Canadian Mineralogist
Vol. 23, pp. 423-430 (1985)

A GOLD–SPHALERITE ASSOCIATION IN A VOLCANOGENIC BASE-METAL-SULFIDE DEPOSIT NEAR TILT COVE, NEWFOUNDLAND

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ABSTRACT

Stratiform base-metal sulfides are hosted in mafic volcanic rocks of the Cape St. John Group near Tilt Cove, Newfoundland. The pyrite - sphalerite - chalcopyrite - native gold occurrence overlies ophiolites of the Snooks Arm Group that carry typical ocean-floor mineralization. Textural observations and neutron-activation analysis of mineral separates indicate that gold is preferentially associated with sphalerite. Tectonic setting, stratigraphic relationships and mineral associations suggest that the sulfides are remobilized sea-floor hydrothermal exhalations originally deposited in an environment of diverging plates.

Keywords: gold, sphalerite, Tilt Cove, Newfoundland, base-metal sulfide, ophiolite.

SOMMAIRE

On trouve des amas stratiformes de sulfures des métaux de base dans des roches volcaniques mafiques du groupe dit de Cape St. John, près de Tilt Cove (Terre-Neuve). L'association pyrite - sphalérite - chalcopyrite - or natif recouvre le massif ophiolitique du groupe de Snooks Arm, porteur de minéralisation typique des fonds marins. D'après les observations texturales et les résultats d'analyses de concentrés par activation neutronique, l'or est associé à la sphalérite. Le milieu tectonique, les relations stratigraphiques et les associations minérales font penser que les sulfures sont le résultat d'une remobilisation d'exhalations hydrothermales marines déposées dans un milieu de plaques divergentes.

(Traduit par la Rédaction)

Mots-clés: or, sphalérite, Tilt Cove, Terre-Neuve, sulfures de métaux de base, ophiolite.

INTRODUCTION

As indicated by mine-production statistics, the recovery of gold from base-metal sulfide ores is of considerable economic significance (Hogan 1977). Careful optical studies of such ores usually record the occurrence of isolated grains of native gold (for example, Roy 1961). However, it has not been established whether gold is preferentially associated with specific sulfide minerals in most classes of base-metal deposits. In general, the frequency of occurrence of grains of native gold is too low to permit statistically reliable assessment of spatial relationships with major sulfide minerals. Direct analysis of sulfide minerals for gold usually presents serious problems. Instrumental methods, such as electron-microprobe analysis, have too low a sensitivity, whereas many methods that hold great promise, such as secondary-ion mass spectrometry, have not yet been widely employed. In principle, the separation of mineral concentrates by physical means should allow routine determination of gold by a variety of analytical methods. However, many ores are too fine grained and carry such an intimate mixture of sulfides that separation of pure mineral concentrates is not feasible. If preferential associations of gold with specific sulfide minerals do occur, the implications for ore genesis and recovery of metals may be significant.

A stratiform occurrence of base-metal sulfides in mafic volcanic flows near the base of the Cape St. John Group, Tilt Cove area, Newfoundland, was found to be characterized by a high frequency of grains of native gold. Pyrite, sphalerite and chalcopyrite comprise the main minerals that occur as replacements and impregnations of basalt and as layered ore. The spatial association of native gold with sulfides, as seen in polished section, suggests a preferential association with sphalerite and chalcopyrite. Analysis of mineral concentrates further suggests that sphalerite is the major host of gold in this occurrence.

REGIONAL GEOLOGICAL SETTING

The mineralization of interest is located approximately 1.5 km northeast of Tilt Cove on the Burlington Peninsula in northern Newfoundland. It is hosted in mafic volcanic rocks of the Cape St. John Group of Silurian age, which overlies Lower Ordovician Snooks Arm pillow lavas and oceanic sediments, and is adjacent to the Betts Cove ophiolite suite (Fig. 1). The age of the Cape St. John Group relative to the Snooks Arm Group was challenged by Dewey & Bird (1971), but considerable field evidence in favor of a younger age has been marshalled by Neale *et al.* (1975) and DeGrace *et al.* (1976). The geological sketch-map shows the Betts Cove - Tilt Cove area, including the boundary of the Snooks Arm and Cape St. John Groups, together with the sulfide locality

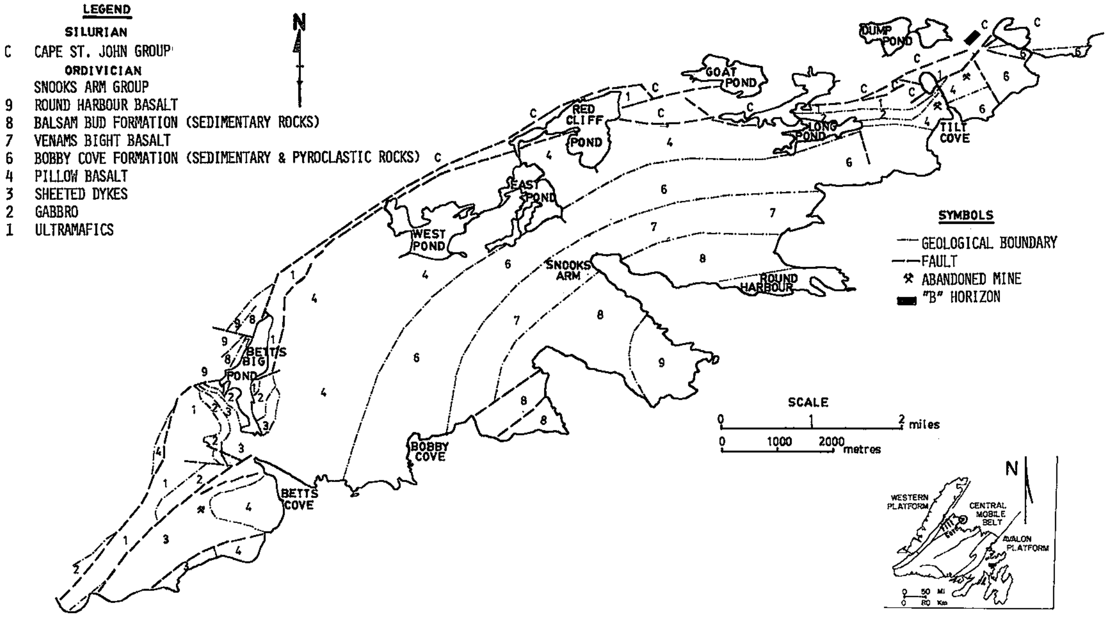

FIG. 1. Geology of the Snooks Arm Group between Betts Cove and Tilt Cove, showing the contact with the Cape St. John Group and the location of the mineralization ("B" Horizon) examined in this study (after DeGrace *et al.* 1976).

referred to here as the "B" horizon. Both groups lie within the Dunnage Zone (Williams 1979), which includes remnants of the Lower Paleozoic oceanic domain, the Iapetus Ocean.

The basal formation of the Snooks Arm Group includes mafic and ultramafic rocks exposed at both Betts Cove and Tilt Cove. Together with overlying mafic volcanic and sedimentary rocks of the upper formations, the Snooks Arm Group has been interpreted as oceanic crust overlain by an island-arc suite (Strong 1977). Recent studies of the basalts of the upper Snooks Arm Group suggest that they formed in an oceanic island or marginal basin setting (Jenner & Fryer 1980) and that an early island-arc setting is unlikely.

The Cape St. John Group was described by Neale *et al.* (1975) and DeGrace *et al.* (1976) among others. Mafic flows and associated pyroclastic rocks, felsic volcanic rocks and quartz–feldspar crystal tuff, along with both subaqueous and subaerial sedimentary rocks, are the major lithic components of the group. Felsic volcanic rocks are more prominent toward the top of the sequence and are absent from the area under study. Strong (1977) included the Cape St. John Group among the post-subduction island-arc assemblages generated after subduction had stopped.

LOCAL GEOLOGY AND PETROGRAPHY OF HOST ROCKS

Rocks of the Cape St. John Group that host the sulfides are variolitic, pillowed, mafic volcanic flows. They are conformably overlain by medium- to coarse-grained calcareous sedimentary rocks, agglomerates, subaerial vesicular basalt and, locally, fine-grained, laminated argillite. These rocks strike northeast, with dips from subhorizontal to 40° northwest. The mafic volcanic rocks host two sulfide zones. One is cherty banded oxide (magnetite) iron-formation, here identified as the "A" horizon, and the other is a sulfide-rich zone termed the "B" horizon. Both zones are stratiform, up to 2 m thick and about 150 m in strike length, with the "A" horizon lying about 3 m above the "B" horizon.

The host rocks exhibit a lower-greenschist-facies assemblage of metamorphic minerals. Chlorite (variety penninite) and quartz with minor plagioclase, calcite and opaque minerals form a typical assemblage. Brown chlorite is also observed. A Jensen plot (1976; Fig. 2) classifies these rocks as magnesian tholeiites. In comparison with the composition of ocean-floor basalts as given in literature compilations (Manson 1967), the host rocks are strongly depleted in K, depleted in Ca and enriched in Na. Bearing in mind alkali mobility, these rocks are regarded as spilitized magnesian tholeiites.

THE "B" HORIZON

The "B" horizon is of interest because of its relatively high gold content, as revealed by chemical analysis and by reflected-light microscopy. The "A"

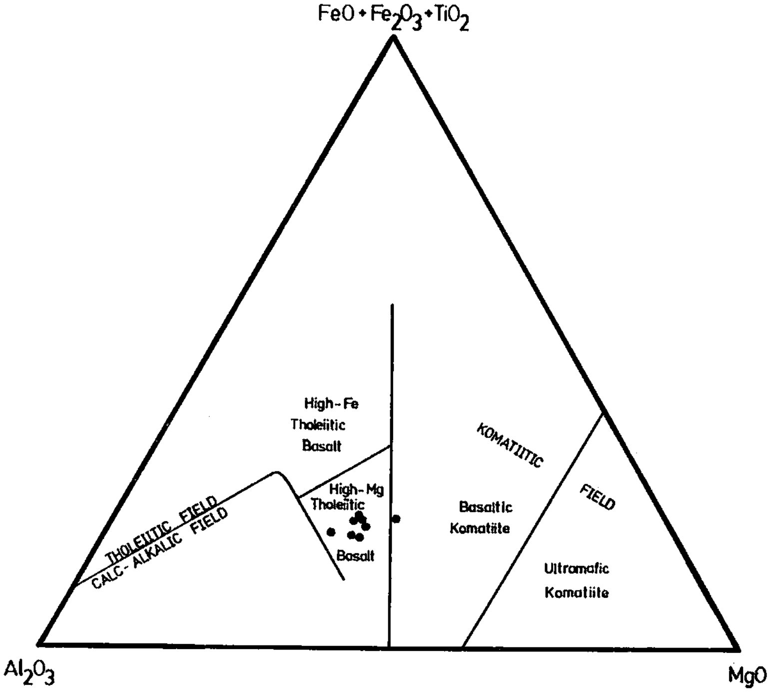

FIG. 2. Classification of the host basalts of the "B" Horizon according to the Jensen (1976) cation plot.

horizon, banded iron-formation, contains much lower gold contents. Some geochemical data for the "A" horizon may be found in Hurley (1982), but no further discussion of the "A" horizon is presented here. The "B" horizon is an auriferous stratiform pyrite - sphalerite - chalcopyrite zone in variolitic, pillowed mafic volcanic rocks and pillow-breccia. Typical mineralization is approximately 75% sulfides and 25% silicate minerals.

The sulfides exhibit two principal modes of occurrence. The most prevalent is as replacement of silicate material; for example, whole pillows or fragments in pillow breccia have been partly replaced by sulfides. In fragmental rocks, much sulfide occurs as a matrix surrounding rock fragments, as seen in Figure 3. Another textural feature of sulfides is layering in which sphalerite-dominated and pyrite-dominated layers occur in juxtaposition, as illustrated in Figure 4. Sulfide layering is more prevalent toward the top of the "B" horizon.

The stratiform nature of the "B" horizon and the banded nature of some of the sulfides are suggestive of deposition from submarine, hydrothermal fluids exhaled in part onto the sea floor and in part emplaced and localized in brecciated or otherwise permeable rocks where hot fluid - rock reactions have resulted in replacement of rock fragments. The localization of much sulfide as matrix to fragments

FIG. 3. Sulfide occurs mainly in the matrix of a fragmental basalt in which it surrounds, impregnates and partially replaces rock fragments. Field of view is 2.5 cm.

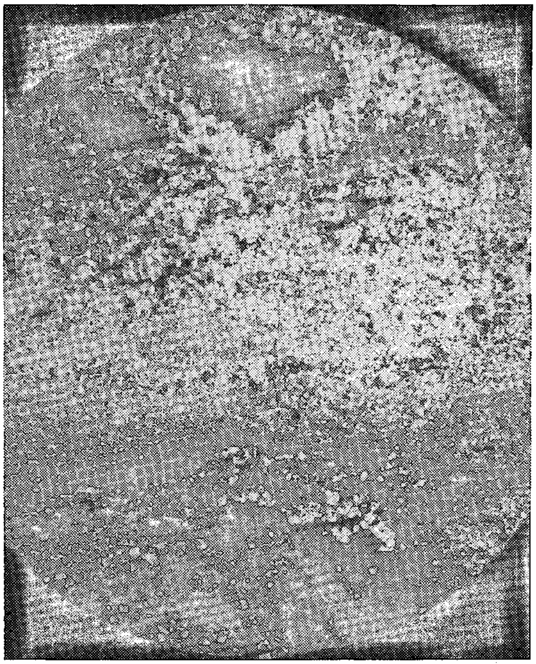

FIG. 4. Layered sulfides with a thick pyrite–sphalerite band characterized by a fine-grained, intimate mixture of minerals above a narrower band of massive sphalerite with a few large pyrite crystals. Field of view is 2.5 cm.

indicates that this sulfide was emplaced before the loss of rock porosity by burial compaction.

ORE MINERALOGY AND TEXTURES

Sulfides

The mineralization ranges from approximately 30 to 95% sulfide, of which pyrite, sphalerite and chalcopyrite are the principal minerals, with minor covellite and native gold. Covellite and native gold, although minor phases, occur in nearly all polished sections. The average modal proportions of minerals, as estimated from polished section, is pyrite 50%, sphalerite 20%, chalcopyrite 5%, and silicates 25%.

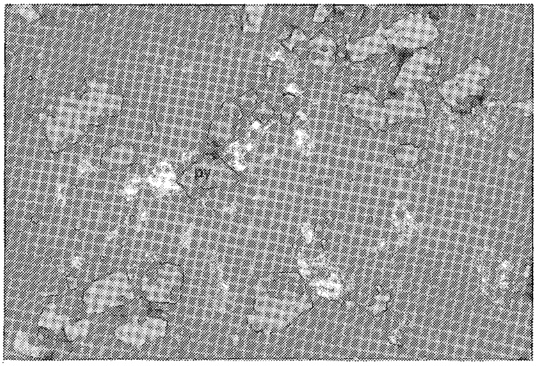

FIG. 5. Subhedral pyrite in massive sphalerite band showing embayment of pyrite by sphalerite. Width of photo: 1 mm.

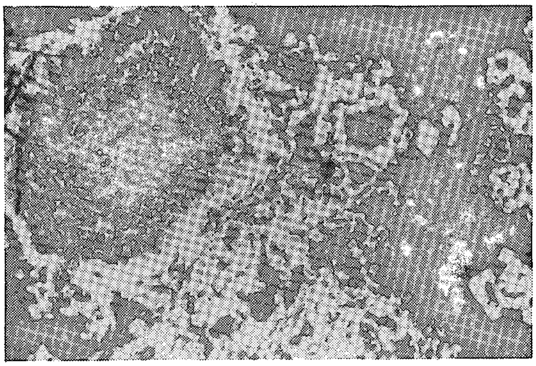

FIG. 6. Possible relict colloform texture suggestive of a primary chemical precipitate. Width of photo: 2 mm.

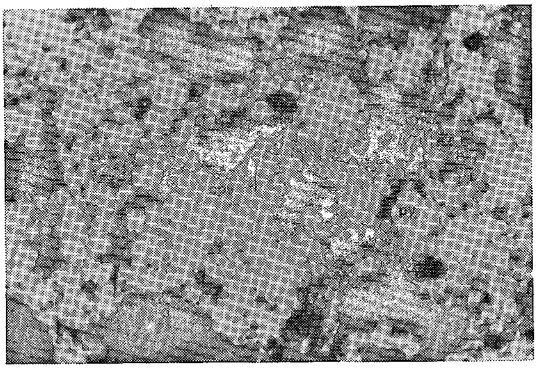

FIG. 7. Possible framboidal pyrite. Width of photo: 1 mm.

The host rocks are in the greenschist regional metamorphic grade, and primary textural features have undoubtedly been modified by this metamorphism. If the layering represents bedding, then the very fine-grained intimate mixture of pyrite and sphalerite in the thick band in Figure 4 suggests that periods of simultaneous precipitation of these minerals alternate with periods of accumulation of predominantly one phase. Alternatively, sphalerite may replace pyrite, as suggested by embayments of pyrite in sphalerite-rich bands (Fig. 5). Preservation of primary textural features is not common, but a possible relict colloform texture of concentric pyrite–chalcopyrite bands is illustrated in Figure 6. Some spheroidal pyrite grains, possibly pyrite framboids, were also noted (Fig. 7). Colloform textures have been interpreted as the result of chemical precipita-

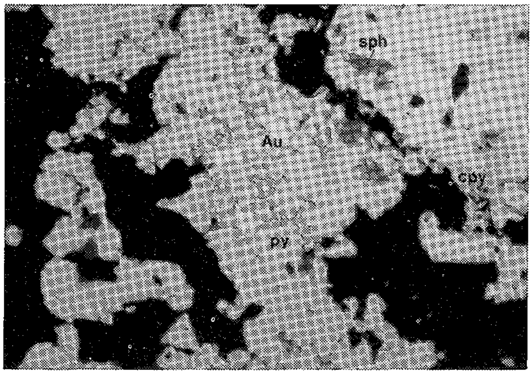

FIG. 8. Anhedral cluster of gold grains hosted by pyrite. Width of photo: 1 mm.

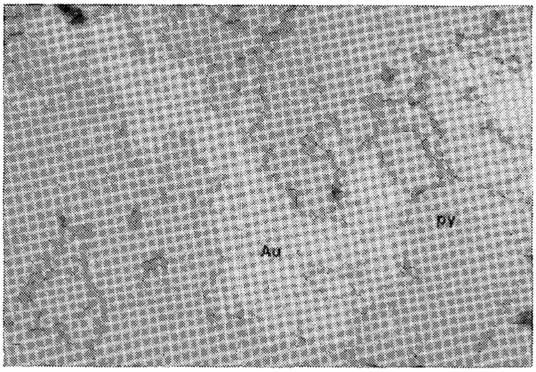

FIG. 9. Planar crystal faces on a grain of gold reflects pyrite morphology. Width of photo: 0.2 mm.

tion (Chen 1978). Some chalcopyrite occurs as tiny blebs in sphalerite, suggestive of exsolution, but most of the chalcopyrite occurs as a discrete phase.

Gold

Thirty-six grains of native gold ranging from 0.01 to 0.2 mm in maximum dimension were observed in a suite of seven polished sections. Gold grains are mainly anhedral, except in some cases in which the mineral occurs within pyrite and assumes a subhedral morphology. Figure 8 shows a large cluster of anhedral gold grains in pyrite. Occasional planar faces on the gold grains, as seen in Figure 9, a × 5 enlargement from Figure 8, reflect crystal faces of pyrite. The texture suggests either that gold was introduced into pyrite when primary porosity was still significant, or that gold and pyrite were subject to mutual recrystallization in response to burial and regional metamorphism, with pyrite generating crystal faces against the very malleable gold. The gold-in-pyrite texture seen in Figure 10 is suggestive of fracture filling and implies that gold is later in the paragenetic sequence than pyrite.

Typical textural relationships between gold, sphalerite and chalcopyrite are illustrated in Figure 11. Here a field of sphalerite encloses a spherical mass of pyrite that in turn hosts a core of chalcopyrite and sphalerite with two grains of gold. This close spatial relationship of gold with sphalerite and chalcopyrite is common and typical. Gold also occurs in close spatial association with chalcopyrite and sphalerite (Fig. 12), and the gold may have replaced chalcopyrite. Gold is often hosted by sphalerite (Fig. 13).

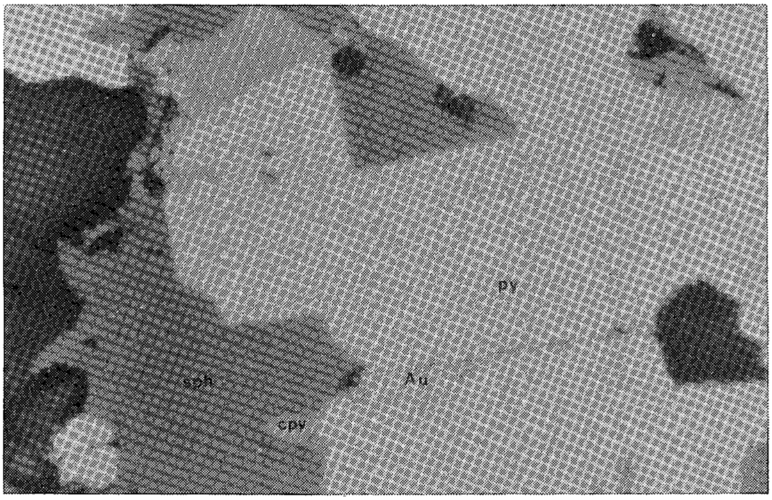

FIG. 10. Gold filling fracture in pyrite, indicating emplacement of gold after crystallization of pyrite. Width of photo: 0.2 mm.

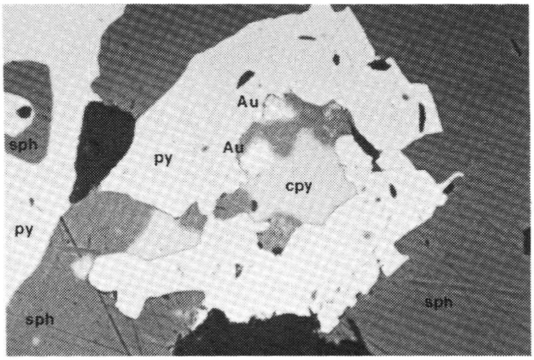

FIG. 11. Spatial association of gold with sphalerite and chalcopyrite in a pyrite host. Width of photo: 0.2 mm.

A total of 75% of the gold grains are in contact with pyrite (and other minerals), and 86% are in contact with sphalerite and chalcopyrite. The modal abundance of pyrite is 50%, or twice as high as that of sphalerite plus chalcopyrite. The percentage of grain-boundary contacts is weighted for the modal abundance of the minerals to provide a basis for comparison of associations. Thus, the percentage of gold grains with a gold–pyrite boundary per unit volume of pyrite is 75/50 or 1.5% compared to 86/25, *i.e.,* 3.4% for gold grains with a sphalerite or a chalcopyrite boundary. This comparison suggests that spatial association of gold with sphalerite and chalcopyrite is much stronger than with pyrite.

As the textural relationships between gold, sphalerite and chalcopyrite are somewhat ambiguous, other means of assessing relationships between gold and the major sulfides were taken.

GOLD CONTENT OF MINERAL CONCENTRATES

Sulfide-rich mineral concentrates were produced by subjecting crushed and sized (100–200 mesh range) material to magnetic separation in a Frantz Isodynamic Magnetic Separator. Although there is a good contrast in magnetic susceptibility between weakly magnetic pyrite and chalcopyrite and the more magnetic sphalerite, the very fine grain-size and intimate intergrowth in much of the sulfide material prevented the separation of pure mineral concentrates. Many composite grains, particularly silicate–sulfide grains, appeared in various fractions. However, selection of relatively pure starting material allowed some concentrates of up 90% purity to be obtained. The approach taken was to determine the mineral proportions in concentrates by counting grain mounts and to evaluate the gold concentration of the concentrate as a function of its mineral content.

Gold was determined by epithermal instrumental neutron-activation. The procedure involved irradiation of samples of about 500 mg weight in a cadmium-shielded site in the McMaster Nuclear Reactor for 1 megawatt hour (nominal total neutron flux of epithermal neutron, 1×10^{12} neutrons•cm^{-2} •s^{-1}). Following a five-day decay period, the 412-KeV gamma ray from the 64.7-hour ^{198}Au was counted on a Series 89 Canberra multichannel gamma spectrometer coupled with a coaxial intrinsic germanium detector (Aptec Engineering).

Gold concentration is strongly correlated with percentage of sphalerite in the concentrates. Figure 14 is a plot of gold concentration *versus* percentage of sphalerite for all determinations; the correlation

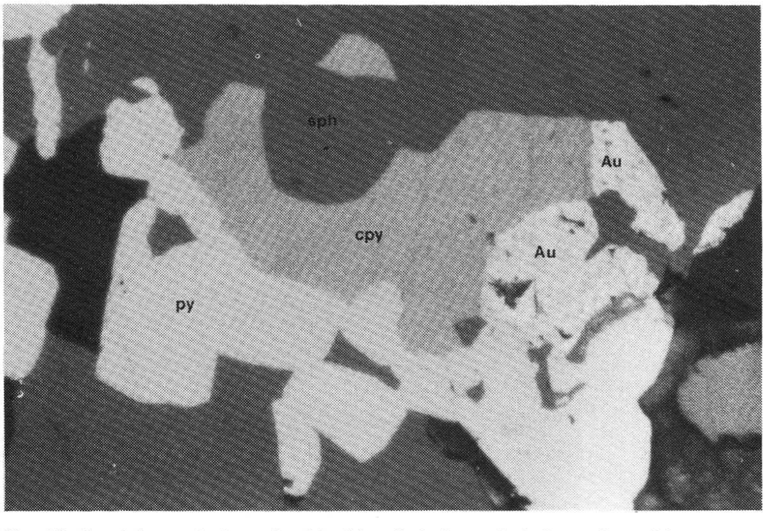

FIG. 12. Spatial association of gold with sphalerite and chalcopyrite, with apparent replacement of chalcopyrite by gold. Width of photo: 0.2 mm.

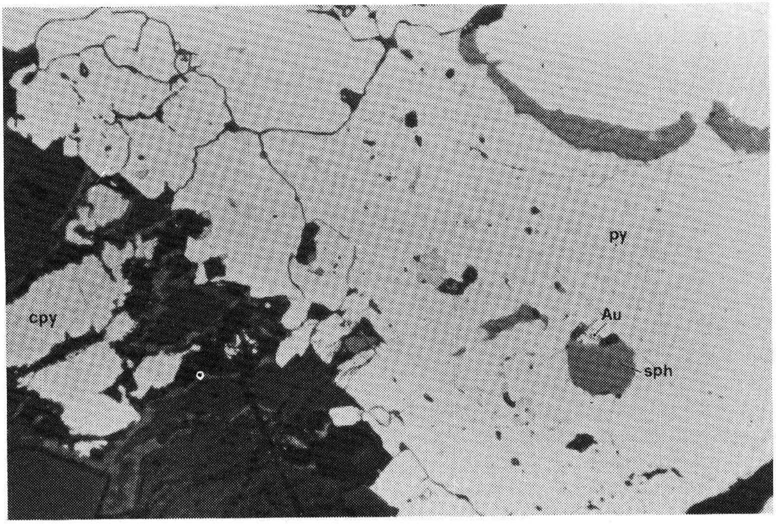

FIG. 13. Gold hosted in sphalerite. Width of photo: 0.5 mm.

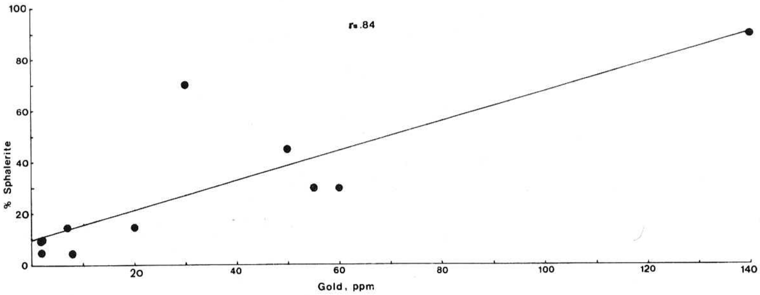

FIG. 14. A plot of gold concentration against proportion of sphalerite (in %) in mineral concentrates, showing a strong positive correlation and indicating that gold is concentrated in sphalerite.

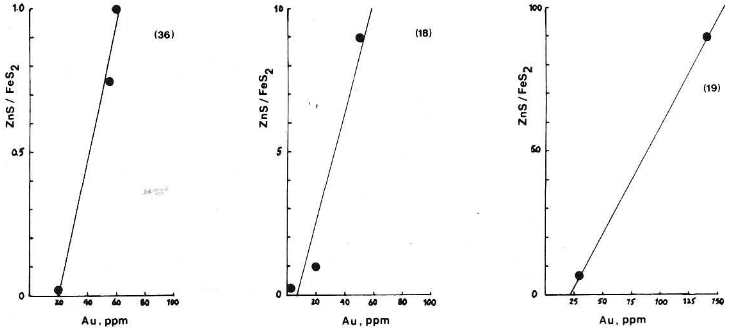

FIG. 15. A plot of gold concentration against sphalerite/pyrite ratio for mineral concentrates of differing mineral proportions produced from the same specimen.

coefficient, $r = +0.84$, is significant at a 1% probability level when tested against a Student T distribution. There were no other significant correlations.

A second approach was to analyze mineral concentrates produced from the same sample, which had very large differences in the proportions of various minerals. Different proportions of minerals were produced from the same initial starting material by varying the tilt and slope setting on the Frantz Separator. Multiple concentrates were prepared for three samples, and the results are shown in Figure 15. The concentrates were comprised of at least 60% pyrite plus sphalerite, with silicates and chalcopyrite making up the remainder. Chalcopyrite generally was less than 5% of any concentrate. Analysis of silicate-rich concentrates generally yielded gold contents of about 1 ppm. As many of the sulfide-rich concentrates contain 50 ppm or more of gold, silicates are essentially a dilutant in the mineral concentrates. Thus, the sphalerite-to-pyrite ratio is an effective measure of the relative importance of the main sulfide constituents as contributors to the total gold content of these concentrates. In all cases there is a marked increase in gold content with increasing sphalerite/pyrite ratio, indicating that a higher content of gold is associated with sphalerite than with pyrite.

Evaluation of chalcopyrite as a gold concentrator by direct analysis was not possible, as concentration of nonmagnetic chalcopyrite could not be achieved. The majority of concentrates contain 5% or less chalcopyrite.

ORE GENESIS

The mineral assemblage of the "B" horizon, with a predominance of pyrite and sphalerite, and lesser chalcopyrite, is typical of sulfide deposits formed in an ocean-floor environment near diverging plate-margins. Studies of such mineralization have recently shown that high gold content may occur in association with sphalerite (Hekinian *et al.* 1980). Thus, the "B" horizon has a metal association recognized in ocean-floor hydrothermal exhalations. However, as noted by Strong (1977), the host rocks of the Cape St. John Group are interpreted to have formed in a post-subduction island-arc setting. Thus, the metallogeny and inferred tectonic setting do not seem compatible.

A possible explanation of this seeming inconsistency is that the "B" horizon represents metals remobilized from ocean-floor sulfides hosted in the underlying ophiolites of the Snooks Arm Group. At Tilt Cove, about 1.5 km to the southwest, the relevant "B" horizon stratigraphic level and the ophiolitic member of the Snooks Arm Group are separated by a stratigraphic interval of only 150 m. Typical ocean-floor deposits in the Tilt Cove area are represented by the Tilt Cove mine.

ACKNOWLEDGEMENTS

We are grateful to Newmont Exploration of Canada Limited for property access, and to R.T. Kusmirski for assistance in the field. The work was financed in part by an NSERC grant to the junior author.

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Received June 26, 1984, revised manuscript accepted April 11, 1985.