Skarn Mineralogy in the Bolivar district

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Executive Summary

Bolivar skarn mineralogy reinforces the recommendation based upon field examination that the district has significant exploration potential. Mineralogically, Bolivar is a fairly typical Cu±Zn skarn with highly saline and metal-rich fluid inclusions. This is consistent with a moderate tonnage but high grade system. Mg skarn is developed from dolomitic protoliths and in addition to magnesian silicate minerals such as forsterite and diopside there is abundant magnetite and bornite in addition to chalcopyrite. The magnetic character of this skarn may be useful in geophysical exploration for blind targets and the high Cu:Fe ratio of bornite may have metallurgical implications for the Mg skarn portions of the Bolivar system.

Introduction

This report summarizes observations about Bolivar skarn mineralogy based upon 20 samples collected during a three day field visit, April 17-19, 2005. Observations and recommendations from that visit were summarized in a previous report dated 20 April, 2005 and will not be repeated here. As required by Canadian Investment Regulations, Dia Bras has my permission to use this report for their own purposes, for their website, and for release to the public. Features described in this report are illustrated in a PowerPoint presentation (Fig. 1) that can be downloaded at:
http://www.science.smith.edu/~lmeinert/MeinertPubs/BolivarMeinertTSPhotos.ppt
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Sample Descriptions

Drill hole under La Increible breccia pipe

28-60 Chilled margin of quartz-bearing granodiorite porphyry dike against quartz-absent andesite (Fig. 2). Contact is cut by chlorite veins with outer margins of zoisite and envelopes of chlorite (Fig. 3).

28-186 Coarse-grained marble (Fig. 4) with wispy, poikiolitic, skarnoid garnet (Fig. 5) with inclusions of wollastonite and diopsidic pyroxene. Minor rosettes of wollastonite (Fig. 6) and vesuvianite also are present. Clear garnet rims on skarnoid garnet are evidence of infiltration of later metasomatic fluids (Fig. 5).

28-218 Skarn marble contact (Fig. 7) with coarse-grained, fibrous bustamite (Figs. 8,9) separated from marble by wollastonite (Fig. 10). Marble has locally been replaced by coarse-grained, euhedral quartz and calcite with disseminated pyroxene (Fig. 11).

15 South drill hole from skarn through several andesite dikes and into granodiorite

93-32 Garnet endoskarn vein with pyroxene envelope cutting altered porphyritic andesite (Fig. 12). The garnet vein center is massive and has obliterated the igneous texture of the host rock but this texture is clearly preserved in the pyroxene envelope and beyond (Fig. 13). Individual pyroxene veins have Kspar ± biotite envelopes (Fig. 14) and beyond the limit of the veins individual phenocrysts (particularly mafic minerals) have been replaced by hydrothermal biotite (Fig. 15).

93-35 Garnet-pyroxene skarn cut by yellowish-green garnet veins and then sphalerite-epidote veins and breccia patches (Fig. 16). Fluid inclusions are abundant in pyroxene (Fig. 17) and clearly indicate the saline, metal-rich nature of the hydrothermal fluids with multiple daughter minerals including halite (NaCl), sylvite (KCl), chalcopyrite, and sphalerite. Sphalerite deposition is associated with retrograde alteration of early garnet-pyroxene skarn to a mixture of epidote and chlorite (Fig.18). This process commonly is associated with brecciation (Fig. 19) which may be a consequence of vapor-phase transitions (boiling). Some evidence for this is seen in the fluid inclusions within epidote which are low salinity (no daughter minerals) and vapor-rich (Fig. 20).

93-89 Chilled granodiorite contact with red-brown garnet-pyroxene skarn (Fig. 21). The garnet is fine-grained with interstitial pyroxene, possibly indicative of a siliceous host rock (Fig. 22). Fluid inclusions are abundant in pyroxene (Fig. 23) and clearly indicate the saline, metal-rich nature of the hydrothermal fluids with multiple daughter minerals including halite (NaCl), sylvite (KCl), chalcopyrite, and sphalerite.

93-92 Contact of equigranular granodiorite with brown garnet skarn (Fig. 24). The granodiorite is equigranular and quartz-rich (Fig. 25) except near the contact where it is finer grained and has a shear fabric (Fig. 26). Garnet is red-brown in hand specimen and in thin section (Fig. 27).

9 South drill hole from skarn into granodiorite

96-60 Pale green pyroxene skarn cut by garnet-pyroxene-sphalerite-chalcopyrite vein (Fig. 28). Pyroxene skarn is relatively fine grained (Fig. 29) giving the rock a hornfels texture in hand specimen. All minerals in the vein are much coarser grained than the early skarn (Fig. 30). As is typical of hydrothermal garnet, the garnet is complexly zoned and birefringent, indicative of rapid growth under rapidly changing conditions (Fig. 31). Fluid inclusions are abundant in pyroxene and contain multiple daughter minerals indicative of highly saline, metal-rich hydrothermal fluids (Figs. 32, 33).

96-61 Green garnet skarn (Fig. 34) cut by birefringent, green garnet veins (Figs. 35, 36) with centers of chalcopyrite (Fig. 37). Note the lack of retrograde alteration at the contact of garnet and chalcopyrite-sphalerite in contrast to the strong retrograde alteration associated with sulfides in 93-35. Some sulfide veins also contain anhydrite, a commonly associated mineral in porphyry Cu deposits and related skarns.

96-76 Coarse-grained calcite±quartz with "blooms" of brown garnet and chalcopyrite-sphalerite (Fig. 38). Note two generations of garnet growth with late isotropic rims on earlier birefringent garnet (Fig. 39). Rare fluid inclusions in garnet lack salt daughter minerals although some contain a tiny opaque daughter mineral which probably is chalcopyrite (Fig. 40).

96-88 Strongly retrograded green skarn at marble contact (Fig. 41). Some remnant garnet is left but any pyroxene that may have existed has been replaced by the abundant chlorite and lesser amphibole (Figs. 42, 43). Quartz associated with this retrograde alteration has abundant fluid inclusions, some vapor-rich but all low salinity (lacking daughter minerals) as has been observed in other Cu skarn systems (Fig. 44).

96-101.5 Contact of andesite dike and marble with < 1cm of chlorite along contact (Fig. 45). Andesite away from contact is quite fresh (Fig. 46) and only contains chlorite within 1 mm of the contact (Fig. 47). Right at the contact are tiny crystals of chamosite, an Fe-rich chlorite (Fig. 48).

96-120 Brown garnet-chalcopyrite skarn (Fig. 49). The garnet is isotropic in thin section and has no retrograde alteration in contact with chalcopyrite and specular hematite (Fig. 50). Iron staining from weathering of the hematite has colored some of the garnet red in hand specimen (Fig. 49).

96-155 Equigranular granodiorite cut by long planar qtz-cp-chl-act veins with white envelopes (Fig. 51). Away from the veins the plagioclase is fresh and exhibits a myrmekitic intergrowth with quartz (Fig. 52). Chalcopyrite and actinolite occur in the vein center and chlorite and clay-altered feldspar occur along the margins (Fig. 53).

South Bolivar Zone drill hole from Mg skarn into granodiorite

124-165 Mg skarn with olivine-pyroxene and mt-cp (Fig. 54). In hand specimen both the olivine and pyroxene are pale green in color but in thin section the olivine tends to be coarser grained and it has higher birefringence than pyroxene (Fig. 55). Both minerals are intergrown with abundant magnetite and lesser Cu sulfides including both chalcopyrite and exsolved (from ISS) bornite (Fig. 56). It is typical to find more Cu-rich minerals such as bornite and even chalcocite in Mg skarns and this may require slightly different metallurgical treatment of these zones at Bolivar to get optimum Cu recovery.

124-256 Equigranular granodiorite cut by qtz-cc-py-cp veins with pink Kspar-sericite envelopes (Fig. 57). The abundance of calcite in the veins suggests proximity to marble and skarn (Fig. 58).

South Bolivar Zone drill hole from Mg skarn into siltstone and andesite dikes

125-168 Green garnet = pyroxene skarn with disseminated chalcopyrite (Fig. 59). Garnet is isotropic and both garnet and pyroxene are intergrown with chalcopyrite (Fig. 60) without retrograde alteration. Fluid inclusions are abundant in pyroxene and contain numerous daughter minerals (Fig. 61).

125-172 Classic Mg skarn with a variety of magnesium silicate minerals (Fig. 62) including forsterite, diopside, clinohumite, monticellite, and vesuvianite (Fig. 63).

125-176 Siltstone altered to biotite hornfels cut by planar white-green pyroxene-kspar veins (Fig. 64). Biotite occurs as tiny flakes interstitial to quartz grains and the biotite is more abundant and coarser grained near pyrite and chalcopyrite grains (Fig. 65).

125-184 Andesite dike cut by pyroxene-hornblende veins with pale green epidote-chlorite envelopes (Fig. 66). Even though both pyroxene and amphibole occur in the veins, the amphibole is altering from the pyroxene (Figs. 67, 68).

Discussion of Bolivar skarn mineralogy

All of the mineralogy observed in thin section is consistent with the previous interpretation that Bolivar is a typical Cu±Zn skarn system. Other than some bustamite in the very distal skarn occurrence at La Increible, there is no evidence of the Mn enrichment typical of Zn skarn systems. This is a positive sign in that Cu skarns are much bigger than Zn skarns. The intensity of the hydrothermal system is reflected in the fluid inclusions present in several different minerals. As with most Cu skarns, pyroxene contains abundant fluid inclusions and most are very saline and metal-rich. Halite and sylvite daughter minerals are present in most of the pyroxene inclusions indicating salinities >>30 wt. % and likely similar to those documented for the Big Gossan skarn in the Ertsberg district (Meinert et al., 1997). Chalcopyrite daughter minerals are also present in many pyroxene fluid inclusions and sphalerite and hematite daughter minerals in some. This is clear evidence for the metal transporting capacity of the Bolivar hydrothermal system. Also similar to documented Cu skarn systems, fluid inclusions in garnet, epidote, and quartz associated with retrograde alteration lack daughter minerals and thus have salinities <26 wt. % NaCl equiv.

Although retrograde alteration locally is intense, most of the Bolivar skarn is relatively fresh with chalcopyrite and sphalerite in apparent equilibrium with prograde garnet and pyroxene. Skarn systems with more abundant and intense retrograde alteration than Bolivar tend to be larger but lower grade. Thus, it is likely that Bolivar will have higher than average grades with a tonnage potential of millions to tens of millions of tons, but likely not hundreds of millions of tons.

The presence of Mg skarn with typical magnesian silicate minerals like forsterite, diopside, clinohumite, monticellite, and vesuvianite with abundant magnetite is indicative of dolomitic host rocks. Possibly due to the amount of iron precipitated as magnetite, the Cu-Fe-S minerals in Mg skarns have higher Cu:Fe ratios than in calcic skarns, in which the dominant Cu sulfide mineral is chalcopyrite. Such Mg skarn is likely wherever hydrothermal fluids encounter dolomitic rocks. This relationship can be used in exploration in two ways. First, if the stratigraphy is well understood then the presence of Mg skarn can be predicted. Second, the abundance of magnetite in Mg skarn should cause a strong geophysical signature which might allow identification of buried Mg skarn bodies.

The other sedimentary rock type at Bolivar is a fine-grained siltstone which has been altered to biotite hornfels with a pyroxene-kspar overprint. This lithology is not likely to be ore grade but is economically important because it channeled hydrothermal fluids into more receptive carbonate lithologies. The siltstone may also serve as a stratigraphic marker horizon as it appears to occur beneath the Mg skarn.

There are two main igneous rock types present in the thin sections, granodiorite and andesite. Most of the granodiorite is equigranular except for a sample of a granodiorite porphyry dike beneath La Increible. All the granodiorite samples are quartz-rich and some may border on quartz monzonite in composition. Alteration of the granodiorite is moderately strong with evidence of secondary kspar as well as sericite and clay as envelopes on quartz veins ± sulfides. Andesite dikes are more intensely and pervasively altered, as would be expected from the more reactive bulk composition. Typical alteration minerals in andesite include ubiquitous chlorite and local amphibole, epidote, and pyroxene.

There is skarn in and/or adjacent to both granodiorite and andesite. As previously noted from general field relations, it appears that hydrothermal fluids postdate both granodiorite and andesite. Skarn is zoned relative to igneous contacts, clear evidence that hydrothermal fluids were channeled along these contacts. Garnet is more abundant and darker in color close to igneous contacts. At the thin section level, garnet associated with chalcopyrite tends to be more isotropic whereas garnet associated with sphalerite is more birefringent and complexly zoned. This likely is due to the formation of both birefringent garnet and sphalerite at relatively low temperature.

References Cited

Meinert, L.D., Hefton, K.K., Mayes, D., and Tasiran, I., 1997, Geology, zonation, and fluid evolution of the Big Gossan Cu-Au skarn deposit, Ertsberg district, Irian Jaya: Economic Geology, v. 92, p. 509-526.