.73	9.4	1.6
CaO %	37	0.01	1.1	0.24	86	0.03	8.3	0.18
Na_2O %	37	0.01	0.13	0.04	86	0.10	2.2	0.13
K_2O %	37	0.04	6.9	1.5	86	0.05	7.8	3.4
TiO_2 %	37	0.02	1.0	0.28	86	0.10	4.6	0.53
P_2O_5 %	37	0.01	0.66	0.08	86	0.03	0.97	0.09
MnO %	37	0.01	0.22	0.07	86	0.01	0.34	0.05
Stot %	37	0.08	7.9	0.77	90	0.01	2.2	0.03
CO_2 %	37	0.02	3.2	0.29	90	0.02	3.8	0.29
Minor elements in parts per million (ppm)								
As	37	50	70,000	6,555	90	7	37,000	40
Ag	37	1.5	6	1.8	90	1.5	6	1.6
B	37	15	1,940	70	90	15	600	57
Ba	37	2	380	117	90	6	590	260
Bi	37	7	530	19	90	7	30	8
Ce	37	4	2,200	17	90	2	200	14
Co	37	10	66,000	142	90	2	3,400	86
Cr	37	8	320	56	90	11	400	59
Cu	37	6	50,000	588	90	1	17,000	230
Eu	37	2	26	2.1	90	1.5	5	1.6
La	37	1.5	1,000	34	90	1.5	110	18
Mo	37	1	5	1.8	90	1	7	1.9
Nb	37	1	17	11	90	1L	100	3.7
Nd	37	2	830	8.9	90	2L	90	6.3
Ni	37	13	3,300	141	90	5	200	20
Pb	37	2	120	15	90	2	640	29
Sc	37	1.5	19	8.3	90	3	33	11
Se	37	0.7	300	9.8	90	0.1	7	0.5
V	37	5	140	34	90	13	280	47
Y	37	5	220	51	90	4	250	2
Yb	37	1	22	5.7	90	1	31	2.8
Zn	37	5	76	13	90	9	120	29
Zr	37	17	424	172	90	66	507	212

Explanation: $FeTO_3$, total iron as Fe_2O_3; L, less than value shown. Results from samples of footwall and hanging-wall strata are combined because no significant difference occurs in the content of most elements. Major elements determined by X-ray fluorescence spectrometry, J. E. Taggart, analyst, except for samples of ore, in which 22 of 37 samples had more than 25 percent Fe or high As content and could not by analyzed by the XRF method, and values by induction-coupled plasma spectrometry (ICP) are reported for most major elements; FeO determined by potassium dichromate titration; minor elements and some major elements in ore samples determined by ICP, Paul Briggs, analyst; Se determined by hydride generator and atomic absorption spectrometry; B and Zr determined by ICP following fusion in Na_2O_2 and total sample solution.