GS-4 Investigation of a Pb-Ag-Au–rich hangingwall in lens 4 of the Chisel North mine, Snow Lake, Manitoba (NTS 63K16): preliminary results

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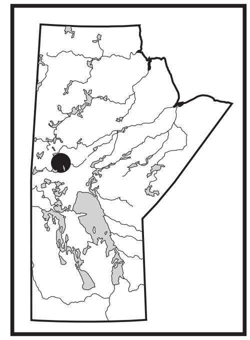

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Summary

Preliminary petrographic and electron microprobe study of mineralized samples collected from the Pb-Ag-Au–enriched hangingwall of lens 4 in the Chisel North mine was undertaken in order to characterize the setting of the mineralization, study the effect of metamorphism and evaluate possible structural controls. The hostrock is a medium-grained garnet-bearing amphibolite with disseminated arsenopyrite and galena-rich veinlets. The petrographic examination indicates that there is likely no paragenetic relationship between arsenopyrite and gold. Galena veinlets are characterized by complex intergrowth and replacement textures between galena and various sulphosalts. The sulphosalts are the main Ag-bearing phase and native Au is commonly found as inclusions or in contact with Ag-rich sulphosalts. The observation of common minute inclusions of native gold along late, galena-rich veins is indicative of a late emplacement of the Au mineralization; however, rare inclusions of sulphide and Au in garnet or amphibole porphyroblasts suggest that the hangingwall was enriched in Pb-Ag-Au prior to attainment of peak metamorphic conditions. Although most of the Au mineralization occurs in association with late sulphide veinlets, the presence Au-sulphide inclusions in porphyroblasts suggests that the actual mineralization is the result of remobilization of an earlier Au generation.

Introduction

This report presents preliminary results of a project supported by the Manitoba Geological Survey (MGS) and the Geological Survey of Canada that aims to investigate the effects of metamorphism on Pb-Ag-Au hangingwall mineralization at the Chisel North mine (Figure GS-4-1) and to establish the relative timing of mineralization. It is part of a larger-scope regional Au metallogenic study of the Snow Lake greenstone belt. The 2007 field season was focused on completing the sample collection for the project. Within the scope of the associated Ph.D. research, other examples of Au and sulphide mineralization (Squall Lake, Puffy Lake and Nokomis Lake; Figure GS-4-1) will also be investigated. This contribution, however, focuses on the progress from the petrographic and electron microprobe study of samples from the Chisel North deposit.

Regional geology

The Chisel North mine is located about 12 km south of the community of Snow Lake. The deposit was discovered in 1987 during deep exploratory drilling 1.5 km north of the original Chisel Lake deposit. The Chisel North sulphide orebody is located at the same stratigraphic level as the main Chisel mine orebody, but 300 m down plunge. The nearby Ghost Lake and Lost Lake deposits also occur along the same stratigraphic horizon. The Chisel North orebody is a stratabound, proximal, volcanic-hosted massive sulphide (VMS) deposit (Galley et al., 1993) in which sulphide mineralization occurs mainly as silicate-dolomite–rich semimassive to massive sphalerite-pyrite lenses (Bailes and Galley, 1996).

The Chisel North deposit is hosted by evolved subaqueous volcanic rocks from the mature portion of the 1.8–1.9 Ga Snow Lake arc assemblage (Bailes and Galley, 1996, 1999). The Amisk Group volcanic and volcaniclastic rocks of the Snow Lake assemblage have been divided into five depositional phases by Galley et al. (1993). The first phase is dominated by mafic volcanism and includes basalt and basaltic andesite. The second phase starts with the deposition of felsic breccia followed by rhyolite and basalt extrusion, and terminates with the deposition of mafic wacke and breccia. The third phase consists of aphyric basalt and breccia at the base, overlain by the Powderhouse feldspar-phyric dacite and the Chisel and Ghost Lake rhyolite units at the end of the cycle. The fourth depositional phase comprises mafic basalt, wacke and breccia, topped by felsic volcanic rocks. The Chisel North deposit occurs at the contact between felsic volcanic and associated volcaniclastic rocks of the third depositional phase and mafic volcanic and reworked volcaniclastic rocks of the fourth phase (Galley et al., 1993). The last depositional cycle consists mostly of pillowed aphyric basalt.

The Chisel Lake and Chisel North deposits are located within a northwest-trending, pre-D_3, synformal fold interference structure locally known as the Chisel basin. The Chisel basin is an ~5 km thick arc assemblage comprising mainly mafic wacke, mafic breccia, pillowed basalt, synvolcanic gabbro intrusions and felsic volcanic components, including the Powderhouse feldspar-phyric

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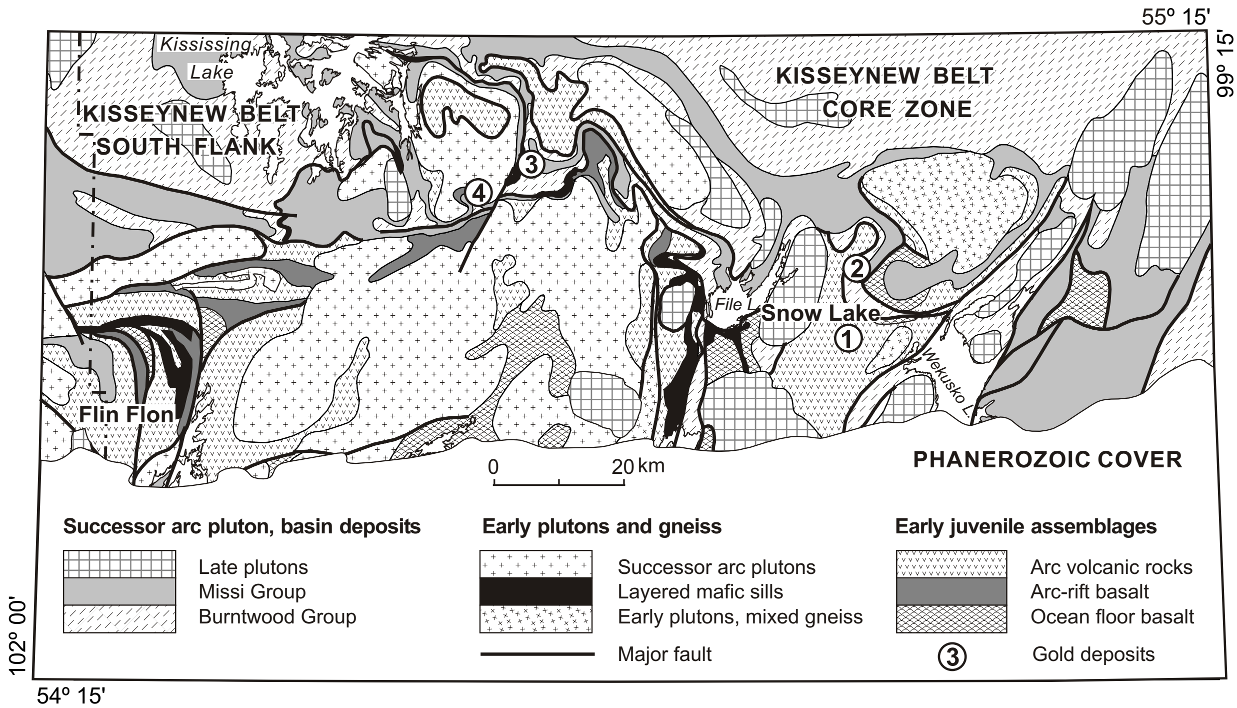

Figure GS-4-1: *Regional geology of the Flin Flon–Snow Lake greenstone belt.*

dacite and the quartz-feldspar–phyric Chisel rhyolite and associated volcaniclastic rocks.

Four generations of folds have been identified in the Snow Lake area (Kraus and Williams, 1999), with the three earliest phases having the most effect on the ore geometry at Chisel North. The first deformational event developed isoclinal folds that trend northwest and were accompanied by regional low-grade (greenschist-facies) metamorphism. The second deformational phase also generated isoclinal folds, but these folds have a northeast trend and were accompanied by peak pressure-temperature (P-T) conditions of the lower-amphibolite facies in the Chisel area (Bailes et al., 1996). The regional structural geometry is dominated by open northwest-trending folds produced during the third deformational event. The F_3 Threehouse synform folds the thrust-imbricated Burntwood Group turbidites and Amisk Group volcanic rocks in the Snow Lake area about a shallow- to moderate-plunging axis that also corresponds to the regional stretching lineation (Kraus and Williams, 1999). Menard and Gordon (1995) carried out thermobarometric calculations for the Photo Lake mine and calculated peak P-T conditions of approximately 5 kbar and nearly 535°C.

Previous work

The prolific Snow Lake mining camp, which is host to more than 15 VMS deposits, has been the subject of many studies spanning a broad range of topics over the last two decades. Froese and Moore (1980) provided the first sound understanding of the metamorphism in the vicinity of Snow Lake. The area around Chisel North was mapped at a regional scale by the MGS (Bailes et al., 1996). Galley et al. (1993) and Bailes and Galley (1996, 1999) examined in detail the alteration and mineralization of the Chisel and Chisel North orebodies. Zaleski et al. (1991) investigated the metamorphosed alteration at the Linda deposit, which records peak P-T conditions similar to those in the Chisel Lake area. Their work focused on the mineral equilibrium of altered metamorphosed wallrock that has been enriched in Zn and F. Menard and Gordon (1995) studied the effect of metamorphism on sulphide ore and metamorphosed wallrock at the Photo Lake deposit and found evidence for local synmetamorphic alteration of the orebody wallrocks. For example, they recognized that within 5 m of the deposit, the cores of garnets contained sulphides in much greater abundance than the rim or surrounding matrix, suggesting the removal of sulphides during garnet growth. This is likely the result of variations in fO_2 and fS_2 conditions driven by the metamorphic fluid, which may have resulted in the formation of a sulphidization and oxidation halo around the orebody. Recognition of a sulphidization-oxidation halo around an orebody is important, since it means that the variation of fO_2 and fS_2 conditions was significant. It also implies that altered wallrock within the sulphidization-oxidation halo does not simply represent the result of isochemical metamorphism of the original synvolcanic alteration. Menard and Gordon (1995) also identified various settings of Au, including along late fractures filled with serpentine, which was interpreted as the result of remobilization during the third deformational event.

Objectives of the study

The objectives for the Chisel North study are to establish the origin and relative timing of the hangingwall Pb-Ag-Au mineralization, study the effect of lower-amphibolite–facies metamorphism on ore mineralogy, investigate metamorphic sulphide-silicate-oxide interaction, verify for the presence of a metamorphic sulphidization-oxidation halo around the deposit and, if confirmed, investigate the effect of the halo on host mineralogy and mineral composition. Also, particular attention will be paid to the processes involved in the remobilization of Pb-Ag-Au.

Deposit geology

The Chisel North deposit comprises a series of shallowly northeast-dipping massive sulphide lenses (Figure GS-4-2). The lenses are located along the same stratigraphic horizon as the adjacent Chisel Lake deposit, and the Chisel North deposit appears to be a down-plunge extension of the Chisel Lake deposit (Galley et al., 1993). The stratabound deposit is composed of four stacked lenses, whose long axes plunge subparallel to the regional stretching lineation and the axis of the Threehouse synform. The lenses are stacked in an en échelon fashion down the dip of the stratigraphy. The relationship between the ore lenses is not well understood.

The Chisel North ore typically consists of up to 20 m of silicate-dolomite–rich, semi-massive sphalerite-rich ore with thin, massive sphalerite-pyrite or sphalerite bands containing up to 100% sulphide minerals. Pyrite is typically more abundant near the base of the ore horizon and locally massive pyrrhotite occurs near the hangingwall. The ore horizon is locally underlain by discordant zones of disseminated and vein sulphides, comprising mostly chalcopyrite and pyrrhotite. Throughout the deposit, the hangingwall is locally variably enriched in Au, Ag and Pb with values reaching as much as 7–10 g/t Au, 300 g/t Ag and 1% Pb over a few metres. The hangingwall mineralization, however, is heterogeneously distributed and is typically found associated with tectonically remobilized sulphide veins. In the hangingwall of lens 4, where samples were collected, mineralization is associated with both late sulphide veins and disseminated arsenopyrite in the altered wallrock.

The hangingwall to the mineralization consists of mafic volcanic wacke in the southern third of the Chisel North deposit, whereas the rest of the orebody is overlain by a heterolithic breccia, locally truncated by a fine-grained dioritic intrusion (Galley et al., 1993). In the vicinity of lens 4, the hangingwall is mostly occupied by the dioritic sill. The footwall to the Chisel North sulphide lenses is generally the quartz-feldspar–phyric Chisel rhyolite and its volcaniclastic equivalents that have been recrystallized and hydrothermally altered to currently consist of sericite and chlorite with common kyanite, biotite, staurolite and garnet porphyroblasts (Galley et al., 1993). Within the immediate vicinity of the area sampled in fall 2006, the intensity of alteration and metamorphic recrystallization renders the hangingwall rock difficult to identify with confidence.

Current mining activities afforded the opportunity to conduct complete reconnaissance structural analysis in two areas of the sulphide lens 2 of the Chisel North mine, which sits structurally above lens 4. One area is an undercut that exposes the immediate footwall-altered Powderhouse dacite (2 Zone, 5 South lower) and the second area is a series of drifts through the ore zone (2 Zone, 8–11 South upper). In the areas visited, the orebody appears highly deformed. Both the mineralization and hostrocks are well foliated and isoclinal folds are pervasive. Sulphide mineralization exhibits penetrative deformation structures and local redistribution of constituent mineral phases; accordingly, Tessier (2001a, b) speculated that there is a strong likelihood that the distribution of the mineralization is most probably fold controlled. The orientation of D_1 and D_2 structures observed in this project supports this assertion, but further structural analysis is required to adequately demonstrate fold control.

Fabric elements and overprinting relationships developed in the orebody are the products of four discrete periods of ductile deformation, consistent with the regional structural history of the Snow Lake area established by Kraus and Williams (1999). Deformation structures in the mine are dominated by shallowly inclined to recumbent, subhorizontally plunging F_2 folds and pronounced L_2 crenulation lineation (Figure GS-4-3a, b). This generation of structures corresponds to the D_1 deformation of Martin (1966) in the adjacent Chisel Lake mine. These folds plunge northwest and refold isoclinal intrafolial F_1 folds (Figure GS-4-4a). The F_1 folds are recumbent and appear to plunge shallowly west. The two generations of tight to isoclinal folds (F_1 and F_2) produce a complex mesoscopic fold interference pattern (Figure GS-4-4b). Primary layering is locally preserved (Figure GS-4-5) and outlines F_1 folds, but rocks in the mine generally have structural fabrics consistent with transposition of the orebody and hostrocks and a composite S_1-S_2 transposition foliation is ubiquitous. In the siliceous footwall to the mineralization (2 Zone, 5 South lower), the transposition foliation is manifested as a differentiated layering defined by alternating sericitic bands and transposed sulphide (dominantly pyrite) stringers (Figure GS-4-5). The existence of the earlier F_1 generation of folds was not fully appreciated during the underground structural analysis at the adjacent and genetically related Chisel Lake deposit, although Martin (1966) postulated the possibility of an older generation of isoclinal folds, based on the statistical analysis of structural orientation data.

Overprinting the F_1-F_2 geometry are two generations of crossfolds (F_3 and F_4). The F_3 folds are upright, open

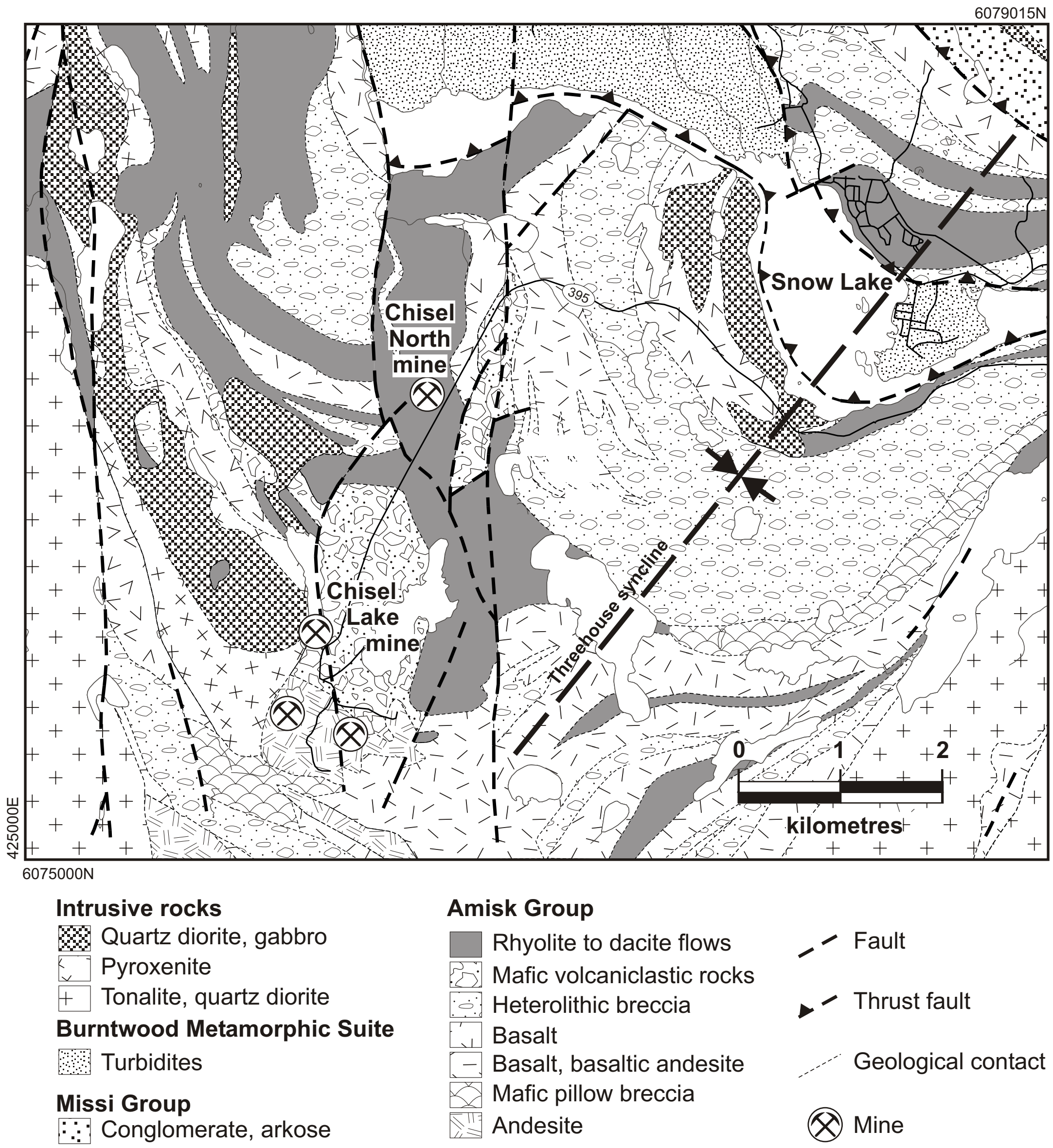

Figure GS-4-2: *General geology of the Snow Lake area.*

to close folds (Figure GS-4-6a) and are associated with a weakly developed axial planar foliation and locally pronounced crenulation lineation (Figure GS-4-6b). The F_3 crossfolds are associated with the regional northeast-trending Threehouse synform and the orientation of the L_3 lineation is parallel to the regional stretching lineation (*see* Kraus and Williams, 1999). The F_3 crossfolds may be responsible for the large open warps apparent in the mineralization and may be an important control on high-grade, remobilized mineralization (Tessier, 2001a, b). Moderately to shallowly plunging, open to box F_4 folds are locally observed. These folds do not appear to represent a significant feature with respect to reorienting the mineralization.

Folding has had a pronounced effect on the distribution of the mineralization in the areas of the mine that were visited. This is consistent with the distribution of mineralization at the Chisel Lake mine (Martin, 1966). The intensity of the early folding events produced significant fold thickening of mineralization observed mesoscopically; therefore, by analogy, there is a high likelihood that the orebody has experienced significant fold thickening during the early periods of deformation. Layer-parallel attenuation and boudinage of high-grade, sphalerite-rich mineralization is also common.

The relationship between the ore lenses is not well understood. The orientation and the distribution of the ore lenses suggest that the geometric relationship between the lenses may be a product of F_2 folding. The four ore zones form a series of stacked, stratigraphically upward- facing lenses (Tessier, 2000, 2001a, b). Based on a review of Tessier (2000, 2001a, b) and the limited structural analysis undertaken in this study, the structural geometry for this arrangement can be explained by the

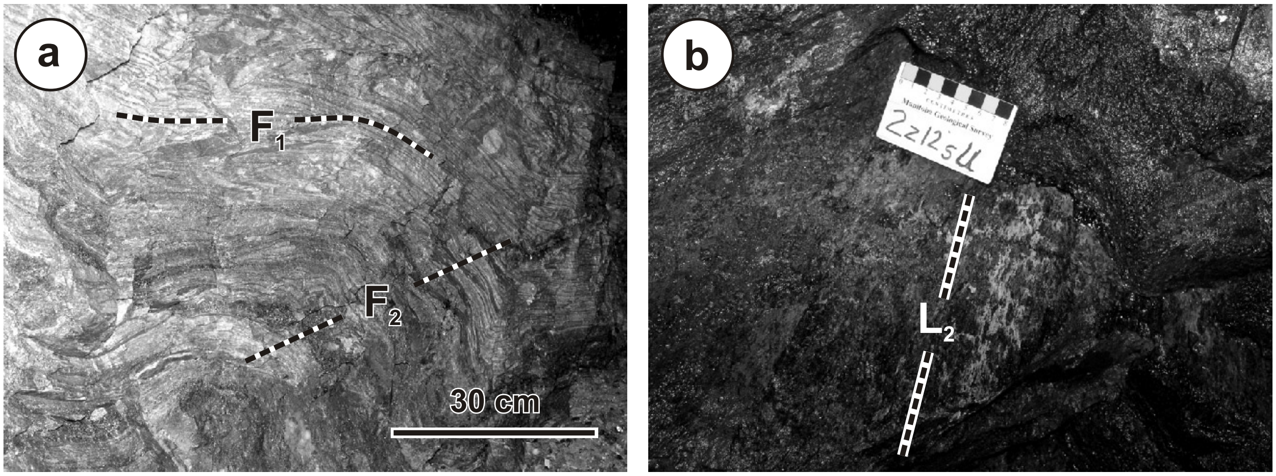

Figure GS-4-3: *Elements of D_2 fabric:* ***a)*** *recumbent F_2 fold refolding F_1 isoclinal folds;* ***b)*** *L_2 crenulation lineation developed in sericitized Powderhouse dacite.*

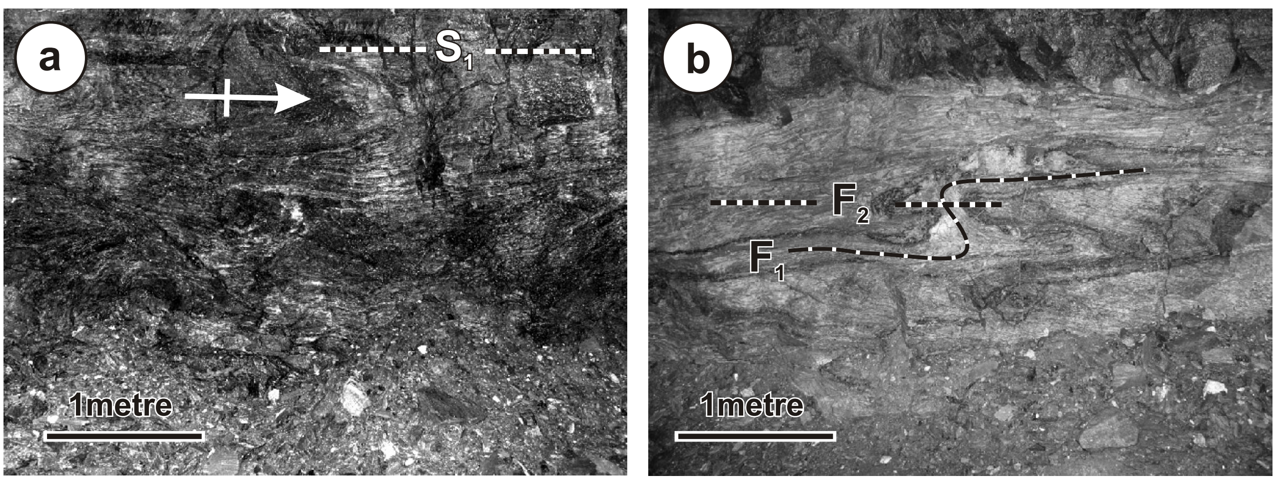

Figure GS-4-4: *Elements of D_1 fabric:* ***a)*** *F_1 isoclinal folds;* ***b)*** *F_1-F_2 fold interference pattern.*

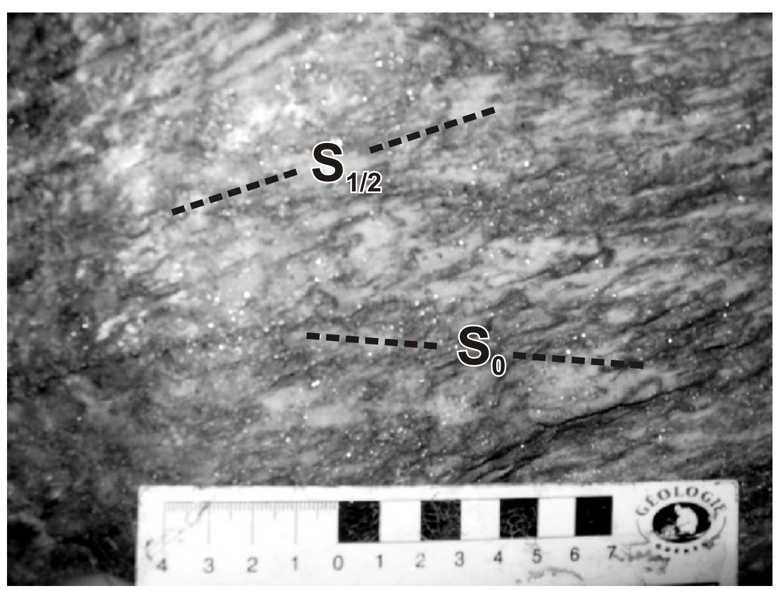

Figure GS-4-5: *Transposition foliation, S_1-S_2, developed in the footwall Powderhouse dacite.*

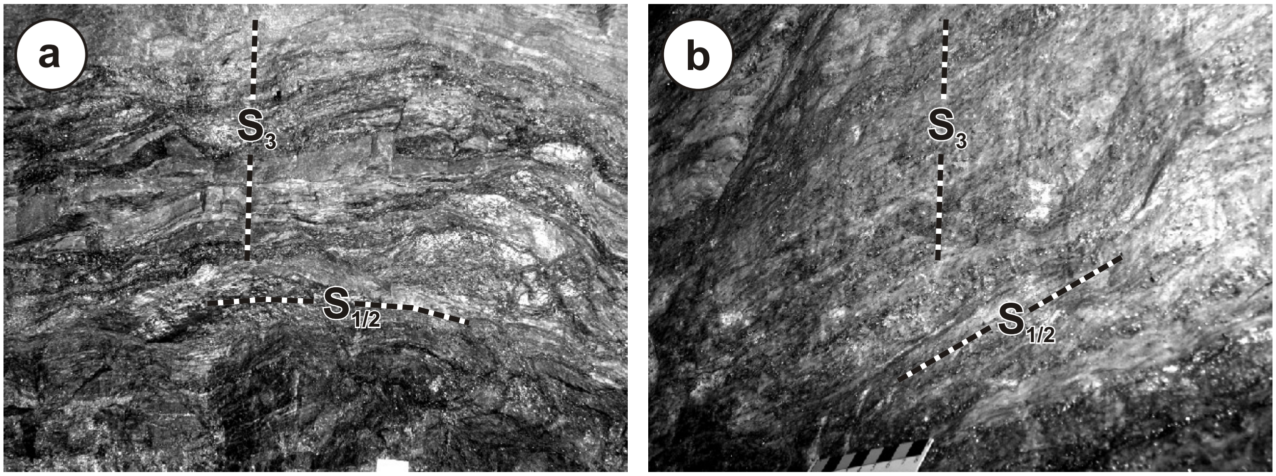

***Figure GS-4-6:** **a)** Open F_3 fold; **b)** associated weak crenulation cleavage.*

development of highly attenuated, asymmetrical F_2 folds having consistently attenuated short-fold limbs maintaining the upward-facing direction. Although, note that the same geometry could also be explained by thrust faulting or episodic deposition along a primary synvolcanic fault. Additional structural analysis is required to determine the structural relationship between the ore lenses.

Hangingwall Pb-Ag-Au mineralization

Samples from the Pb-Ag-Au mineralization that occurs in parts of the hangingwall of lens 4 at the Chisel North mine were collected during the summer of 2006. Preliminary petrographic description and electron microprobe analysis work were completed on the sample suite. The hostrock to the mineralization is a moderately foliated, medium- to coarse-grained amphibolite with variable amounts of garnet and sulphide. The amount of garnet in the rock varies from 1 to 15%. Higher garnet content coincides with a greater abundance of disseminated arsenopyrite. Garnet varies from small (1–6 mm) euhedral crystals with 5–15% inclusions to large poikiloblastic masses (5–20 mm) with 20–50% inclusions. Actinolite also forms large (1–10 mm) poikiloblastic masses and is locally altered to chlorite.

Mineralized hangingwall typically contains garnet, arsenopyrite, galena and pyrrhotite with the highest Au-Ag values correlating with greatest galena content. Arsenopyrite is typically euhedral (1–5 mm). Although arsenopyrite is common in the mineralized hangingwall, it was not observed to contain any inclusions of Au, nor was it seen in direct contact with Au grains. Galena is mostly found infilling late fractures, but is also commonly observed as irregular masses within the matrix. Petrographic work and electron microprobe analysis have shown that most of what has been identified macroscopically as galena is in fact a complicated graphic and/or myrmekitic intergrowth between galena and various sulphosalts (Figure GS-4-7a, b), including

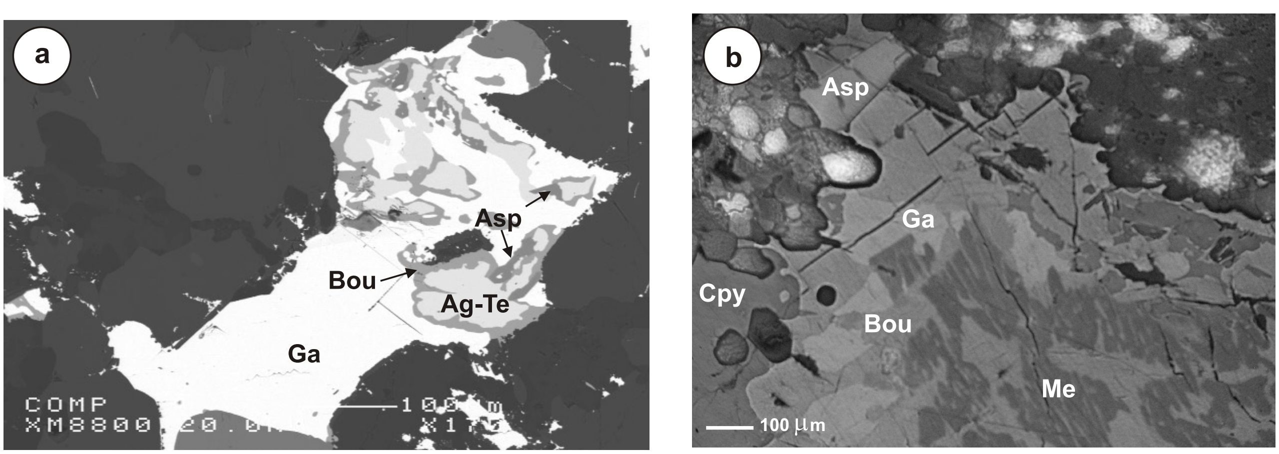

***Figure GS-4-7:** **a)** Electron-microprobe image of intergrowth of sulphosalts in galena, a complex zoning with core of Ag-rich tennantite surrounded by boulangerite, then galena; small graphic inclusions of arsenopyrite are present (field of view is 650 µm); **b)** optical microscope picture with inclusions of galena in boulangerite and complex meneghinite intergrowths (field of view is 600 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Asp, arsenopyrite; Bou, boulangerite; Cpy, chalcopyrite; Ga, galena; Me, meneghinite.*

meneghinite ($Pb_{13}CuSb_7S_{24}$), boulangerite ($Pb_5Sb_4S_{11}$), jordanite ($Pb_{14}(As,Sb)_6S_{23}$) and Ag-rich tennantite ($(Ag,Cu,Fe)_{12}(Sb,As)_4S_{13}$). Silver is mostly hosted in the structure of Ag-rich tennantite. Preliminary electron-microprobe analyses have yielded Ag content varying from 22 to 28 wt% for Ag-rich tennantite. Galena and other sulphosalts typically have low Ag content (less than 1000 ppm).

The common occurrence of galena and associated sulphosalts along late fractures, and the fact that they commonly rim other sulphide phases, such as arsenopyrite, chalcopyrite, pyrite and pyrrhotite, suggest that the former minerals crystallized later than other sulphides (Figure GS-4-7a).

Gold is spatially associated with sulphosalts (mostly Ag-rich tennantite) and Bi or Ag tellurides, and typically occurs in its native form or as electrum. Locally, Au inclusions are also observed in galena, mostly near contacts with, or included in, Ag-rich tennantite (Figures GS-4-8a, b, 9c). More typically, Au occurs as free grains in the silicate matrix in association with minute crystals of sulphosalts (Figure GS-4-9b). It varies in size from 1 µm to as much as 20 µm, but most grains are between 5 and 10 µm in length by 2–5 µm wide. The identification of a minute Au inclusion within sulphides in a garnet porphyroblast (Figure GS-4-8a) indicates that some Au was already present before peak metamorphic conditions. In a couple of samples (CH-08 and CH-17), Au was found along small sulphosalt veinlets that cross-cut the foliation, suggesting a late emplacement of some of the Au mineralization (Figure GS-4-9a). In another sample, Au is located along the cleavage surface of an amphibole, which suggests that it crystallized there after the amphibole formed.

In summary, galena and sulphosalts appear to have been recrystallized and remobilized late in the

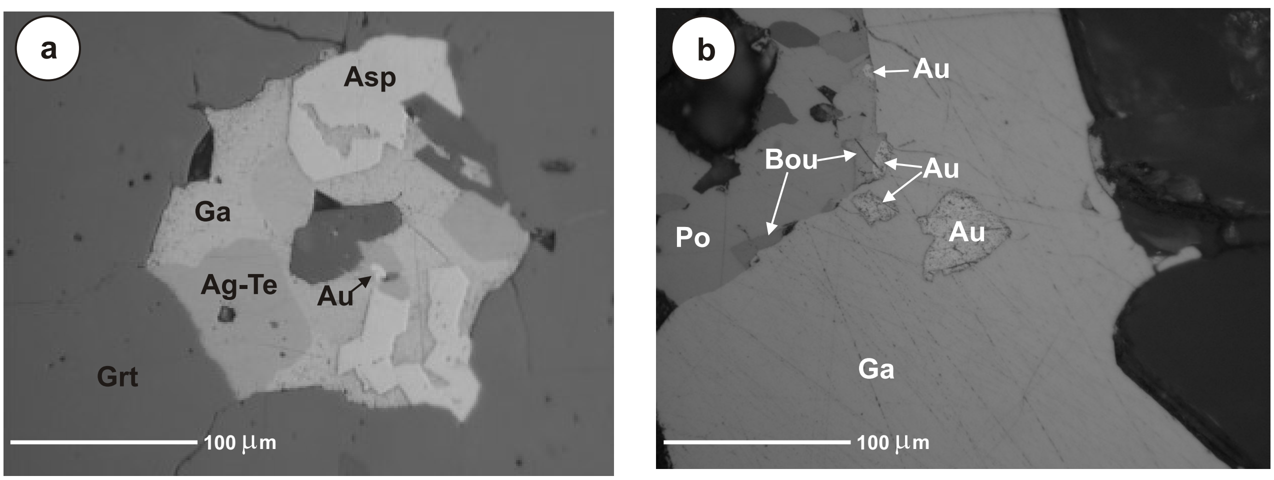

Figure GS-4-8: *Gold in association with sulphide mineral phases:* ***a)*** *sulphide inclusion in garnet porphyroblast showing a small Au inclusion in Ag-rich tennantite, which is intergrown with galena (field of view is 1200 µm);* ***b)*** *gold inclusions in galena and along the grain boundary between galena and boulangerite (field of view is 240 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Asp, arsenopyrite; Au, gold; Bou, boulangerite; Ga, galena; Grt, garnet; Po, pyrrhotite.*

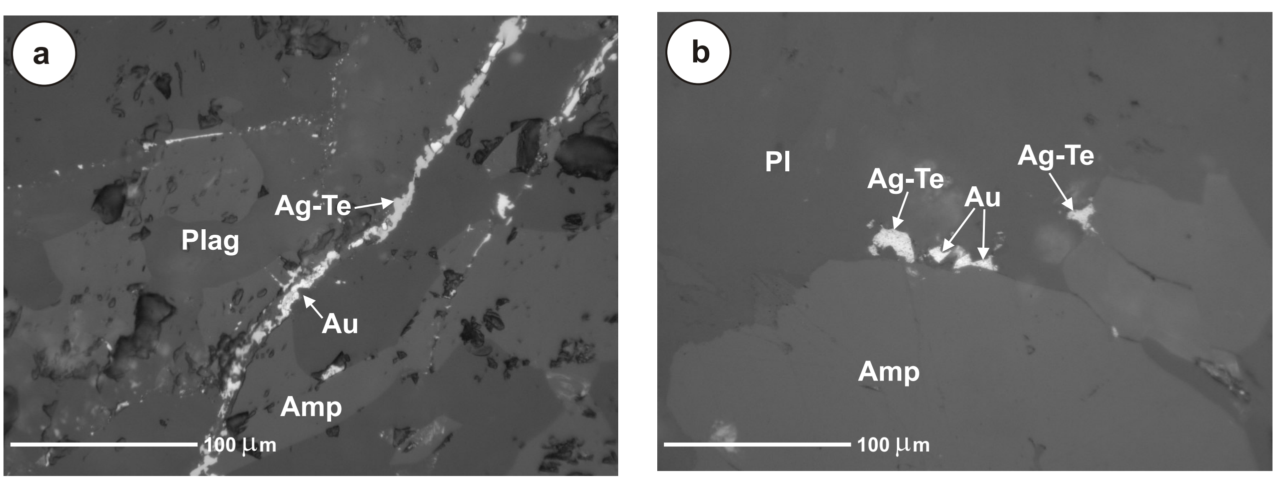

Figure GS-4-9: a) *Gold and Ag-rich tennantite grains forming a thin veinlet (field of view is 240 µm);* ***b)*** *gold and Ag-rich tennantite grains in a plagioclase matrix along a grain boundary with amphibole (field of view is 240 µm); mineral abbreviations: Ag-Te, Ag-rich tennantite; Amp, amphibole; Asp, arsenopyrite; Plag, plagioclase.*

paragenesis. Gold is mostly associated with galena and Ag-rich tennantite. Several occurrences of Au and sulphosalts along fractures suggest a late structural emplacement or remobilization, whereas a few occurrences of Au and sulphosalts included in porphyroblast indicates that the hangingwall was already enriched in Pb-Ag-Au prior to peak metamorphism. These textural relationships, however, do not permit the unequivocal statement of whether the hangingwall mineralization was synvolcanic (i.e., related to the VMS mineralization), had resulted from late remobilization of Pb-Ag-Au from main orebody or had resulted from *in situ* remobilization of a postvolcanic Pb-Ag-Au mineralization event.

Future work would require collecting oriented samples to verify the structural controls on the mineralization and more petrographic work to establish with confidence the paragenetic sequence and the timing of remobilization.

Economic considerations

Investigation of sulphide-Au mineralization will provide new constraints on the timing of mineralization and a better understanding of the mineralogical and compositional consequences of mid-amphibolite–facies metamorphism on sulphide-dominated ore. The study will also increase knowledge of sulphide-silicate-oxide interaction during prograde metamorphism and help understand the effect of sulphidization and oxidation halo on altered wallrock. This information may provide useful guidelines to help explorationists in the selection of exploration targets in medium- to high-grade metamorphic terranes.

Acknowledgments

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