

**Mineralization and Alteration of the Late Triassic Glacier Creek Cu-Zn VMS deposit,
Palmer Project, Alexander Terrane, Southeast Alaska**

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Abstract

The Glacier Creek volcanogenic massive sulfide (VMS) deposit is hosted within Late Triassic, oceanic back-arc or intra-arc, rift-related, bimodal volcanic rocks (Hyd or Tats Group) of the allochthonous Alexander terrane known as the Alexander Triassic Metallogenic Belt (ATMB). The deposit presently consists of four tabular massive sulfide lenses with a resource of 4.75 Mt. at 1.84% Cu, 4.57% Zn, 0.15% Pb, 0.28 g/t Au and 29.07 g/t Ag. A deposit-scale thrust fault offsets stratigraphy along the axial surface of a deposit-scale anticline.

The massive sulfide lenses are barite-rich and are divided into 6 main ore-types based on mineral assemblages. There is a large range of sphalerite compositions, with low-Fe sphalerite dominant throughout the lenses and high-Fe sphalerite at the top and bottom of the lenses in pyrrhotite-rich zones. Lenses contain anomalous Sb, Hg and Tl. Gangue minerals include barite, quartz, barian-muscovite, calcite, albite, highly subordinate chlorite and locally hyalophane and celsian. Overlying massive sulfide is a tuffaceous hydrothermal sediment with anomalous REE patterns and local hyalophane.

The general footwall to all four lenses is a thick unit of coherent to volcanoclastic feldspar-phyric basalt containing extensive lateral alteration. Four alteration facies are recognized based on mineral assemblages. Mass balance calculations for the footwall indicate general gains of S, Fe, Si and K with coincident loss of Ca, Na and Mg, along with trace element gains of Tl, Sb, Hg, Ba, Zn, Cu, As and loss of Sr with increased alteration intensity.

Short wavelength infrared (SWIR) spectroscopy shows a general decrease in Na, K and Al content of muscovite and increase of Fe+Mg and Ba content towards ore.

Integrated petrographic, mineral, chemical and sulfur-isotope data suggest a transition during deposit formation, from high-temperature, acidic, reduced hydrothermal fluids mixing with oxidized, SO_4 -rich seawater, to later cooler, low $f\text{O}_2$ - $f\text{S}_2$ conditions of formation and a lack of SO_4 in seawater.

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DEFINITION OF TERMS

Minerals:

-Apy	Arsenopyrite
-Brt	Barite
-Ccp	Chalcopyrite
-Gn	Galena
-Mag	Magnetite
-Py	Pyrite
-Po	Pyrrhotite
-Qz	Quartz
-Sp	Sphalerite
-Tel	Telluride
-Ttr	Tetrahedrite

Grain Sizes:

-Cryptocrystalline	< 0.01 mm
-Microcrystalline	0.01 - 1.0 mm
-Very fine	0.1 - 0.3 mm
-Fine	0.3 - 1.0 mm
-Medium	1.0 - 3.3 mm
-Coarse	> 3.3 mm

Other:

-PPL:	Plane polarized light source
-XPL:	Crossed-polarized light source
-RL:	Reflected light source
-IR:	Internal Reflections

Chapter 1

INTRODUCTION

1.1 Introduction and Location

The Late Triassic Glacier Creek Cu-Zn volcanogenic massive sulfide (VMS) deposit is a significant new discovery within the well established, yet poorly explored Alexander Triassic metallogenic belt (ATBM) of southeast Alaska. The Glacier Creek deposit is the most developed and studied of several VMS occurrences within the Palmer Property, currently held by Constantine Metal Resources Ltd., based in Vancouver, British Columbia. The Palmer Property falls on the Alaska side of the U.S.-B.C. border, at the northern boundary of southeastern Alaska, near Haines. Presently, a 4.75 Mt resource has been inferred, averaging 1.84% Cu, 4.57% Zn, 0.15% Pb, 0.28 g/t Au, and 29.07 g/t Ag (Greig, 2010). The Glacier Creek deposit is hosted within Late Triassic, bimodal volcanic rocks of the Alexander terrane, possibly correlative with rocks hosting the nearby world-class Greens Creek and Windy Craggy deposits. Intense, widespread alteration, combined with multiple episodes of deformation have made stratigraphic correlation and targeting of ore at the Palmer property a challenge.

1.2 Access and Physiography

The Palmer property is on the eastern margin of the St. Elias mountain range, with local relief reaching 2000 m above sea level. Mineralization at Glacier Creek outcrops at approximately 1300 m elevation on the south and west slopes of what is unofficially named Mount Morlan. The mountain is located south of the U.S./B.C. border, across the Klehini River from the Haines Highway which leads to the town and deep-sea port of Haines, AK.,

60 km to the south. Currently access is by helicopter and an alternative route is available along overgrown logging trails that lead to the base of the mountain. Core is stored and logged at a permanent camp along the Haines highway, 55 km north of Haines, and a 5 minute flight from the deposit.

1.3 Objectives

The objectives of this study are to determine how the Glacier Creek deposit formed and in what environmental conditions, to determine the causes of the observed paragenetic relationships, to unravel some of the structural and stratigraphic problems at the deposit-scale, to develop exploration tools for use in the Palmer area, and to compare these conclusions to nearby VMS deposits to better understand the metallogeny of the Alexander Triassic Metallogenic Belt. This study will describe the mineralization and hydrothermal alteration of the Glacier Creek massive sulfide lenses and surrounding host rock using detailed petrographic, geochemical and spectroscopic analyses and compare these observations to current knowledge of VMS deposits within the literature. Characterizing the nature of the ancient hydrothermal system will help to simplify genetic and structural concepts at Glacier Creek and aid future mineral exploration at the Palmer property. A direct comparison of mineralization and alteration at Glacier Creek to other deposits within Late Triassic rocks of the Alexander terrane will help further define the nature and distribution of mineralization within this important yet understudied metallogenic belt.

1.4 Methods

Core Logging, Mapping and Sampling

Core from seven diamond drillholes was logged in detail for this study, with initial focus in 2010 on one of four known massive sulfide lenses (Zone I). A second round of work in 2011 focused on two nearby, subordinate lenses (Zones II and III) to better establish the stratigraphic and structural control on mineralization. Drillholes CMR07-09, CMR08-11b, CMR08-13, CMR08-18 and CMR08-19 were selected to create a cross section through Zones I, II and III. Drillholes CMR08-14 and CMR08-17 provide a long section through Zone I. Core logging was done by the author and detailed graphic logs were created for each hole. An effort was made to identify pre-alteration lithologies while logging drillcore in order to better correlate units within the deposit stratigraphy. Where possible, descriptive rock names for volcanic and volcanoclastic rocks were based on McPhie et al. (2003). Alteration was qualitatively described by intensity, based on alteration mineral abundance, as weak, moderate, strong or intense. In addition to core logging, a transect in the area above the cross section was mapped by the author in order to correlate the subsurface drillhole logs with surface geology.

153 samples were taken from 7 drillholes, representing subunits within the ore zones and in both footwall and hanging-wall alteration zones. Care was taken to preserve at least one quarter of the drill core for company records. Photographs were taken and core descriptions were completed for each sample. Samples were then prepared for both transmitted and reflected light microscopy at the University of Ottawa. Rocks were crushed and pulverized at the University of Ottawa, using a hardened-steel jaw crusher and chrome-steel ring mill.

Equipment was cleaned after each sample was crushed and pulverized. Pulverized samples were sent to Activation Laboratories, Ancaster, Ontario, for multi element analyses. Massive sulfide samples were analyzed separately from sulfide-poor, altered and unaltered rocks, taking into account the different matrices. Ba analyses from historic 4-acid leach data prove unreliable where barite concentrations exceed several volume percent. Sr values may provide a reliable proxy for Ba in barites, however, they are not useful for Ba from muscovites and feldspar.

Analytical Methods: Sulfide-rich samples

Following sodium-peroxide fusion, 27 sulfide-rich samples were dissolved in 4 acids and analyzed by inductively couple plasma atomic emission spectrometry and mass spectrometry (ICP-AES and ICP-MS) for Ag, Al, As, B, Ba, Be, Bi, Ce, Cd, Co, Cr, Cs, Cu, Dy, Er, Eu, Fe, Ga, Gd, Ge, Hf, Ho, In, K, La, Li, Lu, Mg, Mn, Mo, Nb, Nd, Ni, P, Pb, Pr, Rb, S, Sb, Sc, Se, Si, Sm, Sn, Sr, Ta, Tb, Te, Th, Tl, Ti, Tm, U, V, W, Y, Yb and Zn (Actlabs Code UltraTrace-7) . Powdered samples were also encapsulated and analyzed by instrumental neutron activation analysis (INAA) with enhanced detection limits for Ag, As, Au, and Sb, as well as Ba, Br, Ca, Ce, Co, Cr, Cs, Eu, Fe, Hf, Hg, Ir, La, Lu, Mo, Na, Nd, Ni, Rb, Sc, Se, Sm, Sn, Sr, Ta, Tb, Th, U, W, Yb, and Zn (Actlabs Code 1D enhanced). Sulfide-rich samples were also analyzed for Hg at ppb detection limits using a cold vapour-flow injection mercury system (CV-FIMS: Actlabs Code 4F-Hg) and for CO₂ by coulometry (Actlabs Code 4F-CO₂)

Analytical Methods: Host rock (sulfide-poor) samples

Thirty-six, low-sulfur, altered footwall and hanging-wall host rock samples were analyzed for 36 trace elements (Ag, As, Au, Ba, Be, Bi, Br, Cd, Co, Cr, Cs, Cu, Ga, Ge, Hf, In, Ir, Mo, Nb, Ni, Pb, Rb, Sb, Sc, Se, Sn, Sr, Ta, Th, Tl, U, V, W, Y, Zn, Zr), all major oxides and REEs by ICP-AES, INAA, ICP-MS and X-Ray Florescence (XRF) (Actlabs Code 4E-Research and 4E-ICP/MS). Altered samples were also analyzed for Hg at ppb detection limits using cold-vapour FIMS (Actlabs Code 4F-Hg), for CO₂ by coulometry (Actlabs Code 4F-CO₂), and for C and S by combustion and infrared detection (LECO analyzer, Actlabs Code 4F-C, S).

Electron Microprobe Analysis and Scanning Electron Microscopy

Individual representative mineral grains were analyzed by microprobe at the University of Ottawa microprobe lab using a JEOL 8230 SuperProbe fitted with five WDS spectrometers. Sulfides, sulfates and silicates were analyzed using a 20 eKv accelerating voltage, 20 nA beam current and a 5 μ m diameter beam. Carbonates were analyzed using a 15 eKv accelerating voltage, 20 nA and a 10 μ m diameter beam. Several minerals were also examined, identified and photographed using a JEOL JSM-6610LV scanning electron microscope.

Short Wavelength Infrared Spectroscopy

Short wavelength infrared spectroscopy was conducted on 79 variably altered, dried, cut drillcore samples from the seven drillholes mentioned above. Samples were analyzed at the University of Ottawa by a 60-count analysis using a portable ASD Terraspec Pro instrument. The instrument measures reflectance in the 350 to 2500 nm wavelength range.

Spectra were examined and analyzed using SpecWin™ software. Absorption features were identified using “SpecMin™” software’s “Feature Search” function.

Sulfur Isotopes

Twenty-two sulfide (pyrite, pyrrhotite, sphalerite and chalcopyrite) and five sulfate (barite) samples from Zones I and II were analyzed for sulfur isotopic composition at the G.G. Hatch Laboratory within the University of Ottawa. Minerals were separated by hand and care taken not to contaminate sulfides with sulfates. For analysis, samples are weighed into tin capsules with at least twice the sample weight of tungstic oxide. Calibrated internal standards are prepared with every batch of samples for normalization of the data. Samples are then loaded into a Vario el (Elementar, Germany) elemental analyser to be flash combusted at 1800°C. Released gases are carried by helium through the elemental analyzer to be cleaned, then separated by double “trap & purge”. SO₂ gas is then carried into the Delta XP isotope ratio mass spectrometer (Thermo Finnigan, Germany) for analysis. Analytical precision is $\pm 0.2\text{‰}$. Values are reported relative to the Canon Diablo meteorite standard (Rees, 1978).

Chapter 2

GEOLOGY

2.1 Alexander Terrane

The Alexander Terrane is one of the largest allochthonous, tectono-stratigraphic terranes that form the North American Cordillera of southeast Alaska and western B.C. The terrane occupies a large portion of southeast Alaska and extends both north and south through British Columbia, the Yukon Territory and into eastern Alaska (Figure 2.1). Rocks of the Alexander Terrane preserve an excellent geologic record of arc volcanism, back-arc spreading and marginal basin development (Figure 2.2; Gehrels and Saleeby, 1987, Gehrels et al., 1996). Although the terrane was initially defined by Schuchert (1923) as an isolated geosyncline from the Cordillera, it is now thought to represent an entirely oceanic arc succession (Samson et al., 1989) accreted to North America around the Early to Middle Jurassic (McClelland and Gehrels, 1990).

The tectonic evolution of the Alexander Terrane can be simplified into three main phases. The first phase is characterized by oceanic island arc-type magmatism along a convergent plate margin from Late Proterozoic-Early Cambrian through to Early Devonian (Figure 2.2). The Late-Proterozoic through to Early Cambrian sequence is represented by metasedimentary and bimodal metavolcanic rocks of the Wales Group (Gehrels and Saleeby, 1987; Gehrels and Berg, 1994). These are the oldest rocks recognized in the Alexander Terrane and include both basaltic and rhyolitic breccias and tuffaceous sediments, basaltic pillowed flows, greywackes, mudstones, and limestones (Gehrels and Saleeby, 1987). This

assemblage was later deformed and metamorphosed to greenschist, and locally amphibolite, facies during the Wales orogeny from Middle Cambrian to Early Ordovician (Gehrels and Saleeby, 1987; Gehrels and Berg, 1994). Volcanogenic massive sulfide (VMS) occurrences and deposits have been discovered within the Wales Group rocks around Niblack, Anchorage and north of Chomondeley Sound (Figures 2.1, 2.2 and 2.3; Newberry et al., 1997), including the Niblack deposit currently being explored by Niblack Mineral Development Inc. and Heatherdale Resources Ltd. on southeastern Prince of Wales Island, southeast Alaska. Ordovician into middle Early Silurian volcanic arc magmatism and related sedimentation, mainly in the southern part of the terrane, formed rocks of the Descon Formation that unconformably overlie the Wales Group (Figure 2.2; Gehrels et al., 1996). Basaltic to andesitic pillowed flows and breccias, rhyolitic to dacitic tuffaceous rocks and breccias, mudstones, greywackes, and subordinate limestones, conglomerates and shales of the Descon Formation are intruded and underlain by related bodies of diorite, quartz-diorite, granite and syenite (Newberry et al., 1997; Gehrels et al., 1996). Several minor VMS occurrences, hosted by bimodal volcanic rocks and sediments of the Descon Formation, occur on southern Prince of Wales Island, around Nichols Bay and the Barrier Islands (Figures 2.2 and 2.3; Gehrels et al., 1983). This initial phase of tectonic evolution of the Alexander Terrane, characterized by arc magmatism, ended with a final orogenic event known as the Klakas orogeny from Middle Silurian to earliest Devonian (Figure 2.2; Gehrels and Saleeby, 1987). The end of the Klakas orogeny marks a significant change in tectonics within the Alexander terrane.

The second phase of tectonic evolution of the Alexander Terrane was characterized by relative quiescence from Middle Devonian to Early Permian, marked by the deposition of

limestone, dolomite, chert, shale and subordinate basalt and sandstone (Figure 2.2; Gehrels and Saleeby, 1987; Gehrels et al., 1996). In southern Alaska, Middle Pennsylvanian monzonite-syenite-alkali granite intrusions cut the contact between the Alexander Terrane and the adjacent Wrangellia Terrane, which borders the Alexander Terrane to the west and north (Figure 2.1; Gardner et al., 1988). Although the tectonic relationship between the two terranes is currently unknown, the ages of the intrusions suggest that the two were juxtaposed by at least Middle Pennsylvanian to form a composite terrane. According to Newberry et al. (1997), no significant VMS occurrences have been discovered within upper Paleozoic rocks of southeast Alaska. However, the Orange Point VMS deposit may be hosted by Permian intermediate volcanic rocks of the Alexander Terrane (Figure 2.1 and 2.2; Still, 1991; Nokleberg et al., 2005).

The third phase of tectonic evolution, and the most significant for this study, was an extensional event which deposited Middle (Anisian) to Late (Norian) Triassic bimodal-volcanic and rift-fill sedimentary rocks unconformably on the Upper Paleozoic rocks (Figure 2.2; Gehrels and Saleeby, 1987; Taylor et al., 2008). The Triassic rocks occur discontinuously along the eastern flank of the Alexander Terrane and vary significantly from south to north (Figure 2.3). The southern Triassic rocks in the study area are characterized by a 200-800 m section of rhyolitic flows and tuffs, massive limestones, calcareous argillites and basaltic to andesitic pillow flows and breccias (Gehrels and Berg, 1994). These rocks are all underlain by a basal conglomerate and capped by a thick sequence of mafic volcanic rocks (Gehrels and Berg, 1994). In general, the volume of felsic volcanic rocks and conglomerate decreases northward and the volume of mafic volcanic rocks increases (Figure 2.4). This belt

of Middle to Late Triassic rocks is host to a variety of structurally-controlled and stratiform base and precious metal deposits, and is referred to by Taylor et al. (2008) as the Alexander Triassic Metallogenic Belt (ATMB).

2.2 Alexander Triassic Metallogenic Belt (ATMB)

The Alexander Triassic metallogenic belt (Figure 2.3), as defined by Taylor et al. (2008), represents an asymmetrical, wholly oceanic, back-arc or intra-arc rift environment within the Alexander Terrane. The Triassic rocks exhibit a transition from shallow water, high energy, near-source stratigraphy, including thick packages of limestone and conglomerates in the south, to low energy, distal, deep-water stratigraphy, including carbonaceous shales in the north (Figure 2.4). There is also a distinct change in magmatism, from a calc-alkaline, proximal-arc type, rhyolite-dominated section in the south, to more peralkaline, basin-margin type rhyolites in central sections, and finally to a more MORB-like and tholeiitic basalt dominated section in the north (Taylor et al., 2008).

A distinct, proximal-facies conglomerate marks the base of the Late Triassic section in the southern and central section of the ATMB (Taylor et al., 2010). This basal conglomerate transitions to a more distal-facies towards the Duncan Canal area (Figure 2.3 and 2.4). In the north, the conglomerate is only locally present and difficult to place stratigraphically (Taylor et al., 2010). Overlying the basal conglomerate in the south is a thick section of rhyolites, followed by a thick section of limestones and calcareous greywackes (Taylor et al., 2010). To the north, this section is absent and is instead occupied by mafic to intermediate volcanics, volcanoclastic rocks, and deep-basin sediments, with rare occurrences of rhyolite

(Figure 2.4). A thick sequence of mafic, pillowed, amygdaloidal and relatively undeformed volcanic rocks form a cap across the entire ATMB. This mafic volcanic package has a complex, transitional geochemical signature, suggesting variable degrees of rifting across the terrane, and therefore variable degrees of partial melting of the underlying mantle and assimilation of earlier arc-type crust (Taylor et al., 2010).

The morphology, metallogeny and genesis of mineral deposits vary significantly from south to north along the ATMB. There is a transition from shallow-level, structurally-controlled occurrences in the south to deep-water, mafic-siliciclastic VMS deposits in the north.

2.3 Palmer Area Geology

The Palmer property is located within a pocket of Late Triassic rocks approximately 75 km from the Windy Craggy deposit and 160 km from the Greens Creek deposit (Figure 2.5). Hudson et al. (1982) estimate dextral offset along the Chatham Strait fault system (Figure 2.5), between mid-Cretaceous and Holocene, to be approximately 150 km. Reconstruction of this offset would place the Greens Creek deposit within 50 km of the Palmer property.

Late Triassic rocks around the Palmer property (Figure 2.6) have been described in detail in several studies (e.g., Still et al., 1984; Still et al., 1991; MacIntyre and Schroeter, 1985) and in particular by Green (2001). Fifteen significant VMS-style occurrences have been discovered in the area, the most significant being the Glacier Creek deposit (this study), followed by the Cap and Mount Henry Clay (MHC) prospects. Prospects are separated by large areas of glacial ice cover, creating challenges in mapping and correlation across the

property.

In general, stratigraphic sections across the Palmer property are quite similar. They are dominated by mafic volcanic rocks of transitional to tholeiitic affinity, all derived from similar primary magmas (Green, 2001), with minor, local volumes of felsic volcanic rock. A generalized stratigraphic section of the Palmer area is shown in Figure 2.7. A package of fine-grained basinal clastic rocks (black calcareous argillites) known as the Porcupine Slate (Figure 2.6 and 2.7) underlie the submarine volcanic rocks described above (Figure 2.5; MacIntyre et al., 1985). Below these argillites stratigraphy is poorly understood. Overlying the Porcupine Slates is a sequence of mafic volcanoclastic and locally hyaloclastic rocks intercalated with thin argillite and limestone units. This sequence is capped by a very thick package of pillowed, massive, and locally brecciated, aphyric to feldspar phyric mafic volcanic rocks intercalated with thin tuffaceous limestones. Typically at the known prospects, a thick section of intensely quartz-sericite-pyrite schist occurs near the contact between the volcanoclastic package and the overlying massive to pillowed flows. Locally, host rocks contain minor volumes of rhyolite and VMS mineralization.

The hanging-wall mafic volcanoclastic rocks and pillowed and massive volcanic flows overlying the VMS occurrences at Palmer likely represent the thick, late Triassic capping sequence of mafic volcanic rocks described by Taylor et al. (2008) that occurs across the Alexander Terrane. To date, rhyolite flows have been observed at the Glacier Creek deposit, as well as the Boundary and Nunatak occurrences (Figure 2.6). Rhyolite within boulders and debris at the Cap prospect and rhyolitic dykes/sills at the MHC prospect have

also been recognized. The volume of rhyolite is greatly subordinate, however, to basaltic and basaltic-andesitic volcanic rocks in the area. All of the volcanic rocks are typically intercalated with thin horizons of tuffaceous limestones and calcareous argillites, which suggests that numerous short episodic breaks in volcanism occurred across the property. Little to no fine-grained sediment has been observed at the MHC prospect, however, suggesting protracted volcanism in this area (Green, 2001). Mafic intrusive rocks have been observed, as sill-like bodies within hanging-wall sequences at the Glacier Creek and Cap occurrences, and as peperitic sills and dykes throughout the section at MHC (Green, 2001). Similar mafic and ultramafic intrusive bodies appear to have a significant genetic relationship to VMS-style occurrences throughout the Alexander Triassic Metallogenic Belt (Taylor et al., 2010).

Three main deformation events affected the rocks at the Palmer property. D1 is represented by a variable, pervasive fabric (S1), observed as strong to intense schistosity in strongly altered rocks to a weak fabric in coherent mafic volcanic rocks. The intensity of the S1 fabric is strongly controlled by the original composition of the units. D1 is also reflected in south-verging folds and southerly-directed movement along thrust faults (Lewis, 1998). D2 is represented locally by megascopic, tight folds that plunge northwest (Green, 2001). Finally, a weak, local, northeast striking crenulation cleavage is present within schistose rocks and is interpreted as D3 (Green, 2001). Late southwest- and northwest-striking, high angle, brittle faults offset stratigraphy at Palmer, and likely post-date D1 to D3 deformation. These faults significantly complicate deposit-scale exploration.

2.4 Host-Rock Stratigraphy of Glacier Creek

The Glacier Creek deposit is exposed on the informally named Mount Morlan. The general structure of Mount Morlan is that of a large, overturned, south verging anticline with an axial trace plunging shallowly to the east on the south-facing slope of the mountain (Figure 2.8). The axial surface likely dips shallowly to the northeast. VMS mineralization outcrops in several places on the southern and western flanks of the mountain. A poorly constrained, deposit-scale fault with an orientation similar to the axial plane of the anticline offsets the upper limb from the lower limb of the fold (Figures 2.9 and 2.10). The area between massive sulfide lenses is structurally complex and poorly understood, and the complexities are considered further below. Greenschist facies metamorphism and hydrothermal alteration has caused abundant recrystallization of the host-rock units, especially within and around the ore zones. The dominant lithologies are shown in Figures 2.11 and 2.12, and are outlined below.

Massive Sulfide and Barite Lenses

Massive sulfide and barite lenses at Glacier Creek range up to approximately 35 m true thickness and are composed mainly of barite, pyrite, chalcopyrite and sphalerite. Most sulfide has been annealed and recrystallized, making a confident paragenesis difficult. Four lenses have been identified to date (the RW Zone, and Zones I, II and III), and they are shown in Figures 2.8 and 2.9. The massive sulfide lenses are discussed in detail in Chapter 3.

Mafic Volcanic Rocks

Seven mafic volcanic rock units from the Glacier Creek area have been described

by Green (2001) based on textural and compositional differences. The immobile-element geochemistry of mafic volcanic rocks is discussed in Chapter 4. In general, pillowed and massive, amygdaloidal mafic volcanic rocks form the hanging wall to ore lenses and hydrothermally altered rocks at Glacier Creek. Discontinuous, 5-10 m thick layers of argillite, tuffaceous rock and strongly altered, volcanic breccias directly cap the massive sulfides (Figure 2.9, 2.10 and 2.11).

The lowermost of the hanging wall basalts is a dark green, fine-grained, aphyric, magnetite-bearing, pillowed and amygdaloidal unit, referred to by Green (2001) as the B5 basalt. Locally, large sections are autobrecciated or hyaloclastic, and it is variably intercalated with thin layers of calcareous, tuffaceous rocks. The basalt is variably magnetic and exhibits very little to no quartz-sericite-pyrite alteration. Chlorite is abundant in this unit, and likely formed from regional greenschist metamorphism. Pillow selvages are variably altered to epidote and carbonate, typically calcite and Mn-carbonate. Green (2001) also describes chemically distinct, spherulitic B4 basalts, and pillowed B3, B2 and B1 basalts further up-section. B1, B2 and B3 basalts closely resemble the B5 basalts texturally, and only fresh, unaltered samples may be chemically distinguished using immobile element geochemistry. For the purposes of this study, these basalts are referred to collectively as the hanging-wall basalts.

A chemically and texturally distinct, feldspar porphyritic basalt underlies and is locally intercalated with the dark green, pillowed, amygdaloidal basalt. This basalt, referred to by Green (2001) as the B6 basalt, is dominant in the footwall of VMS mineralization at

Glacier Creek. It is medium green, aphanitic and locally weakly amygdaloidal. The feldspar phenocrysts in fresh, least altered samples are coarse (up to 5 mm), subhedral to euhedral and comprise up to 25% of the rock (Figure 2.12 C). Towards mineralized zones however, feldspars become increasingly deformed and altered to muscovite, forming dark coloured, flattened augens (Figure 2.12 D).

Structurally above Zone I mineralization is a massive, coherent, very fine-grained, relatively homogeneous and locally weakly amygdaloidal basaltic unit, referred to by Green (2001) as B7 basalt. The rock is variably altered to quartz and muscovite and contains local stringers of pyrite and pyrrhotite $\pm$ sphalerite $\pm$ chalcopyrite (Figure 2.12 F). The alteration intensity is weak compared to the overlying and underlying rocks. The contact with the underlying strongly quartz-muscovite-altered zone is sharp and may be structural. The contact with the feldspar phyric B6 basalt is also sharp, although can be locally ambiguous and possibly structural. This unit is likely a subvolcanic sill or dyke, possibly structurally emplaced, and will be discussed below.

Argillites

Argillites within the Glacier Creek stratigraphy are typically dark grey to black, very strongly calcareous, moderately to highly foliated, and are composed primarily of carbonate, with 5-20% quartz and locally grade into cherts or pale calcareous tuffaceous sediment. They contain approximately 5% disseminated sulfide (either pyrite or pyrrhotite). Trace amounts of chalcopyrite and sphalerite are present, associated with pyrite or pyrrhotite. The sphalerite is dark red to burgundy, with dark red internal reflections, suggesting high-Fe con-

tent.

Cherts

Chert occurs overlying and underlying massive sulfide lenses at Glacier Creek and commonly grades into calcareous tuffaceous sediment or argillite. They are laminated, massive or brecciated. Locally brecciated cherts have large angular chert clasts within a sulfide matrix. The chert is composed of annealed, recrystallized, fine- to coarse-grained quartz, with minor and variable muscovite, feldspar, carbonate and sulfide (Figure 2.12 B). Locally, cherts are cut by sulfide stringers.

Tuffaceous rocks

Dominantly calcareous, tuffaceous interflow sediments are common within the hanging wall mafic volcanic units as discontinuous, 1-5 m lenses. Calcareous and quartz-muscovite-pyrite altered tuffaceous rock is also common directly above and/or below massive sulfide lenses. These rocks can be highly mineralized (Chapter 3). Less altered examples locally contain fine-grained feldspar phenocrysts and amygdules. The mineralogy is typically quartz and carbonate, with highly variable sulfide content (1-15%; Figure 2.12 E). Several samples contain abundant chlorite, epidote and/or feldspar. Tuffaceous rocks surrounding ore lenses commonly have (Ba-K)-feldspars.

Rhyolite

A massive, tabular, rhyolite body, with local breccia underlies much of the RW massive sulfide lens on the west side of Mount Morlan (Figure 2.8). No felsic volcanic rocks

have yet been identified within the ‘southwall’ area associated with Zones I, II and III. The rhyolite is pervasively altered to quartz-muscovite-pyrite, and locally contains chalcopyrite- and sphalerite-bearing stringer veins (Green, 2001). Rhyolite samples were not examined during this study.

Mafic Dykes

Mafic dykes and sills are abundant throughout the stratigraphy and are especially common around massive sulfide mineralization within the ‘southwall’ zone where they exhibit chilled margins. Dykes/sills can range from <10 cm to >10 m wide in drill core. They are typically dark green, fine-grained, dominantly chloritized and calcareous. They contain minor disseminated sulfides, are variably magnetic and locally have small amygdulites. Dykes/sills exhibit a pinch and swell structure and are difficult to correlate between drill holes. Where they cut massive sulfide lenses, the dykes/sills typically have concentrations of massive chalcopyrite and dark red sphalerite along their margins, which suggests remobilization of metals. Some dykes appear to have influenced the penetration of oxidized groundwater as malachite, smithsonite, and even native copper are observed along fractures adjacent to or within dykes.

Footwall Volcaniclastic Rocks

Where primary textures are preserved, the footwall to the known massive sulfide lenses within the ‘southwall’ zone is comprised mainly of altered mafic volcaniclastic rocks. Volcaniclastic rocks are highly variable in appearance, including, for example, finely layered, foliated, and strongly quartz-muscovite-pyrite altered rocks (Figure 2.12 G) and weakly to

moderately quartz-muscovite-pyrite and carbonate-altered hyaloclastic rocks (Figure 2.12 H). Volcaniclastic rocks also locally contain minor epidote, chlorite and carbonate. Clasts range in size from fine to very coarse (>3 cm) and rounded to angular and curvilinear. Clasts may appear heterolithic, due to variable degrees of alteration and may exhibit oscillatory quartz, muscovite and pyrite zoning. Locally, minor chalcopyrite and sphalerite stringers are observed, but no significant stringer zone has been delineated in these rocks. Altered volcaniclastic rocks typically contain trace amounts of disseminated chalcopyrite and sphalerite mineralization.

Structure

The structural geology at Glacier Creek remains unresolved. The model proposed here is that of an imbricated anticline (Figure 2.8 and 2.9). A reverse fault is proposed along the axial surface of the deposit-scale anticline, thrusting the shallowly-dipping upright limb approximately 200 to 300 m to the south. A decameter slab containing the Zone I lens is dropped down relative to Zone II. Late, steeply dipping brittle faults locally offset geology, further complicating the structure.

Summary

The stratigraphy of the upright limb of the deposit-scale anticline, around the RW zone (Figure 2.8), is generally intact and has been relatively undisturbed by folding or faulting. A feldspar-phyric basalt, referred to by Green (2001) as the B6 basalt, underlies the horizon that hosts rhyolite and the RW zone massive sulfide. Younger, amygdaloidal, massive to pillowed and locally spherulitic basalts (B5 to B1 of Green, 2001) overlie the RW zone.

These basalts can be clearly differentiated chemically (Chapter 4). Green (2001) proposed that the second massive sulfide lens referred to here as Zone I was situated stratigraphically beneath the feldspar-phyric basalt, within the upright limb. The present study shows that instead, Zone I is overturned and lies within the overturned limb of the deposit-scale anticline (Chapter 3). This would suggest that somewhere between the RW zone and Zone I is the axial surface of the anticline. This study will also show that the B6 feldspar-phyric basalt is the general footwall to known mineralization at Glacier Creek. A deposit-scale thrust fault cuts stratigraphy between Zones I and II (Figure 2.9), although the nature of this fault remains ambiguous. The model proposed here is that of a thrust fault along the axial surface of the deposit-scale anticline, with approximately 200 to 300 m displacement. A structural slab containing Zone I was normally faulted, likely after the thrusting event.

Several drillholes intersect an aphyric, amygdaloidal basalt underlying the feldspar-phyric basalt, although the intense alteration masks this relationship. The aphyric basalt is geochemically similar to the hanging-wall basalts (Chapter 4). Rocks below Zone I and stratigraphically underlying Zones II and III, have been very strongly sericite-quartz altered making identification of the protoliths and correlation with other rock units extremely difficult (Figure 2.9). Primary textures, where present, indicate that much of the rock was volcanoclastic in nature (Figures 2.12 G, H), and the widespread and pervasive alteration may reflect the permeability of the volcanoclastic precursor. Several later, brittle, vertical faults are also observed throughout the deposit (Figure 2.8 and 2.10), further complicating correlation within the footwall and reconstruction of the deposit.

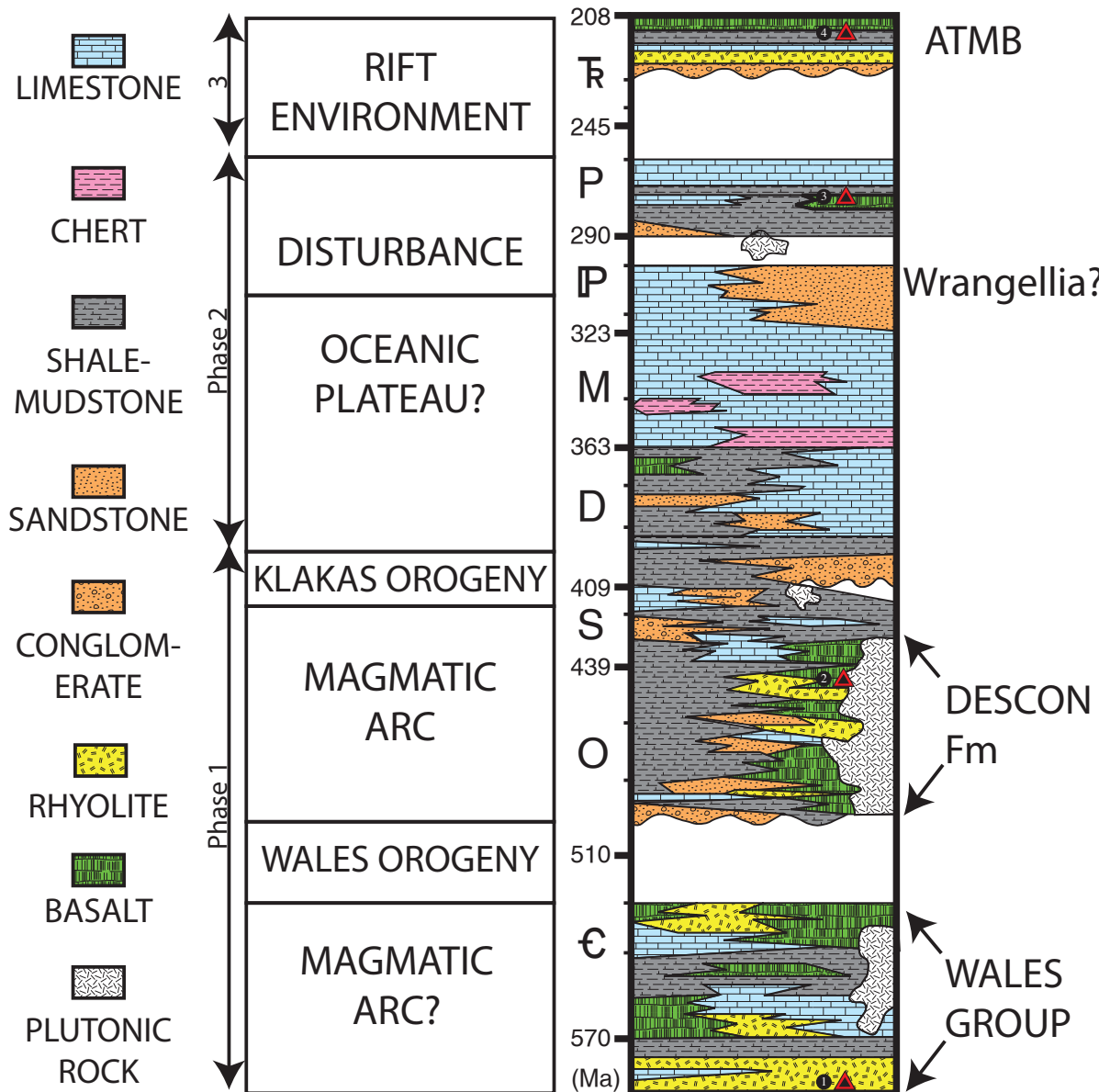


Figure 2.2. Generalized, schematic stratigraphic section of southern and central Alexander terrane, exhibiting a nearly complete Paleozoic geological record. Red triangles indicate VMS occurrences: 1) Niblack deposit, 2) Nichols Bay and Barrier Island occurrences, 3) Orange Point deposit, 4) Greens Creek, Windy Craggy and Glacier Creek. The Late Triassic rocks that host VMS mineralization (ATMB) overlie a regional unconformity. See Figure 2.4 for Triassic section. Modified from Gehrels et al (1996).

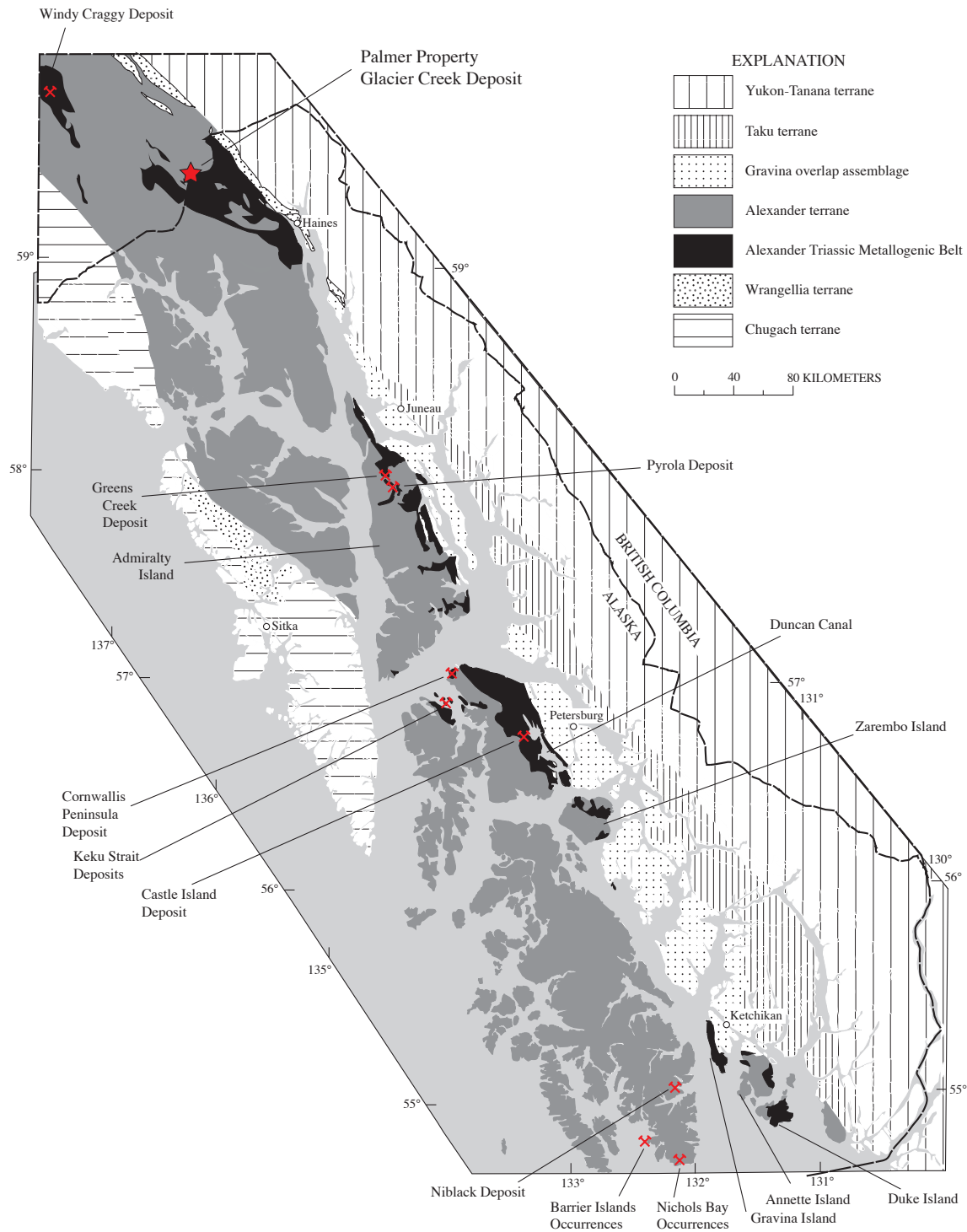


Figure 2.3. Terrane map of southeastern Alaska. The Upper Triassic Alexander Triassic Metallogenic Belt (black) hosts numerous VMS occurrences; those mentioned in the text are highlighted. Modified from Taylor et al. (2010). Data from Szumigala et al. (2009), Newberry et al. (1997), Gehrels et al. (1983), and Taylor, et al. (2008).

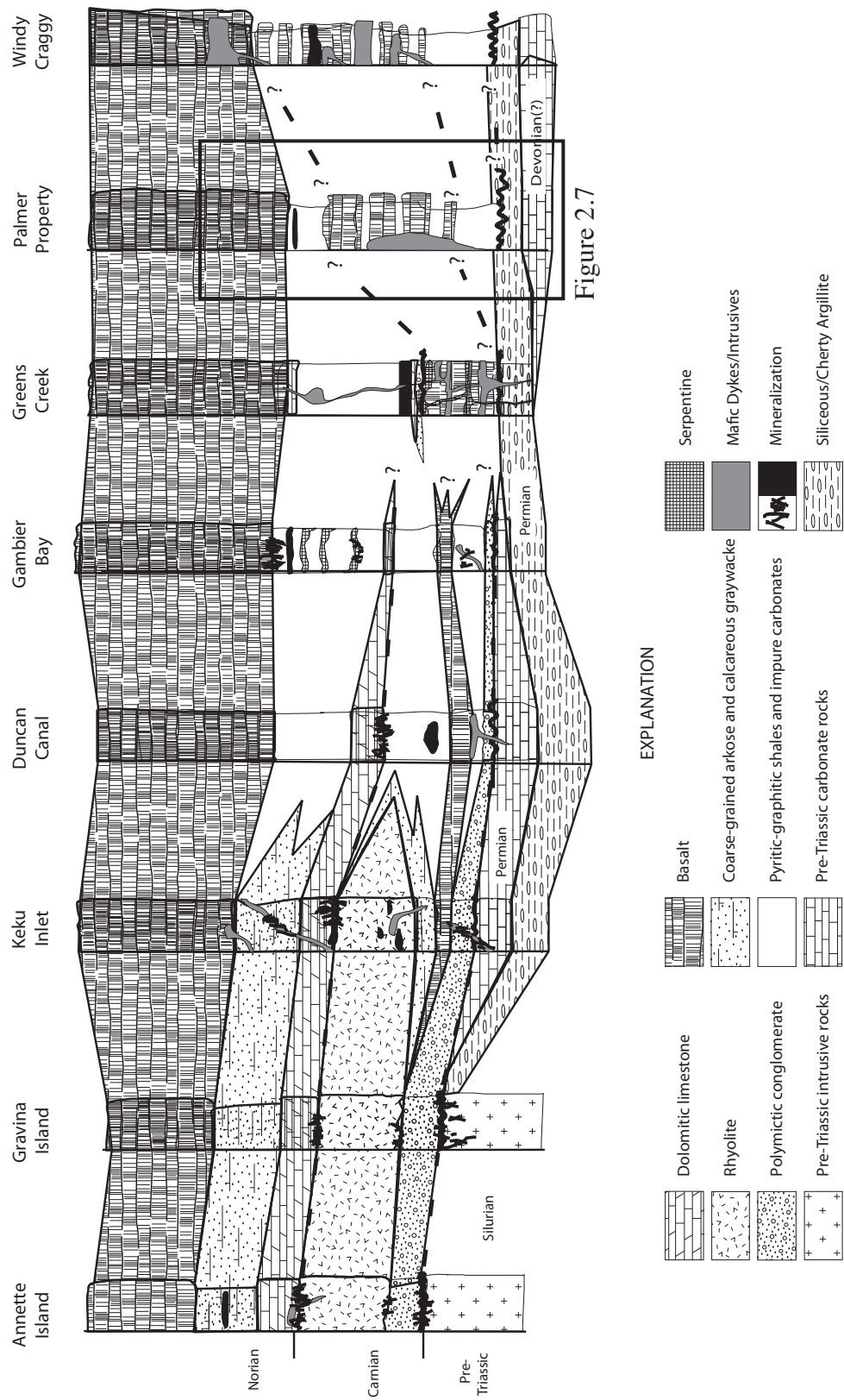


Figure 2.4. Schematic stratigraphic section, from south to north, of upper Triassic rocks, across the Alexander Triassic Metallogenic Belt (Figure 2.3), showing a general increase in the abundance of shales and mafic volcanic rocks, and a loss of felsic sedimentary and volcanic rocks towards the north. This may indicate deeper oceanic setting towards the north. Modified from Taylor et.al. (2010).

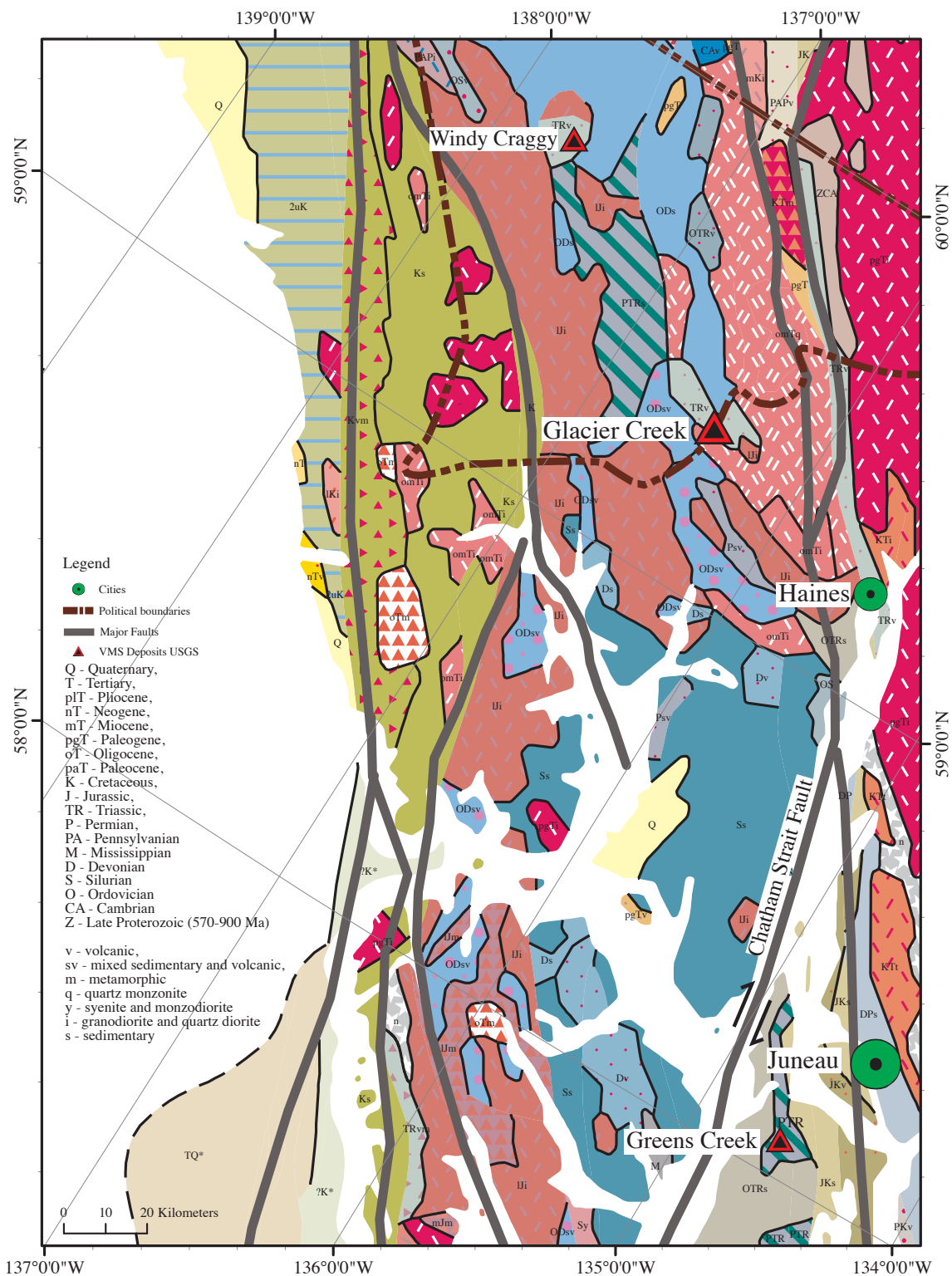


Figure 2.5. Regional scale geology map centered on northern southeast Alaska. The Greens Creek, Windy Craggy and Glacier Creek deposits are all situated within Triassic volcanic and sedimentary units. Reconstructing offset along the Chatham-Strait fault places Greens Creek <50 km from Glacier Creek.

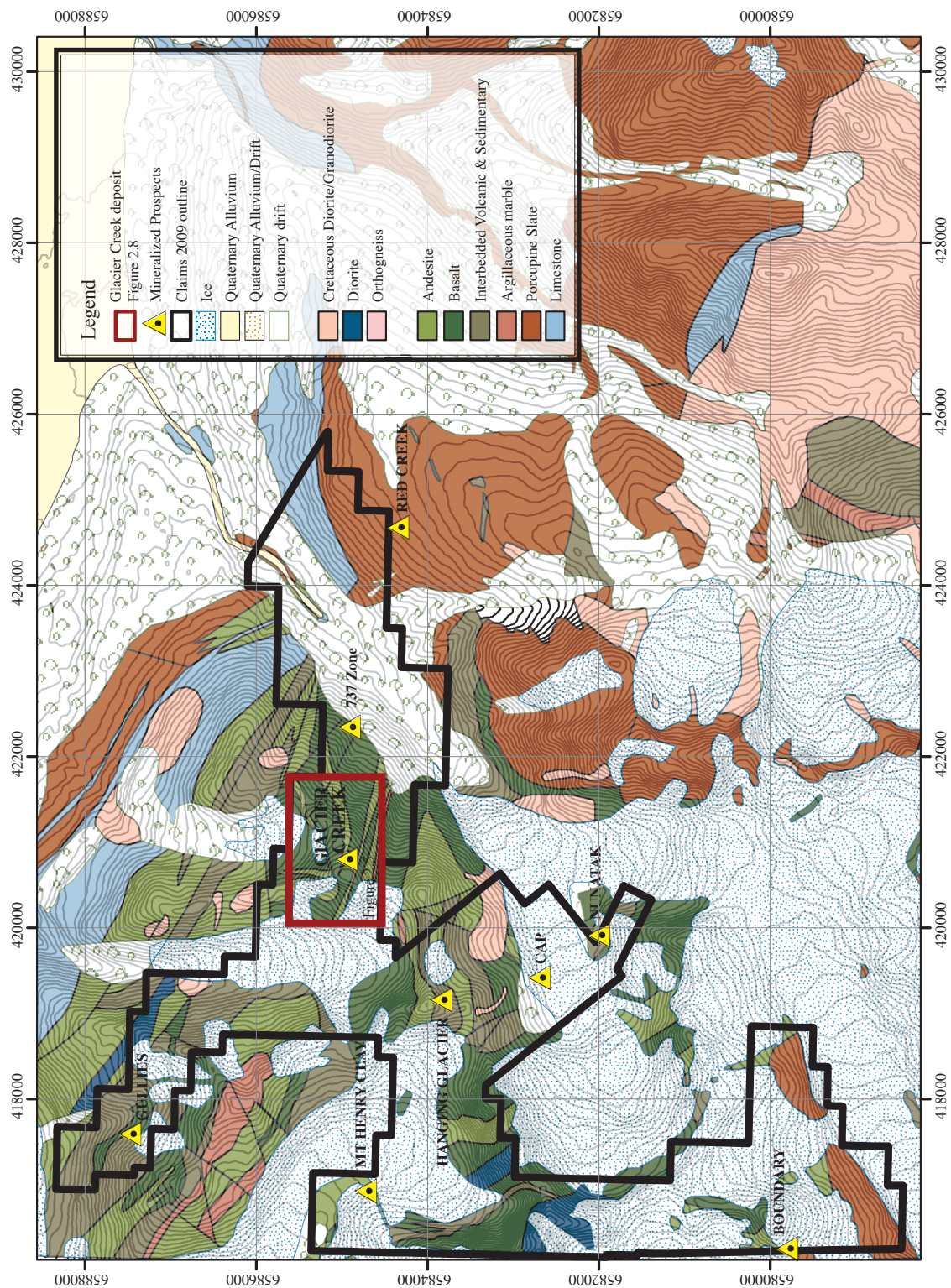


Figure 2.6. Property-scale geology map of the Palmer property. 5 VMS occurrences exist <5 km west of the property, in B.C. Modified from Redman et al., (1985).

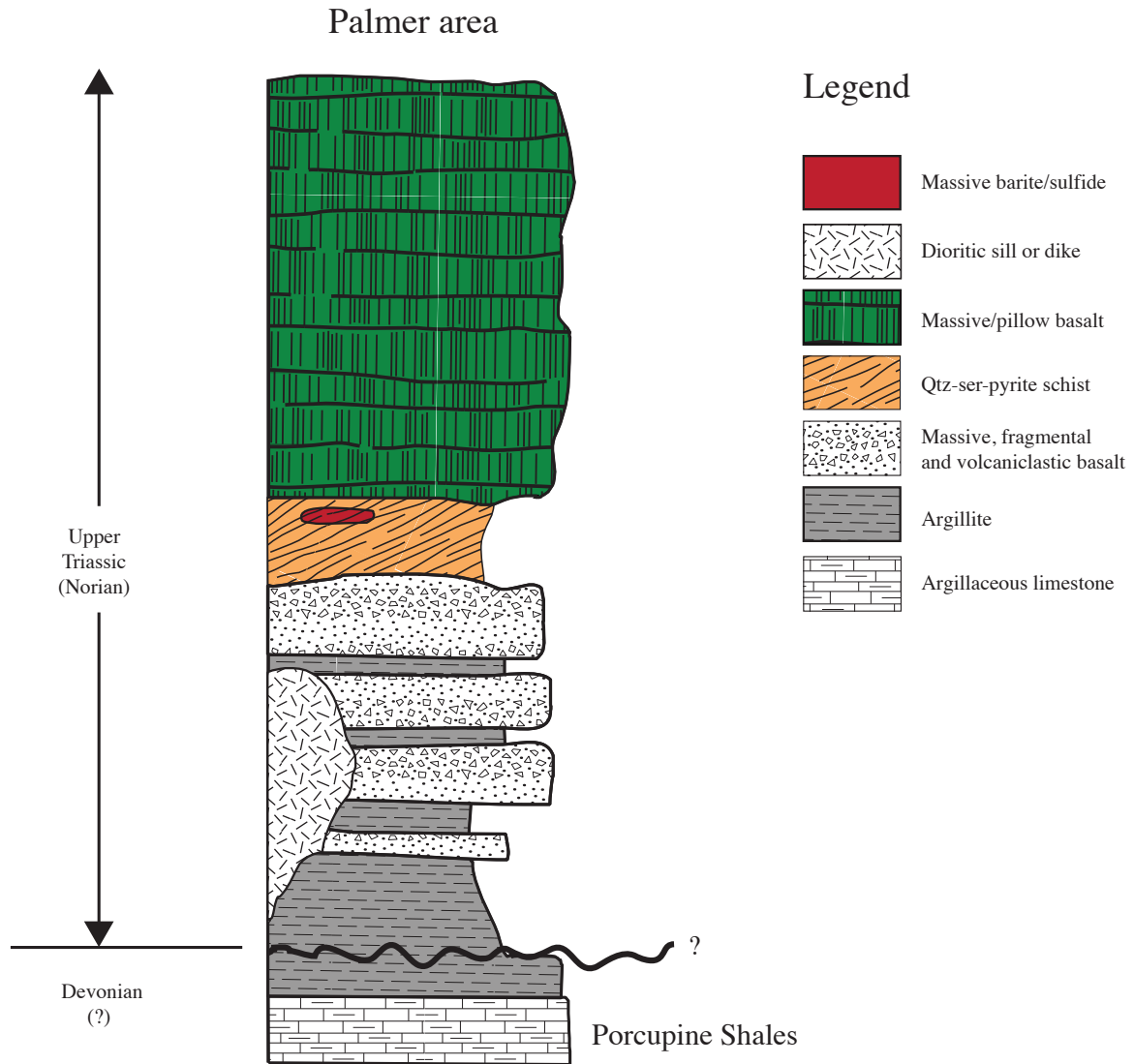


Figure 2.7. Generalized stratigraphic section for the Palmer area. Devonian shales and limestone unconformably underlie a package of mafic volcaniclastic and hyaloclastic rocks intercalated with calcareous argillites and tuffaceous rocks. A thick sequence of altered rocks and minor, local rhyolite host massive sulfide. A thick package of mafic volcanic rocks cap the sequence. Modified from Taylor et al (2008).

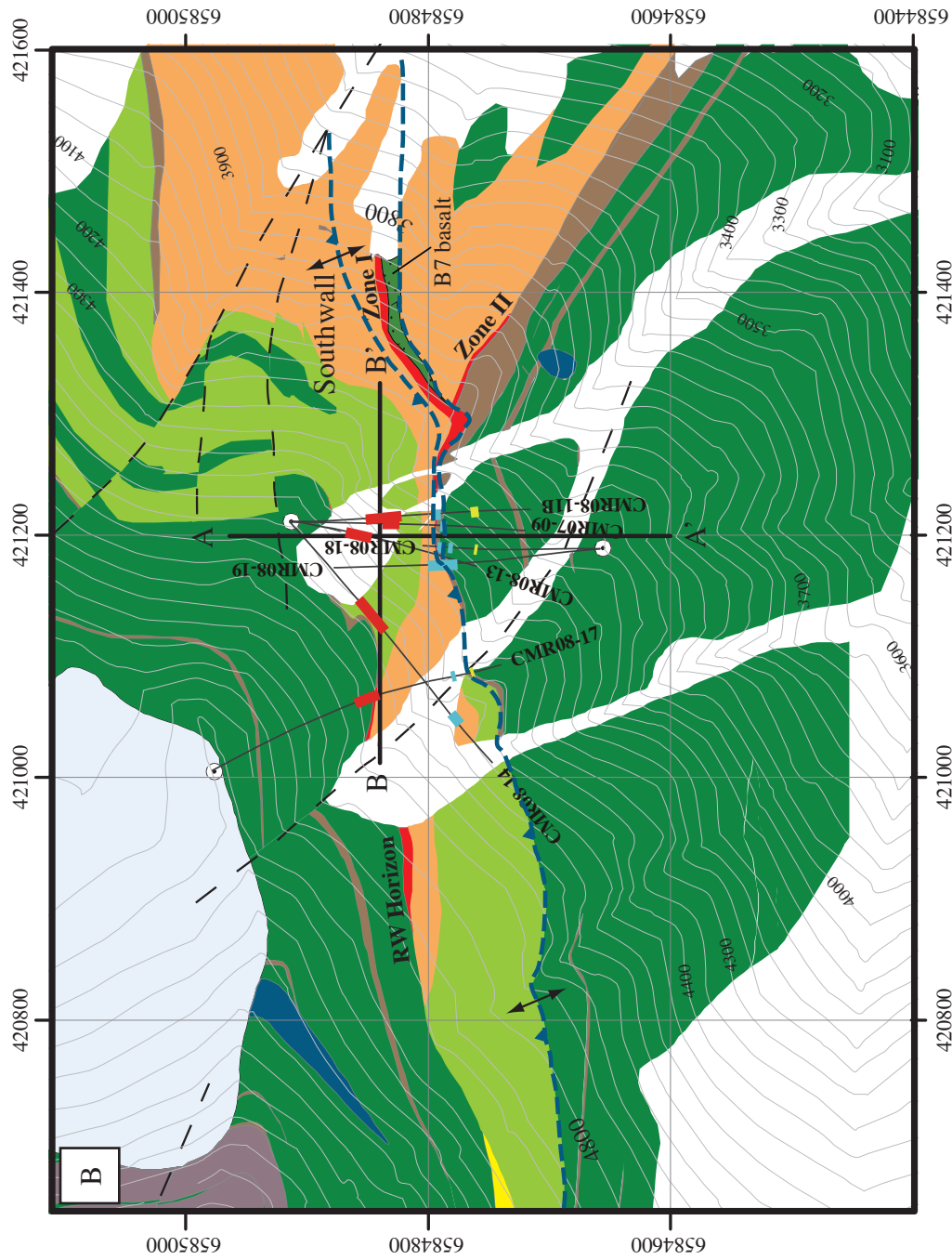


Figure 2.8. B) Geology map of the southwall zone. See Figure 2.8 (A) for reference and legend. A-A' outlines Figure 2.9 and 4.4 cross-sections. B-B' outlines

Figure 2.10 long section. Blocks on the drillhole traces represent Zone I (red), Zone II (Blue) and Zone III (yellow) intersections.

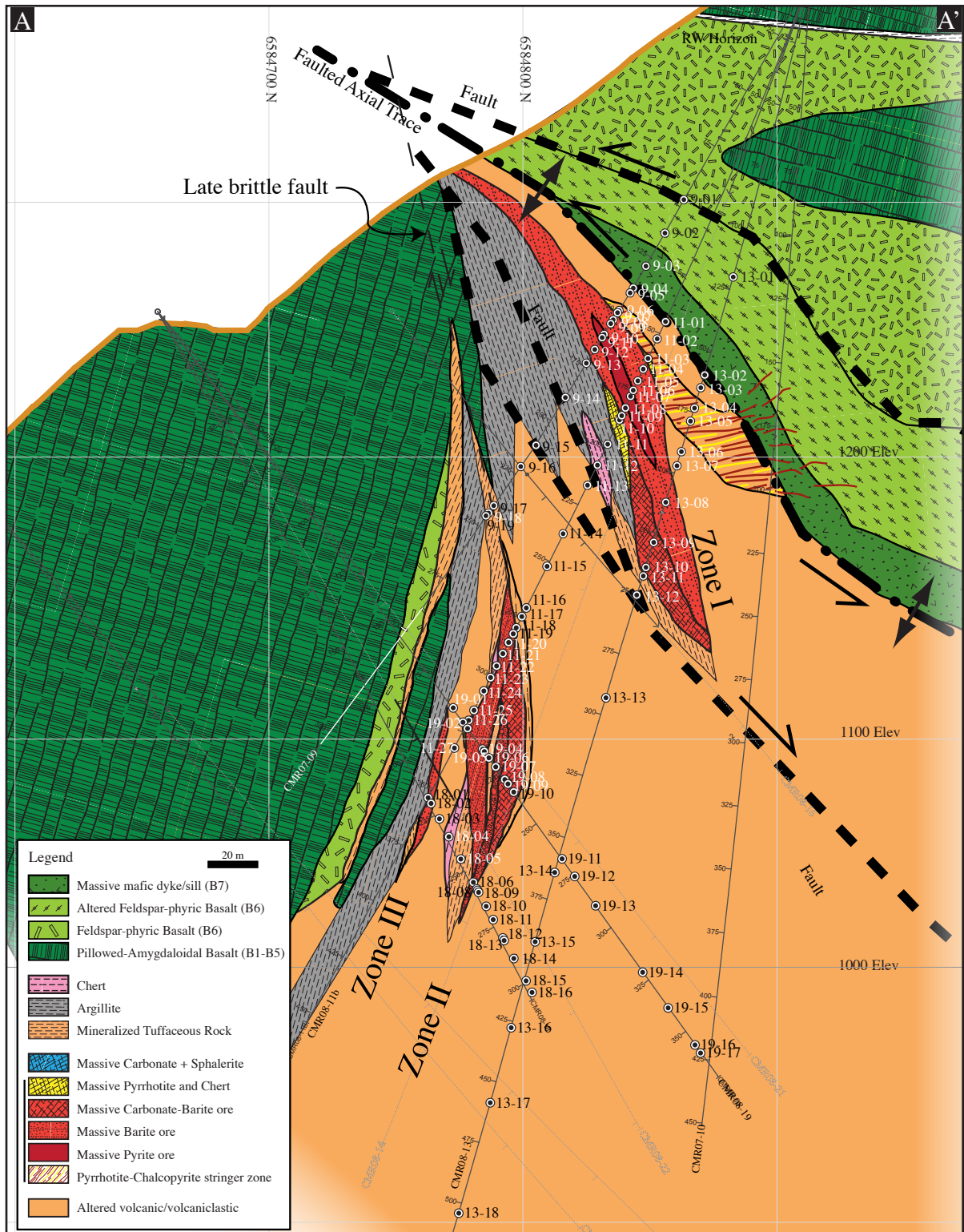


Figure 2.9. Cross-section through the southwall zone at 421200E, showing Zones I, II and III. Sample locations indicated by bull's eyes. Surface contacts projected from surface mapping.

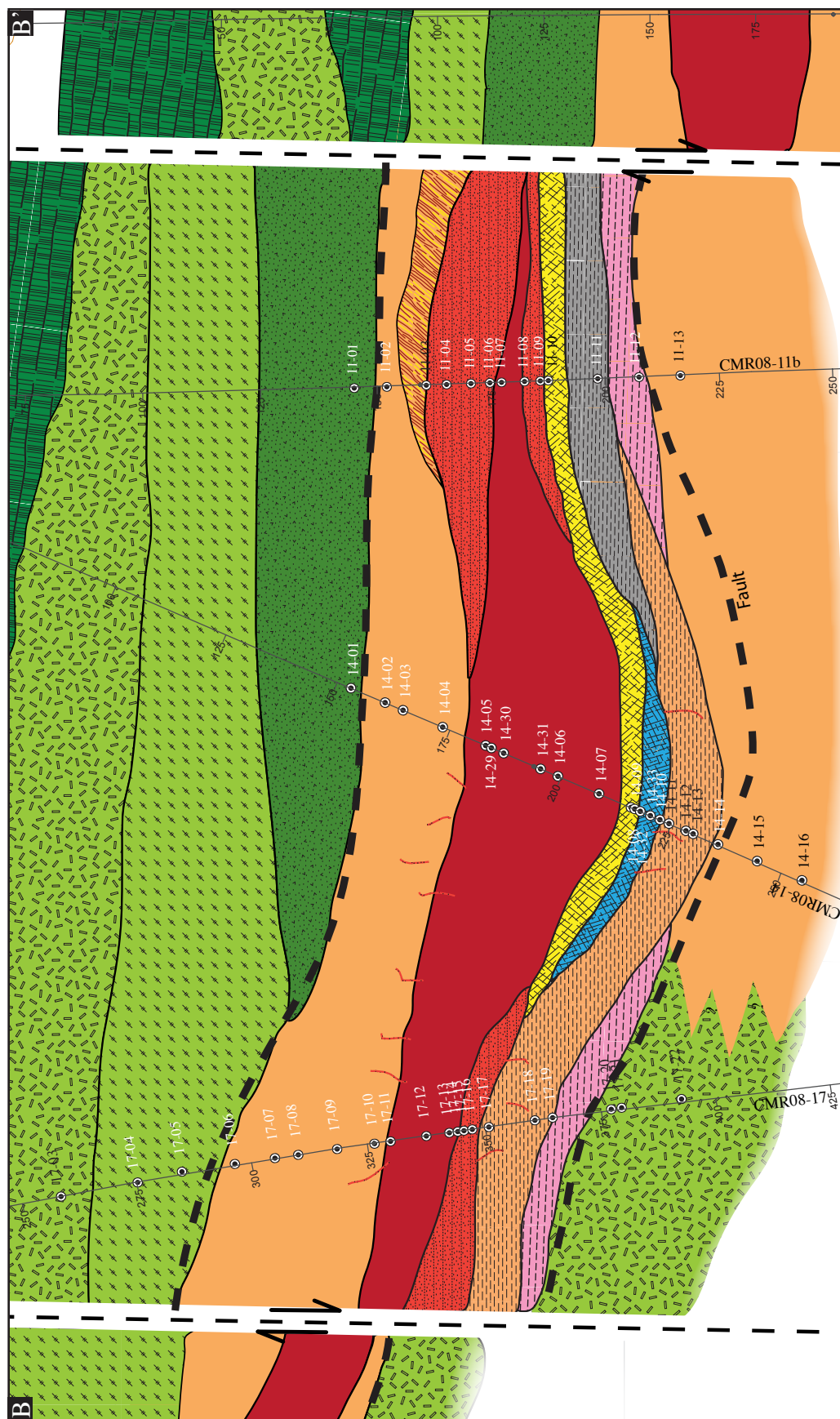


Figure 2.10. Long-section of Zone I. See Figure 2.9 for Legend.

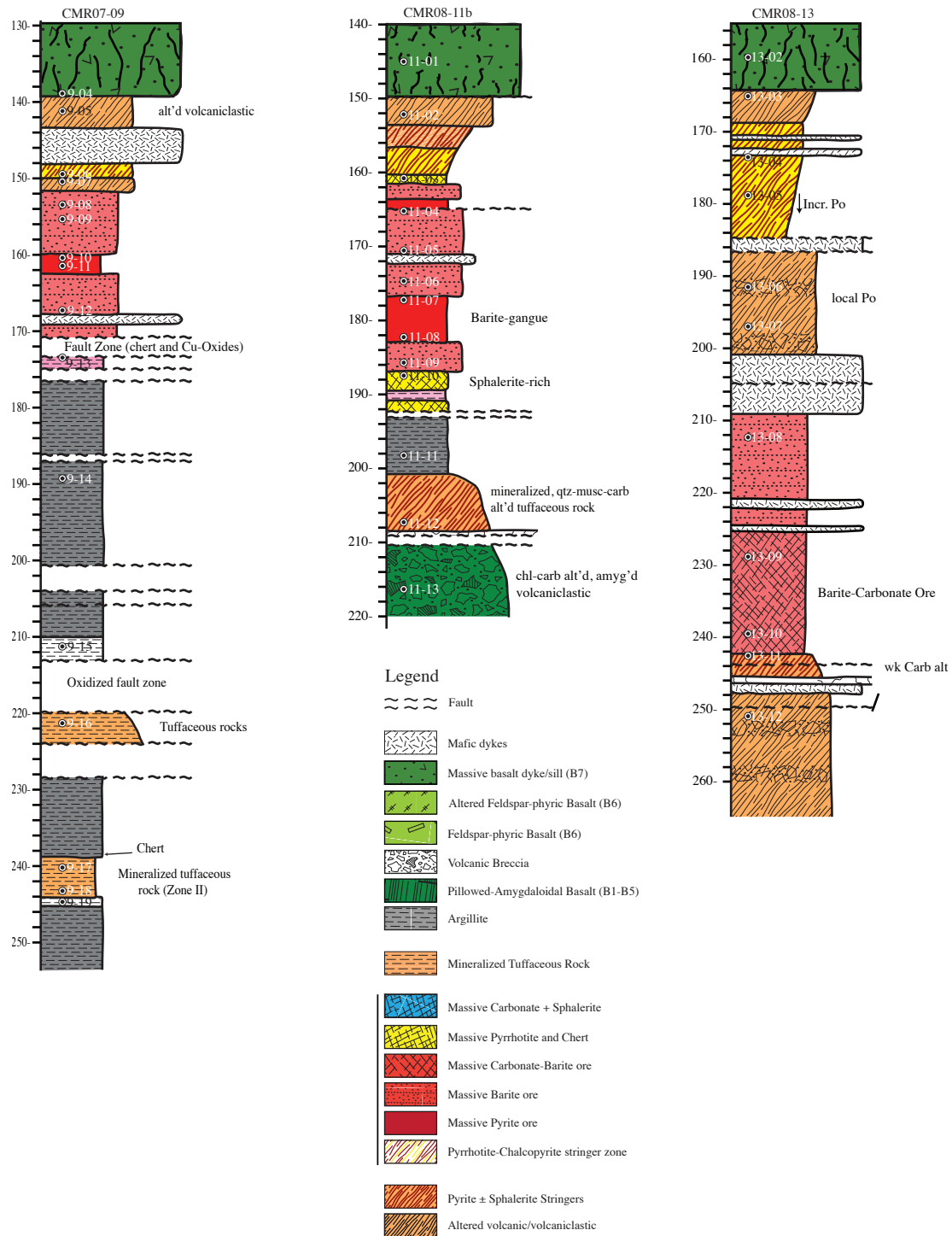


Figure 2.11. Graphic logs of mineralized zones from 7 drill holes logged during this study. Samples are indicated with thin-section ID number.

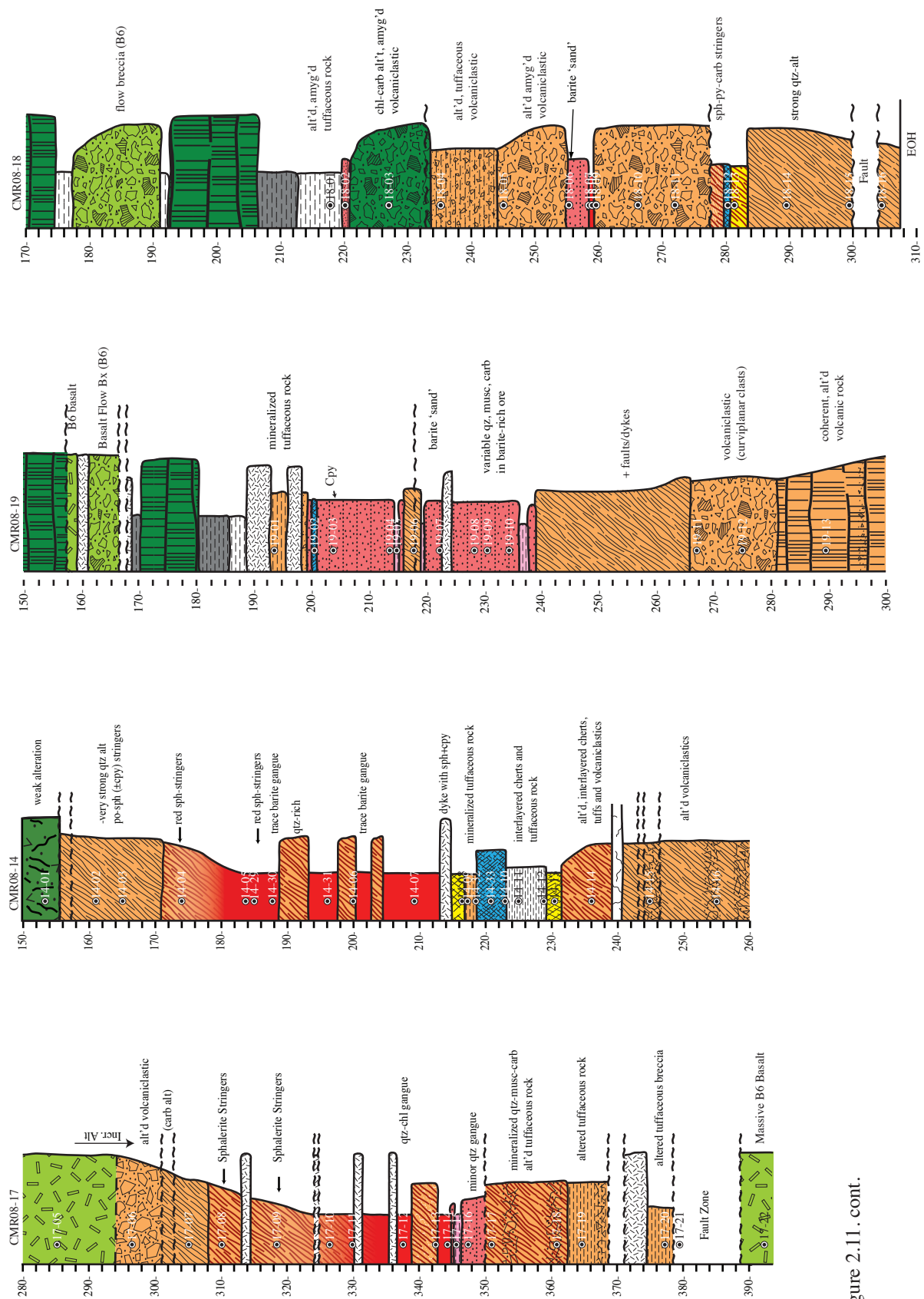


Figure 2.11. cont.

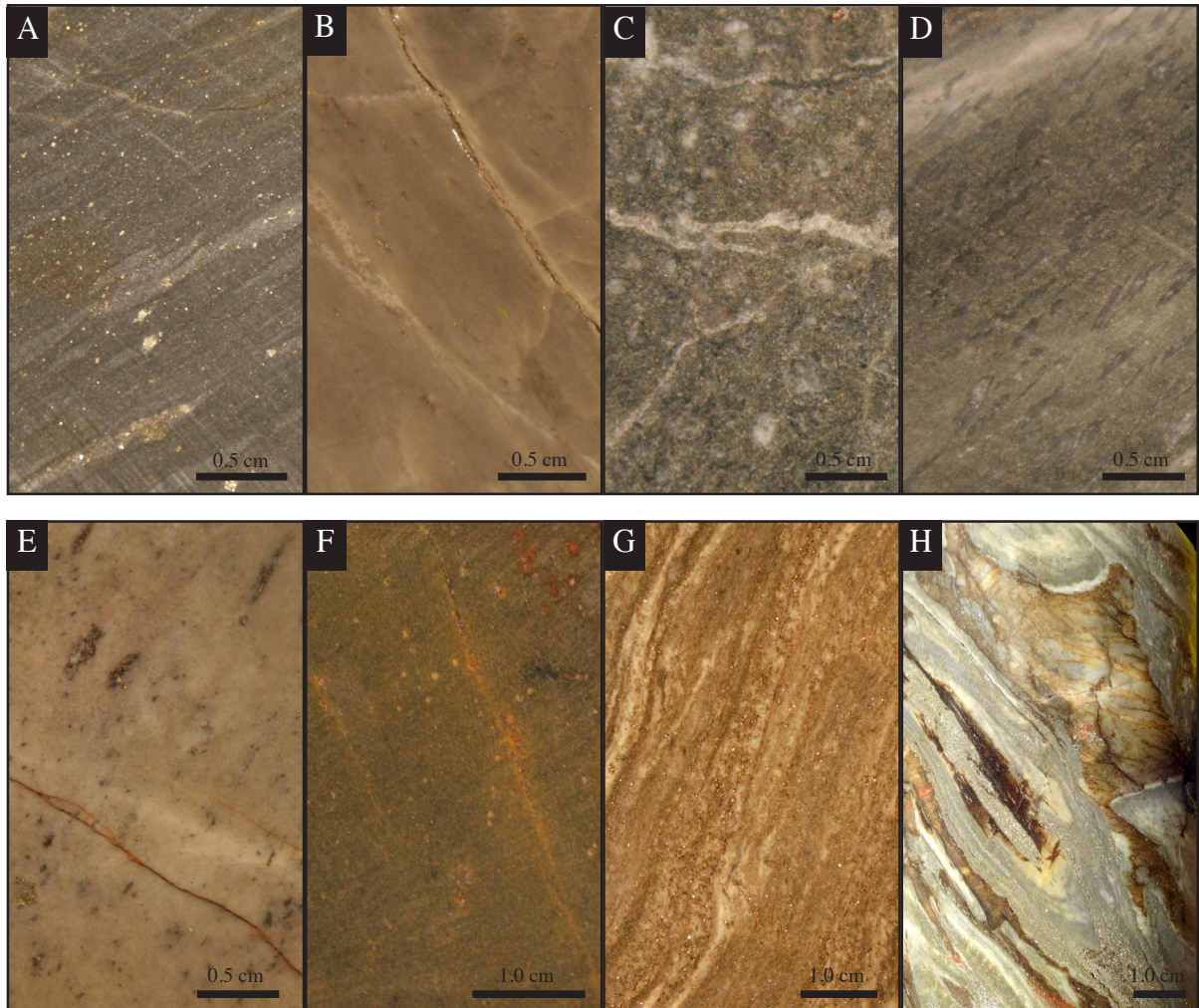


Figure 2.12. Drill core photographs showing the main rock units of the Glacier Creek deposit stratigraphy. See Figure 2.9 and 2.10 for samples locations. Photos are of wet, cut core. A) Laminated calcareous argillite with disseminated pyrite grains and sandy lenses. NS9-14. B) Homogenous chert. NS17-15. C) Undeformed feldsparphyric basalt, cut by thin calcite veins. NS17-01. D) Moderately altered feldsparphyric basalt. Feldspar phenocrysts have been replaced by muscovite, and flattened. NS17-04. E) Altered, calcareous tuffaceous rock. NS14-11. F) Massive, weakly altered, fine-grained mafic volcanic or subvolcanic sill/dyke. NS9-03. G) Finely layered, strongly quartz-muscovite-pyrite altered volcanoclastic. NS13-17. H) Quartz-muscovite-pyrite-carbonate altered volcanoclastic rock with weakly deformed clasts. NS19-12.

Chapter 3

MINERALIZATION

The Glacier Creek massive sulfide deposit consists of four known tabular, massive sulfide lenses. These lenses occur on both limbs of a megascopic, deposit-scale anticline, disrupted by significant faulting. This study focuses on the mineralization in Zones I, II and III lenses, which are located on the overturned, steep, south-facing limb of the fold referred to as the ‘southwall’ (Figure 2.8 and 2.9). The RW zone, located on the north-facing, gently dipping upper limb is described briefly below but is not a focus of this study.

At the time of writing, all ore lenses remained open in all directions, therefore much of what is known of the geometry, metal zonation, grade distribution and depositional characteristics may change with further exploration. In 2010, twenty-six drillholes were used to establish a resource estimate of 4.75 Mt of ore (Greig and Giroux, 2010), seven of which have been used to study the ‘southwall’ massive sulfide lenses (Figure 2.8 and 2.11). Of the four massive sulfide lenses discovered to date, the majority of tonnage and grade currently lies within the RW zone and Zone I lenses. In this study, particular attention has been attributed to Zone I in order to address several problems related to its stratigraphic location, structure, and the possibility for expansion through exploration.

3.1 Massive Sulfide Zones

Zone I

Zone I has been intersected by 11 drillholes to date and outcrops for over 120 m

along the southern slope of Mt. Morlan (Greig and Giroux, 2010). The massive sulfide lens is located at the core of the deposit-scale anticline and appears to have been disrupted by faulting. Mineralization in several drillholes is terminated by a fault zone, although the exact orientation of the fault is ambiguous (Figure 2.9).

Zone I is up to 35 m thick, approximately 200 m wide, and over 300 m in length, forming a tabular body. It is composed mainly of massive pyrite (Py>Ccp>Qtz), semimassive pyrite (Py>Qz>Ccp-Sp) and massive to layered barite ore (Brt>Sp~Py>Ccp). Pyrrhotite-chalcopyrite and pyrite $\pm$ sphalerite stringers overlie and underlie massive pyrite and barite ores (Figures 2.9, 2.10 and 2.11). Cherty, tuffaceous, or carbonate-rich ores presently underlie the massive ores, suggesting that Zone I is overturned and on the south-verging limb of the anticline.

Zones II and III

Zones II and III have been intersected by 15 drillholes. Zone II outcrops discontinuously for over 100 m as a 2-3 m thick, leached, stratiform massive barite-sulfide and chert horizon (Figure 2.8; Greig and Giroux, 2010). The lenses are stacked, with Zone III stratigraphically above and south of Zone II, and are separated by strongly altered basalt and volcanoclastic material. These lenses stratigraphically underlie argillite and a thick package of pillowed and amygdaloidal hanging-wall basalts (Figure 2.9). Zone II is up to 27 m in true thickness, approximately 200 m wide and extends over 200 m in length. Zone III is up to 10 m in true thickness, up to 200 m wide and over 400 m in length. Most of Zones II and III consist of massive, mineralized barite ore, with thin mineralized chert and carbonate horizons

stratigraphically above and below (Figure 2.9). Zone III also contains significant resedimented barite-sulfide mineralization, similar to that seen in several Kuroko-style deposits in Japan (Eldridge et al., 1983).

RW Zone

The RW zone, on the upright limb of the anticline, was the initial discovery massive sulfide lens at the Glacier Creek deposit. The zone outcrops discontinuously along both the western and southern faces of Mt. Morlan, overlying a coherent rhyolite unit (Figure 2.8). A western section and an eastern section of the RW zone have been partially defined, but have yet to be correlated by drillholes. A large portion of the eastern section has been oxidized and leached of much of its sulfide content. The mineralized zone grades laterally and vertically into tuffaceous rocks, much like the other lenses (Green, 2001).

3.2 Principal Mineralization Styles

Five mineralization styles have been identified from the three massive sulfide lenses sampled in this study and are grouped according to dominant mineral assemblages and texture. The principal mineralization facies are summarized in Tables 3.1 and 3.2.

Barite Ore (Zn-rich)

Barite-rich ores contain abundant pale honey-brown, low-Fe sphalerite with variable amounts of pyrite, locally minor galena, tetrahedrite, arsenopyrite and variable concentrations of late chalcopyrite (Figures 3.1 A-B and 3.2). Barite ores contain >50% barite and 30-50% sulfides and resemble some types of “black ore” in the Kuroko deposits (e.g.,

Eldridge et al., 1983). Chalcopyrite occurs locally as bands and as late, massive, anhedral grains forming around and replacing pyrite and sphalerite. Barite ores also contain minor microcrystalline to fine grained arsenopyrite, tetrahedrite and galena. Trace amounts of microcrystalline magnetite and rare covellite (as coatings on sphalerite or chalcopyrite) are also observed locally. Some samples may contain up to 30% quartz (e.g., sample NS11-19, NS09-10) and trace muscovite, although barite is the dominant gangue mineral. Establishing the paragenesis is difficult as all minerals have been completely annealed and recrystallized, forming granoblastic mosaics of polygonal grains. Compositional bands dominated by either barite, sphalerite, pyrite or chalcopyrite occur locally (Figures 3.1 A and 3.2). This compositional banding is likely primary, by comparison with Kuroko analogs, but may have been enhanced by deformation. Chalcopyrite is known to mobilize more readily during annealing (Vaughan and Craig, 1997) and the locally observed chalcopyrite banding may be a result of pressure solution/transposition.

Barite-rich ore grades locally into massive pyrite ore as sulfide content increases and quartz becomes the dominant gangue. Barite ore also grades into a barite-carbonate ore at the upper limits and flanks of Zones I, II and III, with carbonate increasing in abundance at the margins of the lens (Figures 2.9, 2.10 and 2.11). Locally a resedimented barite-carbonate ore is found, resembling a 'barite sand' as seen in Kuroko-style VMS deposits (e.g., Eldridge et al., 1983; Sewell and Wheatley, 1994).

Massive Pyrite Ore (Cu-rich)

Massive pyrite ores dominate Zone I and a small portion of Zones II and III. They

are classified as having >50% sulfide content, typically as pyrite and chalcopyrite with lesser sphalerite and associated minor quartz and/or barite gangue (Figure 3.3). These ores resemble the ‘yellow ore’ of the Kuroko deposits (e.g., Eldridge et al., 1983). Minor muscovite, carbonate, chlorite and feldspar are interstitial to pyrite or occur as veins and stringers. Chlorite is rare but may occur as minor gangue at the center of the Zone I lens (Figure 3.3 B). The massive ores sampled contain up to 85 vol.% pyrite, up to 40 vol.% chalcopyrite, and up to 10 vol.% sphalerite. The pyrite typically occurs as subhedral to euhedral, granular masses within a matrix of massive chalcopyrite and/or sphalerite and fine- to coarse-grained, polygonal quartz or barite. Pyrite is commonly heavily fractured, with chalcopyrite and sphalerite filling fractures or at grain boundaries and locally replacing pyrite (Figure 3.3 C). Massive pyrite ores may have trace disseminated microcrystalline to fine-grained arsenopyrite and tetrahedrite and rarely trace covellite along fractures.

The massive pyrite ores commonly exhibit compositional banding (Figure 3.3 A) with variable amounts of sphalerite and chalcopyrite, typical of many recrystallized massive sulfide ores (eg., Yui, 1983). They also show fine-grained, dispersed pyrite followed by later, coarser, anhedral pyrite-with remobilized intergranular chalcopyrite or sphalerite.

Semimassive and Stringer-style Mineralization

Semimassive and stringer-style pyrite ± sphalerite ± chalcopyrite zones (Figure 3.4) stratigraphically underlie and form feeder-zones to massive sulfide mineralization. They consist of 30-50 vol.% and 15-30 vol.% sulfide, respectively. These zones show seafloor replacement type mineralization and differ from strong muscovite-quartz-pyrite alteration

in that they contain >2% base metal sulfides and significantly more quartz gangue. Pyrite grains occur as very fine disseminated grains and as coarser grains within stringers. Sphalerite and chalcopyrite are also disseminated with pyrite and within stringers (Figure 3.1 G and 3.4). The greater base-metal and quartz content suggest that these represent hydrothermal fluid pathways within the altered footwall to the ore lenses (Chapter 4). Other gangue minerals include muscovite and locally minor carbonate, chlorite and albite. These last three typically occur within sulfide stringers that cut pervasively quartz-altered rock. Minor muscovite occurs pervasively with quartz and as coarser grains within stringers.

Locally, stratigraphically below Zone I massive sulfide mineralization within the alteration zone and also stratigraphically below Zone II and III mineralization (Figure 2.9 and 2.10), stringer-style mineralization is dominated by pyrrhotite and chalcopyrite, rather than pyrite and sphalerite (Figure 3.5). This facies is characterized by <50 vol% sulfides as stringer-style and stockwork veins and >50 vol.% gangue of quartz (>30 vol.%) and muscovite (>20 vol.%; Figure 3.1 K). The chalcopyrite content ranges from 3 to 15 vol.%, with pyrrhotite content up to 40 vol.%. Trace sphalerite (< 1 vol.%) is present in most samples as dark red, anhedral grains. Chalcopyrite and sphalerite locally replace pyrrhotite (Figure 3.5 C and D). Minor pyrite occurs as “bird’s eye” replacement around the edges of pyrrhotite grains and locally as minor, fine-grained, disseminated subhedral to euhedral crystals. Muscovite typically occurs as stringers, cross-cutting earlier more pervasive quartz alteration. Trace amounts of chlorite, carbonate and albite also occur within stringers, similar to the pyrite-dominant facies.

Massive Pyrrhotite Ore

Massive pyrrhotite ores (Figures 3.1 D and 3.6) occur both above and below massive pyrite ores and barite ores within Zones I and II. They contain more than 50 vol.% sulfide with up to 15 vol.% chalcopyrite, up to 20 vol.% sphalerite and <1 vol.% pyrite. Chalcopyrite and sphalerite occur within massive pyrrhotite and in fractures in pyrrhotite. Sphalerite is dark red to burgundy and has dark red internal reflections characteristic of high-Fe sphalerite. Sphalerite typically exhibits chalcopyrite disease. Pyrite has a “bird’s eye” texture, replacing pyrrhotite along edges of grains and fractures (Figure 3.6 F). Fine- to very coarse-grained, locally euhedral quartz and carbonate, suggestive of porphyroblastic growth, occur within massive pyrrhotite (Figure 3.1 D and 3.6 A and D). Chalcopyrite and sphalerite are concentrated around the edges of these grains.

The dominant gangue minerals are quartz (<20%) and carbonate (<50%) with minor (<5%) very fine-grained muscovite (Figure 3.6 D). Booklets of pale, euhedral chlorite (Figure 3.6 E) occur locally within fractures and as disseminations. Chlorite replaces, or occurs as inclusions in quartz. Trace hematite and rare molybdenite are present within muscovite-rich patches cross-cutting quartz and sulfide grains (Figure 3.6 D).

Carbonate Ore

Carbonate-rich ores (Figures 3.1 H and 3.7) are found at the stratigraphic top of Zone I (Figures 2.9 and 2.10) and in a very small sulfide lens intersected in drillhole CMR08-18 (sample NS18-12). Carbonate ores typically contain 60 vol.% coarse-grained carbonate, with minor quartz, muscovite and dark green chlorite, up to 35 vol.% dark red-burgundy

sphalerite and up to 5 vol.% chalcopyrite. Trace amounts of partially replaced (Ba-K)-feldspar are also observed. More massive carbonate contains relatively coarse, subhedral to euhedral, interlocking crystals of calcite (up to 3 mm). Late chalcopyrite stringers cross-cut carbonate as thin veinlets, and sphalerite is disseminated throughout, locally as relatively coarse anhedral to euhedral grains (up to 1 mm) forming aggregates (Figure 3.1 H). These rocks appear to be highly recrystallized.

One sample from CMR08-14 of carbonate ore that caps Zone I is dominated by relatively coarsely crystalline quartz, with lesser carbonate, minor chlorite, abundant pyrrhotite, lesser sphalerite and chalcopyrite, and minor ‘bird’s eye’ pyrite replacing pyrrhotite. It may represent annealing of primary carbonates and precipitation of metals as hydrothermal fluids passed through a tuffaceous limestone or cherty horizon capping Zone I.

Resedimented, Tuffaceous Barite-Carbonate Ore

At the margins of Zones I and II and to a lesser extent in III, there is a mix of carbonate-rich and sulfide-rich mineralization. These include a finely-layered barite-carbonate-sulfide facies, a sulfide-clast and barite crystal-rich facies, and a variably mineralized tuffaceous and cherty facies. Barite ore grades outward into a barite-carbonate ore as the disseminated carbonate content increases (Figure 2.9) and gradually becomes more tuffaceous, with interlayered barite and carbonate laminae (Figure 3.8 F). Above this unit is a weakly mineralized, barite-free tuffaceous horizon. Several of these tuffaceous and calcareous units contain abundant, disseminated (Ba-K)-feldspar. The capping tuffaceous horizon (Figure 3.8 D) overlies the entire lens and is characterized by weak mineralization, (Ba-K)-feldspar,

barian muscovite, local albite, cherty patches/layers and is strongly calcareous. It is intercalated with cherts and altered volcanoclastics and may continue laterally along the ore horizon. These rocks are difficult to distinguish from the pervasive muscovite-quartz-pyrite altered rocks in drill core. However, the high Ba-content and lack of barite, the calcareous nature, and the overall 'tuffaceous' appearance can help to identify these horizons in drill core.

Cherts and tuffaceous units above Zones I and II are locally cross-cut by thin pyrite $\pm$ sphalerite stringers containing quartz, carbonate, albite and muscovite, which is suggestive of continued hydrothermal activity after to the deposition of each lens. Tuffaceous units locally contain chalcopyrite, possibly as replacement of amygdules and/or feldspars and sphalerite (Figure 3.8 D and E).

Locally within Zone II the barite-carbonate ore has a distinctive clastic texture (Figure 2.11 and 3.8 A-C). These rocks contain euhedral, and locally broken, barite crystals and clasts of massive barite, sulfide and/or quartz within a very fine-grain carbonate matrix. Massive barite clasts are irregular, angular and can reach up to 1 cm across. Other minerals include minor to trace albite, muscovite and chlorite. Sulfides are dominantly pyrite and pale honey-brown sphalerite, with minor to trace chalcopyrite, galena, tetrahedrite, and arsenopyrite. Chalcopyrite typically replaces pyrite, which is framboidal and less recrystallized than in the main massive sulfide lenses (Figure 3.8 C). The clastic nature of this facies and the abundant broken crystals of barite suggest that this material was resedimented.

3.3 Metal Zonation

Metal zonation plays a key role in understanding the structure at the Glacier Creek deposit. Constantine Metal Resources Ltd. provided the assay data to help constrain metal zonation in each lens. The assays are from halved core, ranging from 30 cm to 1.5 m in length, and sampling intervals were restricted to lithology boundaries. Data from, drill ‘cave’, and fault zones were removed before plotting. Twenty plots of Cu, Zn, Pb, Au and Ag from 16 drillholes are shown in Figures 3.9 and 3.10. Only drillholes with significant intercepts and grades were chosen for comparison. With a few exceptions, all lenses exhibit typical, vertical metal zonation, with Cu-rich zones underlying Zn and Pb-rich zones.

Zone I

Metal zonation in Zone I shows generally Cu-rich ore at the tops of the holes and Zn- and Pb-rich ore at the bottom, suggesting that the lens is overturned. This is true for holes 14, 17, 23b, 24, 25, 40, and 42 (Figure 3.9), all of which exhibit typical zonation for a single large ore lens. Locally, a spike of Zn or Cu from sulfide stringers located stratigraphically below (structurally above) the lens is seen (e.g., CMR08-14, Zone I). The fact that Zone I appears to be overturned has significant implications for the structure at Glacier Creek, in particular the location of the axial surface of the deposit-scale anticline and the nature and extent of faulting. Several drillholes (CMR07-09, CMR08-11b and -13) exhibit complicated zonation, which may reflect structural complications. Gold and silver show generally parallel trends, and appear to correlate variably with both Cu and/or Zn and Pb increases. An example of this is seen in drillhole CMR09-24 (Figure 3.9), where Au and Ag increase with Cu around 322 m, and again with Zn and Pb around 335 m. In general, Zone I has a chalco-

pyrite, pyrrhotite and Fe-rich sphalerite stringer zone underlying a barite, pyrite, chalcopyrite and Fe-poor sphalerite massive sulfide lens. The top of the lens has carbonate-rich ores with pyrrhotite, chalcopyrite and Fe-rich sphalerite (Figure 3.9).

Zones II and III

Zones II and III exhibit typical VMS metal zonation. Several drillhole intersections of Zone II, however, can be divided into three closely spaced intervals, based on metal zonation and lithology (Figure 2.11 and 3.10). Drillhole CMR08-19, for example, shows 3 intervals, with a coherent barite ore zone from 200-215 m (downhole depth) and an underlying resedimented barite ore zone, from 220-240 m (Figure 2.11). These are separated by a thin, altered volcaniclastic unit and a thin horizon of chert. The resedimented barite section exhibits poor metal zonation. Below these two intervals is a third, very thin (1 m) barite horizon separated by a thin (1 m) chert horizon. CMR08-22 (Figure 3.10) contains three closely stacked lenses, separated by thin horizons of altered volcaniclastic rock. CMR10-40 contains two stacked lenses of Zone III separated by a thin section of chert and argillite. These drillholes, which contain mixed barite, chert, argillite and volcaniclastic rock, resemble the flanks of a massive sulfide mound. Other drillholes intersecting Zones II and III appear ambiguously zoned due to the angle of intersection. Several, including CMR10-40, CMR08-14 and CMR08-11b, intersect ore at very low angles. Gold and silver concentrations in these holes behave similarly to Zone I, with Au and Ag increasing locally with both Cu and/or Zn and Pb values.

RW Zone

Drillholes intersecting the RW zone (both East and West zones) show unequivocal metal zonation (i.e., Cu below Zn below Pb, with a deeper stringer zone). RW Zone mineralization is spatially associated with a large rhyolite body and may represent a more proximal setting during deposition. Massive sulfides have been intersected both above and below the rhyolite unit. This contrasts with the clastic-associated, locally resedimented Zone II and III ore intersections, which may have formed in topographic lows or on the flanks of the volcanic center.

No large, significant, pipe-like stringer zone has been discovered at the Glacier Creek deposit to date. This may be due to a lack of focused, high temperature hydrothermal upflow through the permeable volcanoclastic rocks, that host Zones II and III (and part of Zone I) or transposition of originally discordant stringer networks. Local, small stringer zones have been intersected below the RW Zone and Zone I, within more competent feldsparphyric basalts and further exploration may reveal more stringer-style mineralization.

3.4 Trace Element Geochemistry

The trace element geochemistry of the different ore types was determined on 25 sulfide-rich samples (<10 cm of quartered N-size drillcore) from Zones I, II and III. The sample locations are indicated in Figures 2.9 and 2.10. Median concentrations of all elements in the principal ore types are reported in Table 3.3 and a Pearson correlation matrix for select elements is presented in Table 3.4.

Barite Ore

Barite-rich ore samples have the highest concentrations of Zn in the deposit (up to 22.9 wt.% Zn), locally high Pb (up to 2.1 wt.%) and high Hg concentrations (723-13000 ppb). Mercury and Cd correlate very strongly with Zn in all ore types. Cadmium concentrations typically range from 200-600 ppm and can be up to 1420 ppm. Arsenic (up to 1140 ppm) and antimony (up to 750 ppm) are notably enriched in the barite ores and also correlate strongly with Zn. Strontium correlates very strongly with Ba, likely substituting for Ba in barite and ranges from 1500-5000 ppm in the barite ores. Gold and Ag concentrations are locally elevated within the barite ores (up to 0.3 ppm Au and 226 ppm Ag). High Au and Ag concentrations appear to correlate with petrographically observed occurrences of galena and tetrahedrite within barite ores.

Massive Pyrite Ore

Massive pyrite ores typically contain elevated Cu (up to 10.7 wt.% Cu). Gold, silver, and arsenic concentrations correlate strongly with copper within the massive pyrite ores. Massive pyrite ores typically have moderate to high Zn concentrations, varying from 2.8-4.1 wt.% Zn; however, Zn does not correlate with Cu and shows a negative correlation across the deposit (Table 3.4). Mercury concentrations are high (1340-4600 ppb) where sphalerite is present. Thallium is also elevated compared to other ore types, ranging from 15-30 ppm, but does not correlate with any other ore elements. Antimony concentrations are quite variable within massive pyrite ore, ranging from below detection limit up to 300 ppm and do not correlate with other volatile elements (As or Tl).

Semimassive and Stringer-Style Mineralization

Semimassive and stringer-style pyrite-sphalerite mineralization varies in mineralogy and composition with proximity to ore. Copper and zinc values can reach up to ~3.5 wt.% each. In contrast, pyrrhotite-chalcopryrite stringers contain up to 7.2 wt.% Cu and little Zn (<3000 ppm). Stringer-style mineralization also contains elevated, correlative concentrations of Rb (up to 93.7 ppm), V (up to 385 ppm) and Cs (up to 1.6 ppm) compared to all other ore types (Table 3.3 and 3.4). These elements occur within muscovite (see below), which may comprise up to 50% of stringer-style mineralization. The concentrations of other trace elements, however, are low (Table 3.3). No significant Au or Ag occur in this ore type (< 50 ppb and <5 ppm respectively).

Massive Pyrrhotite Ore

Massive pyrrhotite ores can be divided into chalcopryrite-rich and sphalerite-rich (Fe-rich sphalerite) end members. Cadmium and Hg correlate with Zn and have higher concentrations in the sphalerite-rich (up to 1130 and 1570 ppm respectively) than in the chalcopryrite-rich (up to 27 and 63 ppm respectively) massive pyrrhotite ore. Massive pyrrhotite ores contain very low Au, Ag, As, Sb, Sn, and Tl compared to massive pyrite ore (Table 3.3), regardless of Cu and Zn content. Manganese concentrations are high compared to other sulfide-rich ores (2000-6000 ppm) and correlate directly with carbonate content (CO₂ and CaO concentrations) as in other calcareous ore types.

Carbonate Ore

The carbonate-sphalerite ores contain anomalous Zn and Cu (7-20 wt.% Zn, 1-2

wt.% Cu) but low Au and Ag (100-300 ppb Au and 30-50 ppm Ag). Cadmium concentrations reflect the abundance of sphalerite and are close to ~1000 ppm. Arsenic and antimony concentrations are at or below detection. Manganese concentrations are anomalously high, averaging 6000-7500 ppm and correlate with the high carbonate content, as in other carbonate-bearing lithologies.

Resedimented, Tuffaceous and Barite-Carbonate Mineralization

The resedimented and barite-carbonate ores are similar in composition to the massive barite ores. They contain ~5 wt.% Zn, ~200 ppm Cd, and ~100 ppm Sb. Ratios of Hg:S are similar to massive barite ore and correlate with Zn content. Manganese concentrations are similar to other carbonate-rich ore types, with values of 1000-3000 ppm. However, the resedimented barite ores have higher Al_2O_3 and MgO, which is consistent with a tuffaceous component.

Tuffaceous rocks related to mineralization have anomalously high Hg, and often show distinct REE patterns with high Eu-anomalies. This is discussed in Chapter 4. They also have a high Ba content and high Ba/Sr ratios due to the presence of Ba-rich muscovite and feldspar.

3.5 Ore Mineralogy and Mineral Chemistry

Sulfide minerals within the Glacier Creek deposit are relatively coarse-grained, annealed and have simple chemistry. Massive sulfides typically show mosaics of equigranular minerals and polycrystalline aggregates. Minerals have straight to mutually curving bound-

aries, and locally myrmekitic or atoll textures. Local, primary textures such as framboids are observed at lens margins. Textural relationships are described below.

Sphalerite

Sphalerite varies throughout the deposit in terms of texture, colour and FeS content. Sphalerite is consistently sub- to anhedral, strongly annealed and recrystallized, and relatively coarse-grained compared to most other minerals (up to 2 mm). Sphalerite locally exhibit ‘chalcopyrite-disease’ (Figure 3.11 A; Barton, 1978) and is often rimmed by small grains or ‘coatings’ of chalcopyrite (Figures 3.2 E-F and 3.11 E). These likely formed during recrystallization as small chalcopyrite inclusions migrated and concentrated along the grain boundaries (Craig and Vaughan, 1981). Elsewhere sphalerite exhibits myrmekite-like intergrowths with chalcopyrite (Figure 3.11 C) suggesting that chalcopyrite has replaced sphalerite (Barton, 1978).

Sphalerite is the most abundant in the barite ores (up to 40 vol.%), as fine-grained (<1.0 mm), light honey-brown, resinous, sub- to anhedral grains disseminated with pyrites. These ores commonly appear recrystallized, and sphalerite is complexly intergrown with granular barite. Sphalerite also occurs interstitially between pyrite grains and often partially replacing pyrite to form atoll structures (Figure 3.2 D).

Sphalerite also occurs as discontinuous bands with chalcopyrite in the massive pyrite ores. These massive sphalerite bands alternate with massive chalcopyrite bands on a mm to cm scale (Figure 3.3 A). The sphalerite fills space between and partially replaces pyrite

(Figure 3.3 D) and is in turn partially replaced by chalcopyrite (Figure 3.3 C and F).

In the pyrite-sphalerite stringers, the sphalerite is typically pale to dark honey-brown (Figure 3.1 G), except where pyrrhotite is present, in which case the sphalerite is dark red (NS14-04, Figure 2.10). The sphalerite occurs as very fine to fine anhedral grains with pyrite, quartz and local feldspars and chlorite (Figure 3.4). These veinlets cut finer-grained, pervasively altered rock.

In the massive pyrrhotite and carbonate-rich ores the sphalerite is dark red to burgundy, resinous and very fine- to medium-grained (Figure 3.1 H). Within massive pyrrhotite ores the sphalerite occurs as anhedral masses and polycrystalline aggregates with pyrrhotite (Figure 3.6 B). In carbonate-rich ores sphalerite occurs as anhedral grains disseminated throughout coarse carbonate and chlorite gangue. Locally, sphalerite in these ores contains “pyrrhotite disease” involving arrays of pyrrhotite inclusions, possibly from the exsolution of FeS (Figure 3.11 B). Sphalerite also occurs with pyrrhotite and chalcopyrite within pyrrhotite-chalcopyrite stringers and is light red to orange with red internal reflections.

The Fe contents of sphalerite fall into two distinct groups, between 1-3 wt.% and 11-13 wt.% FeS (Table 3.5), which correlates very strongly with the presence of pyrrhotite. Massive pyrrhotite ores, carbonate-rich ores and stringers that contain pyrrhotite have high-Fe sphalerite, whereas barite-rich ores, massive pyrite ores and pyrite-sphalerite $\pm$ chalcopyrite stringers have low-Fe sphalerite. Cd contents range from below detection to 1.72 wt.%. Locally minor amounts of Mn also occur within sphalerites, up to 0.13 wt.%. A negative

correlation of Cd, Co, Mn and Fe with Zn exists, consistent with the substitution of these elements with Fe. Ag concentrations up to 1000 ppm were found in some sphalerite grains, but these may be due to submicroscopic inclusions of Ag-bearing minerals.

Pyrite

Within both barite-rich and massive pyrite-rich ores, which comprise the majority of the massive sulfide lens, pyrite is strongly recrystallized and occurs as aggregates of sub- to euhedral cubes (up to 80 vol.%). Pyrite grains are often heavily fractured and replaced to varying degrees by sphalerite and chalcopyrite (Figures 3.2 D and 3.3 C-D). Pyrite within stringer-style mineralization exhibits similar texture but is generally coarser than disseminated pyrites (Figures 3.3 E and 3.4 E). Fine- to medium-grained, euhedral pyrite cubes are also present locally within the pyrrhotite-chalcopyrite stringer zone. Within stringer zones, massive sulfide zones and resedimented ores, pyrite locally preserves primary framboidal or colloform texture (Figures 3.2 F, 3.4 A-B, 3.8 C and 3.11 F).

Pyrite is commonly observed as a replacement of pyrrhotite in massive pyrrhotite and pyrrhotite-chalcopyrite stringer style mineralization. The pyrite occurs as a microcrystalline mixture of pyrite and marcasite in a typical ‘birds eye’ texture (Figure 3.6 C; Craig and Vaughan, 1981). This texture is typical of oxidized sulfides that may have been exposed to near-surface weathering.

Pyrite throughout the deposit is essentially stoichiometric FeS_2 , with no significant or detectable trace elements. A single analysis returned 0.2 wt.% As, however, all other trace

elements, including Au are below detection.

Chalcopyrite

Chalcopyrite throughout the deposit occurs as massive stringers and granular masses, often replacing and/or occurring with either pyrite, sphalerite, pyrrhotite and tetrahedrite (Figure 3.3 C and F and Figure 3.6 F). Inclusions of chalcopyrite are commonly present within sphalerite as oriented grains ('chalcopyrite-disease'), and locally as a 'dusting' that appears to replace sphalerite (Figure 3.11 A and C respectively). Chalcopyrites contain no significant trace elements detectable by microprobe.

Pyrrhotite

Pyrrhotite occurs above and below the Zone I lens as massive and stringer-style mineralization and within carbonate-rich ores as annealed, individual grains (Figures 2.9, 2.10 and 2.11). Pyrrhotite is also present locally as minor inclusions within sphalerite (Figure 3.11 B) within carbonate ores. No significant trace elements were detected within pyrrhotite by microprobe analysis. Pyrrhotites have a relatively high Fe content, averaging 47.3 at.% Fe. It is consistently magnetic throughout the deposit, and therefore likely monoclinic (Vaughan and Craig, 1997).

Galena

Galena is most abundant in barite-rich ores, reaching up to 3 vol.%, as microcrystalline to fine, anhedral grains and locally as inclusions within pyrite, chalcopyrite, sphalerite

and tetrahedrite. Galena is easily remobilized and therefore commonly fills fractures within and triple-junctions between coarser grained minerals, in low-pressure areas (Figure 3.11 D and E).

Several grains of galena analyzed by microprobe contained high Ag, between 0.14 and 0.47 wt.%. Several grains also contain anomalous Se values of ~0.25 wt.% (Table 3.6). The higher Se values correlate with Ag, suggesting that the galena may contain trace Ag-selenides.

Arsenopyrite

Arsenopyrite occurs as trace, euhedral, microcrystalline to very fine-grained crystals, disseminated throughout the barite and massive pyrite ores. Similar to pyrite, arsenopyrite crystals are commonly fractured. Arsenopyrite, like pyrite, is a refractory mineral and recrystallizes easily to form euhedral grains, often overgrowing surrounding minerals (Figure 3.3 C and 3.11 D).

Several grains of arsenopyrite in gold-rich samples contained up to 0.75 wt.% Au in microprobe analyses but other grains from the same samples contain no gold at all. Some arsenopyrites contain relatively high amounts of Sb (up to 1.7 wt.% Sb). Boiron et al. (1989) show that within individual arsenopyrite grains, Au and Sb have an antipathetic relationship which appears to be evident in grains analyzed from Zone I. Gold may also concentrate locally within single arsenopyrite grains as submicroscopic inclusions, as shown by Cabri et al. (2000). The analyzed arsenopyrite is relatively enriched in Bi, with up to 1.0 wt.% Bi (Table

3.6), and Bi shows a relatively strong correlation with Au. Although Zn concentrations up to 0.16 wt.%, were detected, most analyzed arsenopyrite is small and the Zn may be contamination from surrounding minerals.

Tetrahedrite

Tetrahedrite occurs within barite and massive pyrite ore as anhedral, very fine to fine grains spatially associated with galena, arsenopyrite, and chalcopyrite (Figures 3.2 E and 3.11 D). As and Sb concentrations within tetrahedrites range from 1 to 14 wt.% As and 7 to 26 wt.% Sb (Table 3.7 and Figure 3.14). Silver contents are quite significant, reaching up to 10.91 wt.% Ag, and typically an order of magnitude higher than those of galena. Therefore, tetrahedrite is likely the main source of Ag within the Glacier Creek deposit. Bi concentrations are locally significant (up to 1.0 wt.%) and correlate positively with high Sb and Ag, and negatively with As and Cu. Several grains analyzed contain significant Au, between 0.09 and 0.14 wt.%, but these concentrations are too close to detection limit to be interpreted with confidence.

Magnetite

Magnetite occurs in trace amounts near the bottom of the massive barite zone within hole CMR08-11b (Figure 2.9; samples NS11-05 and NS11-06). In thin section, magnetite occurs spatially with galena, tetrahedrite and chalcopyrite as euhedral cubes. It may be partially replaced by chalcopyrite, pyrite and/or galena, in particular where the grains are fractured. Hand samples of barite ore containing magnetite are weakly magnetic.

Other Trace Minerals

Several rare minerals were identified using energy dispersive X-ray spectroscopy (EDS), and can explain several geochemical anomalies within sulfide-rich samples, including native bismuth, several telluride minerals, hematite, molybdenite, and uranium oxide.

Sample NS9-18 contains anomalous Bi, and several rare bismuth minerals and native bismuth were identified in association with galena (Figure 3.12 C and D). Several other samples contain elevated Bi content (~50 ppm), although, no bismuth minerals were identified (Appendix A). Bismuth telluride (possibly tellurobismuthite: Bi_2Te_3) occurs as inclusions within galena and a Bi-sulfosalt (pavonite group: benjaminite $(\text{Ag,Cu})_3(\text{Bi,Pb})_7\text{S}_{12}$ or pavonite $(\text{Ag,Cu})(\text{Bi,Pb})_3\text{S}_5$) occurs as discrete laths spatially associated with galena and tellurides.

Trace amounts of molybdenite were identified within samples NS14-29 and NS11-03, which are massive pyrite and pyrrhotite ore, respectively. Both samples have anomalous Mo content of over 120 ppm, more than double that of typical sulfide-rich samples at Glacier Creek (Appendix A). Molybdenite occurs as sub- to euhedral, elongate laths less than $30\ \mu\text{m}$ long within muscovite and hematite-rich zones in massive pyrrhotite ore (Figure 3.6 D and 3.12 A). The same samples contain rare uranium-oxides, associated with the muscovite and hematite-rich zones (Figure 3.12 B). These samples also have bird's eye pyrite, suggesting that they have likely been oxidized due to weathering.

Rare hematite needles are present within muscovite-rich zones in pyrrhotite stringers

and massive pyrrhotite ore locally associated with molybdenite grains. The hematite needles are up to 60 μm long by 5 μm thick (Figure 3.12 A). These samples also have bird's eye pyrite and have likely been oxidized due to weathering.

3.6 Gangue Mineralogy and Mineral Chemistry

Barite

Barite is abundant in massive barite, massive pyrite, barite-carbonate ore and some resedimented ores. In the massive ores, barite occurs as polygonal, annealed and recrystallized very fine to fine grains, forming a granoblastic texture (Figure 3.2 A and 3.8 F). Zone II contains resedimented barite-sulfide sand that has large, euhedral and locally broken barite crystals within a very fine-grained carbonate matrix. These barite crystals can range up to 1 cm across (Figure 3.8 B). Barite may contain up to 1.1 wt.% Sr, but does not contain any other significant trace elements.

Quartz

Quartz is strongly annealed, and where present in abundance, exhibits a granoblastic texture forming polygonal mosaics (Figure 3.4 C, F and 3.5 B). Quartz within sulfide veins is typically much coarser than the more pervasive quartz in surrounding wall rocks.

Muscovite

Muscovite occurs within sulfide stringers in association with variable amounts of quartz, albite, carbonate and locally within massive ores. This stringer muscovite forms small fans and is coarser than muscovite in the pervasively altered wall rock (Figure 3.4 C).

No significant compositional variation exists between the fine-grained, pervasive muscovite and the coarser muscovite associated with stringers of from within ore samples.

Ore-proximal muscovites contain 1.5 to 9 wt.% BaO, with a mean of 4.3 wt.% and 6.1 to 10.2 wt.% K₂O, with a mean of 8.76 wt.% (Table 3.8). Muscovites also contain ~1-3 wt.% MgO, ~1-5 wt.% FeO, ~0.4 wt.% Na₂O, ~0.6 wt.% V₂O₃ and 0.2 wt.% F (Table 3.8). Muscovite is generally rare in barite-rich ore, but in the samples analyzed, it contains between 1.0-4.3 wt.% V₂O₃. In comparison, V₂O₃ from other ore-related muscovites typically ranges from 0.09-0.30 wt.%. The Mg content of muscovite is similar throughout the deposit. Fe/(Fe+Mg) ratios vary, but are in general <0.50 for muscovites in altered rocks and >0.50 for ore-related muscovites. Little to no Ca, Mn, Cl or Rb is present within muscovites. Ti values range up to 0.9 wt.% throughout. Muscovite element correlations are presented in Table 3.9 and discussed below.

(Ba-K)-Feldspar

(Ba-K)-feldspar is present within carbonate ore, carbonate-barite ore and cherty, calcareous, tuffaceous rocks that overlie the massive sulfide lenses, and locally within semimassive pyrite-rich ore (Figures 2.9 and 2.10). (Ba-K)-feldspar may occur as rounded, anhedral grains, partially replaced by barian muscovite (Figure 3.13 A) or carbonate (Figure 3.7 A), or as euhedral crystals (Figure 3.13 B). Most of these feldspars belong to a solid solution between celsian (BaAl₂Si₂O₈) and K-feldspar (KAl₂Si₃O₈), forming the mineral hyalophane (Ba,K)[Al(Al,Si)Si₂O₈]. The (Ba-K)-feldspars contain 12-36 wt.% BaO, 1-10 wt.% K₂O, 20-30 wt.% Al₂O₃ and up to 1.5 wt.% Na₂O. Table 3.10 presents the average composition of

(Ba,K)-feldspars from 4 samples from Zone I. The samples are of barite-carbonate ore (13-10), carbonate-rich ore (14-10), massive pyrite ore (14-31), and mineralized hangingwall tuff (17-17). The average proportions of celsian (Cn), orthoclase (Or) and albite (Ab) are indicated in Table 3.10 and the compositions plotted in Figure 3.15. The celsian component ranges from 19%Cn to 95%Cn. According to Gay and Roy (1963), true celsian feldspar contains 80-90%Cn and hyalophanes have >15%Cn. Using this definition, the euhedral, well-zoned (Ba,K)-feldspars from the finely interlayered barite-carbonate ores (Figures 3.8 F and 3.13 B) fall within the celsian field, with 70-95% Cn, whereas samples from other parts of Zone I are considered hyalophane, with 18-48% Cn. From the data collected, there appears to be a compositional gap between 48 and 70% Cn (Figure 3.15).

The (Ba,K)-feldspars exhibit a strong zonation in Ba/K. Backscattered electron images illustrate this feature well due to the large difference in atomic mass between Ba and K. The lighter grey areas in Figure 3.14 C and D represent higher Ba/K ratios. Si also shows zonation as higher Si correlates with lower Ba regions (Figure 3.17). This reflects the substitution of divalent Ba for monovalent K and the loss of one atom of Si per formula unit in order to maintain a balanced charge. In some samples, there is a clear primary oscillatory zonation within the (Ba-K)-feldspar crystals and a later, strongly Ba-rich reaction rim, suggesting a Ba-rich fluid altered and replaced the margins of primary (Ba-K)-feldspars (Figure 3.15 C and D).

Carbonate (Calcite/Dolomite/Siderite)

Carbonate occurs in stringers, massive pyrrhotite ore, barite-carbonate mineralization

and as the matrix to resedimented and tuffaceous ores. Carbonate within Zone I is calcite, although several samples at the stratigraphic upper margins of the lens, capping the main massive sulfide are dolomite (Figure 3.16). Sample 13-10 and 17-17 contain both dolomite and calcite. Large porphyroblasts of calcite in massive pyrrhotite locally contain Fe-carbonate and barite on cleavages (Figure 3.12 E). Carbonate present within stringers in the footwall is calcite (Table 3.11). In all samples, carbonates contain 0.5 to 1.1 wt.% MnO (mean 0.98 wt.%).

Chlorite

There is very little chlorite associated with the Glacier Creek massive sulfide deposit. Within Zone I, trace amounts of very fine-grained, pale green to colourless chlorite occurs locally as fans in massive pyrite ore and within sulfide stringers both above and below the deposit, particularly towards the center of the lens around drillhole CMR08-14 (Figures 3.3 B and 2.10). Chlorite is also present as euhedral, dark green aggregates (books) within carbonate ores (Figure 3.7 A) and as very pale green booklets within large quartz crystals in massive pyrrhotite ores (Figure 3.6 A and E). These euhedral chlorites have variable Fe contents (Figure 3.17).

Fe/(Fe+Mg) ratios in chlorite vary throughout the massive sulfide lens and within the immediate footwall and hangingwall with a wide range from 0.2 to 0.85 (Figure 3.17). In general, chlorite within the footwall, near the center of the lens, is more Fe-rich (e.g., samples 14-04 and 17-10: Figure 2.10), with a Fe/(Fe+Mg) ratio of >0.60 (Table 3.12). Chlorite within carbonate ores, near the top of the lens also has high Fe-content, with Fe/(Fe+Mg)

ratios of >0.80 (sample 14-10). Chlorite throughout the rest of the lens, within massive pyrite ore, peripheral stringers, barite-carbonate ore, and in proximal alteration zones, is more magnesium-rich, with Fe/(Fe+Mg) ratios between 0.2 and 0.6 (Table 3.12). Chlorite locally contains trace amounts of TiO₂ (up to 0.2 wt.%), up to 0.3 wt.% V₂O₃ and locally up to 0.4 wt.% F. They typically contain an average 0.4 wt.% MnO (up to 0.9 wt.%). Chlorites were not analyzed for Zn. Fluorine shows a strong negative correlation with Fe and a strong positive correlation with Mg (Table 3.13).

Albite

Very fine- to fine-grained, subhedral albite occurs locally within pyrite-sphalerite stringers above and below the massive sulfide lens in association with variable quartz, carbonate, chlorite, muscovite and sulfides. Albite is also locally present within massive pyrite-rich ores and in pyrrhotite-chalcopyrite stringers. Albites are locally partially replaced by muscovite. The albite crystals typically exhibit albite twinning (Figure 3.5 C). They have a normal albite composition of about Na_{0.95}Ca_{0.05}Al_{1.05}Si_{2.95}O₈, with no other trace elements (Table 3.14).

3.7 Sulfur Isotopes

Sulfides from Zones I and II of the Glacier Creek deposit have δ³⁴S values that cluster between -5 and 5 per mil. Sulfide δ³⁴S values vary between massive sulfide lenses, with a mean of 2.61‰ for Zone I and mean of -1.89‰ for Zone II (Table 3.15 and Figure 3.18). Sphalerite δ³⁴S values are generally lower than those of other sulfides within the same samples (Table 3.15). No ore type related variations are observed in the data. However,

pyrite and pyrrhotite in argillites overlying Zone I have very low $\delta^{34}\text{S}$ values compared to the ore-sulfides of the main lenses. Within the barite ores of Zone I, sulfide sulfur isotopes appear to become heavier towards the top of the lens, increasing from $\sim 2\text{‰}$ to $\sim 4\text{‰}$ (Table 3.15). A similar increase is observed at the Rosebery mine, Tasmania (Green et al., 1981). Sulfate $\delta^{34}\text{S}$ data from Zones I and II barites range from 10.66 to 14.36‰ (Table 3.15 and Figure 3.18), but no lens or stratigraphic variations are observed. The average sulfate $\delta^{34}\text{S}$ values are 10.08‰ greater than Zone I sulfides and 14.57‰ greater than Zone II sulfides.

Summary

The massive sulfide lenses at Glacier Creek are barite-rich and composed dominantly of massive barite-sphalerite-pyrite with massive and semimassive chalcopyrite-pyrite-quartz replacing the base and center of the lenses. All sulfides have been recrystallized and annealed, with only local evidence of primary banding or other textures (e.g., framboidal pyrite), typically on the outer margins of the ore lenses. The flanks and top of the lenses are carbonate-rich, either as interbedded carbonate and resedimented massive barite-sulfide or as mineralized massive carbonate rocks. The clastic barite fragments in resedimented ore are likely locally derived owing to their high specific gravity, and may represent the remnants of collapsed sulfide chimneys or eroded flanks of the ore lens. Similar clastic barite (i.e. barite sand) is seen at several of the Kuroko deposits of Japan (Eldridge et al., 1983) and at the Lerokis and Kali Kinung deposits in Indonesia (Sewell and Wheatley, 1994).

Minor diffuse, ‘stringer-style’ sphalerite-pyrite (and locally chalcopyrite) mineralization occurs above and below the massive sulfide lenses, extending into the footwall

and hanging wall. This likely reflects the permeable nature of the ore-hosting volcanic and volcanoclastic rocks and is evidence of continued hydrothermal activity after massive sulfide deposition. These stringer veins contain quartz, carbonate, muscovite, albite and local chlorite with sulfides. Similar albite-bearing stringers are observed in the footwall mineralization and alteration zone at the Kudz Ze Kayah deposit, Yukon (Layton-Matthews et al., 2008) and locally in the ore lens and footwall of the Rosebery mine, Tasmania (Green et al., 1981). At Rosebery, local albite-carbonate-sulfide veins are interpreted to be the result of a late stage fluid with a relatively high (near-neutral) pH and a high Na^+/K^+ ratio (Green et al., 1981). At Glacier Creek, the albite is partially replaced by muscovite, suggesting varying pH. Green et al. (1981) suggest boiling as a mechanism for the local, periodic increase in pH. No textural evidence for boiling is observed at Glacier Creek. More focused quartz-sulfide ‘feeder zones’ underlying the lenses contain pyrrhotite, pyrite and chalcopyrite and likely represent higher-temperature conduits. These have been moderately transposed into the orientation of the main sulfide lenses.

Massive pyrrhotite occurs locally directly above and below the massive pyrite-sphalerite-chalcopyrite ore. The massive pyrrhotite mineralization is closely spatially associated with carbonate ores. There is a large range of sphalerite compositions, with low-Fe sphalerite dominant throughout the deposit and high-Fe sphalerite in pyrrhotite-rich zones. Galena, arsenopyrite and tetrahedrite are common. Most of the Ag in the deposit is in tetrahedrite. Gold may be hosted within tetrahedrite or arsenopyrite; however, the Au concentrations are highly variable and close to the detection limit of the microprobe. As, Sb and Ag also occur within tetrahedrite. Both tetrahedrite and arsenopyrite are present in both Zn-rich and

Cu-rich ores. This accounts for the apparent bimodal distribution of Ag and Au with both Zn-rich ore and Cu-rich ores. The massive sulfides also contain anomalous Sb, Hg and Tl, locally. Hg also shows a strong correlation with Zn, with up to several ppm Hg in Zn-rich ores. Rare magnetite, molybdenite, native bismuth and tellurides are observed locally within massive sulfides.

Significance of Barian Muscovite and (Ba-K)-Feldspar

Gangue minerals include barite, quartz, barian-muscovite, carbonate (dominantly calcite), albite, highly subordinate chlorite and locally (Ba-K)-feldspar. The abundance of barian-muscovite and (Ba-K)-feldspar associated with mineralization suggest a very Ba-rich hydrothermal fluid and/or limited availability of SO_4 .

There are two mechanisms by which Ba may be accommodated in micas. The first, and simplest, is a coupled substitution of Ba and tetrahedral Al ($^{\text{IV}}\text{Al}$) for K and Si (Hetherington et al., 2003):



The second is a substitution of Ba and Fe or Mg for K and octahedral Al ($^{\text{VI}}\text{Al}$) (Hetherington et al., 2003):



Muscovite microprobe data confirm that Ba has a very strong negative correlation with K and Si and a positive correlation with Al (Table 3.9), indicating that substitution (1) was the most common.

Within the surrounding alteration zone, however, the reaction is less clear. The Ba content of muscovite in the ore zones correlates negatively with Fe and not at all with Mg; in the altered wall rocks, the Ba content correlates positively with Mg, and not at all with Fe. The strong correlation of Ba with Mg, and lack of any correlation with Al suggests that neither substitution (1) or (2) dominate in the altered rock. A Tschermak-style substitution



associated with phengitic muscovite may take place in conjunction with the Ba substitution (1) and the phengite content of muscovites increase towards ore (Chapter 4).

The fluorine content of muscovite ranges up to 0.77 wt.% with an average of 0.26 wt.%, similar to ore-related muscovites from the Kidd Creek deposit in Canada and the Kristineberg district in Sweden (Hannington and Kjarsgaard, 2003). In these deposits, F enrichment was useful for identifying hydrothermal upflow zones, but the bulk rock concentrations are too low at Glacier Creek to see this variation. In all muscovites, both within and surrounding ore zones, F shows a strong negative correlation with Fe, and a strong positive correlation with Mg. This may reflect the well-known Fe-avoidance of F in muscovite, but the Fe content varies widely within altered rocks, from 0.50 to 2.00 wt.% Fe₂O₃, and is generally higher within the footwall than the hanging wall.

Ore-related muscovites in Zone I are similar in composition to several other barian muscovites reported in the literature (Hetherington et al. 2003, Coats et al. 1984, Bradshaw et al. 2008; Hannington and Kjarsgaard, 2003), especially in deposits associated with reduced ore-forming conditions (e.g., Kipushi Zn-Pb-Cu deposit of the Democratic Republic

of Congo, Chabu and Boulègue 1992). Barian and barian-chromian muscovite is common at the Greens Creek deposit, along with hydrous barium-feldspar (cymrite) related to white ores (Taylor et al., 2010). In comparison, the Windy Craggy deposit contains very little Ba and no Ba-rich muscovite is reported (Peter, 1992).

Barium feldspar is an important gangue mineral in some Zn-Pb-Ba $\pm$ Cu $\pm$ Ag massive sulfide deposits hosted within carbonate-rich and shale-rich rocks such as the Errington and Vermilion deposits, Sudbury (Ames et al., 2006), the Tom and Jason deposits, Yukon (Gardner and Hutcheon, 1985), the George Fisher deposit, Mount Isa (Chapman, 2004), and the Rosh Pinah deposit, southwest Africa (Alchin and Moore, 2005), as well as in manganese deposits (e.g., Cuyana Iron Range, Minnesota; McSwiggen et al., 1994). Fortey and Beddoe-Stephens (1982) suggest that barian silicates may form either by replacement of barite or by dehydration of cymrite ($\text{BaAl}_2\text{Si}_2(\text{O},\text{OH})_8 \cdot \text{H}_2\text{O}$) during diagenesis or metamorphism. For cymrite to have formed during hydrothermal deposition instead of barite, there would have to be insufficient seawater SO_4 available to form barite. Evidence for reduced conditions exist in carbonate-rich ores and tuffaceous rocks that cap the massive sulfides (Chapter 5) and suggest a lack of SO_4 during formation of these (Ba-K)-feldspar-bearing rocks (e.g., sample NS17-17, Figure 3.13 A and C). Dehydration of cymrite during diagenesis and regional greenschist-facies metamorphism would then form (Ba-K)-feldspars. For (Ba-K)-feldspar to form by replacement of barite during metamorphism, strongly reducing conditions are required that are not evident at Glacier Creek and there is little evidence that barite was unstable during metamorphism. In rocks where (Ba-K)-feldspar has been partially replaced by barian-muscovite, this likely represents a change in pH conditions during protracted hydro-

Table 3.1. Principal ore types from Zones I, II and III.

Ore Type	Description
Cherty, Tuffaceous and Barite-Carbonate Ore	<50% py±sp±ccp within variable carbonate rich rock; located on the margins of massive sulfide lenses
Carbonate Ores	>50% carbonate; capping massive sulfides and possibly as infilling and replacement of calcareous tuffs
Barite Ore	<50% sulfide with dominantly barite gangue; banded to massive texture; dominated by py-sp, with varying ccp
Massive Pyrite Ore	>50% sulfide; pyrite and chalcopyrite with quartz/barite gangue
Massive Pyrrhotite Ore	>50% sulfide, dominated by pyrrhotite, quartz and carbonate megacrysts; up to 15% ccp, 20% sp
Semimassive & Stringer Pyrrhotite-Chalcopyrite	<50% po-ccp within quartz-muscovite altered rock within footwall
Semimassive & Stringer Pyrite-Sphalerite (±Ccp)	<50% py-sp (±ccp) within quartz-muscovite altered rock, above and below ore lenses; >2% sp ± ccp

Table 3.2. Mineralogy of principal ore types.

Cherty, Tuffaceous and Barite- Carbonate Ore	Carbonate Ore	Barite Ore	Massive Pyrite Ore	Massive Pyrrhotite Ore	Po-Ccp Stringers	Semimassive & stringer Py- Sp (± Ccp)
Pyrite Chalcopyrite Sphalerite ± Galena ± Tetrahedrite ± Arsenopyrite	Fe-Rich Sphalerite Chalcopyrite ± Pyrite ± Pyrrhotite	Fe-poor Sphalerite Pyrite Chalcopyrite ± Tetrahedrite ± Galena ± Arsenopyrite ± Covellite	Pyrite Chalcopyrite Sphalerite ± Tetrahedrite ± Arsenopy- rite ± Covellite	Pyrrhotite Chalcopyrite Sphalerite Pyrite ¹	Pyrrhotite Chalcopyrite Pyrite ± Fe-rich Sphalerite	Pyrite Fe-poor Sphalerite ± Chalcopyrite ± Tetrahedrite
Associated Gangue Minerals						
Barite Carbonate ± Muscovite ± Chlorite ± Ba-Feldspar ± Albite	Carbonate ± Quartz ± Chlorite ± Muscovite ± Ba-Feldspar	Barite ± Quartz ± Muscovite ± Chlorite	Quartz ± Muscovite ± Chlorite ± Barite ± Carbonate ± Albite ± Ba-Feld- spar	Carbonate ± Quartz ± Muscovite ± Chlorite	Quartz Muscovite ± Chlorite	Quartz Muscovite Carbonate ± Albite ± Chlorite

Minerals are listed in approximate, relative order of abundance (± indicates presence in only a few samples)

¹Pyrite only present as 'bird's eye' texture, replacement of pyrrhotite

²Only 3 samples lack carbonate, and instead contain more quartz, or plagioclase (albite?).

Table 3.3. Median concentrations of elements in different ore types at the Glacier Creek deposit.

Element	Unit	Barite Ore	Massive Pyrite Ore	Massive Pyrrhotite Ore	Po-Ccp Stringers	Clastic barite ore	Cherty and Tuffaceous Ore	Carbonate Ore ¹	Py-Sp Semimsv & Stringers ¹
	<i>n</i>	<i>11</i>	<i>2</i>	<i>2</i>	<i>3</i>	<i>2</i>	<i>4</i>	<i>3</i>	<i>4</i>
Fe	wt. %	5.33	41.45	27.30	20.30	23.95	3.15	> 7.8	< 10
Cu		0.58	6.27	1.18	3.89	0.81	1.51	1.55	0.85
Zn		9.88	3.45	5.98	0.14	1.17	1.84	11.66	0.85
Total Metals		19.16	51.17	34.46	22.53	25.93	11.36	> 20.50	> 11.70
Total S		14.05	45.85	19.75	11.90	26.20	7.08	N/A	N/A
Au	ppb	356	1363	44	267	110	874	150	65
Ag	ppm	76	81	5	30	9	61	30	4
Pb		3650.0	627.5	33.3	7.1	262.5	2335.0	158.0	84.0
As		508.0	1506.0	2.4	3.0	50.1	37.9	< 5.0	< 5.0
Sb		159.5	193.5	0.7	0.7	10.2	22.1	25.0	17.5
Cd		417	120	579	38	38	91	> 1000	37
Hg	ppb	9085	2970	817	157	794	7520	N/A	N/A
Tl	ppm	4.7	23.3	0.2	6.1	2.5	2.2	N/A	N/A
Sn		0.3	0.3	0.5	3.2	1.8	0.3	< 20.0	< 20.0
In		1.5	4.9	4.0	0.6	0.5	0.2	N/A	N/A
W		1.8	4.9	11.7	2.8	3.0	4.0	< 10.0	< 10.0
Ga		6.7	2.3	1.8	6.8	2.7	2.5	N/A	N/A
Ge		3.0	9.1	4.8	6.0	2.5	2.5	N/A	N/A
Co		4.4	122.2	23.6	28.0	7.6	5.0	12.0	24.0
Ni		35	20	20	15	15	10	32	39
Se		12.8	10.7	19.2	14.9	23.9	9.8	N/A	N/A
Bi		5	43	4	4	4	1	< 5	< 5
Te		< 6	< 6	< 6	< 6	< 6	8	N/A	N/A
Mo		20	90	79	51	29	9	21	48
V		12	9	20	138	14	10	56	115
Cr ²		72	29	46	101	121	99	93	162
U		2.6	8.5	13.7	5.3	17.1	2.2	< 10.0	< 10.0
Th		0.1	0.1	0.1	0.5	0.4	0.3	N/A	N/A
SiO ₂	wt. %	0.52	0.57	8.28	28.88	1.47	50.28	N/A	N/A
Al ₂ O ₃		0.06	0.09	0.71	4.84	1.08	1.00	2.20	5.26
MgO		0.03	0.01	0.66	0.76	1.05	0.22	1.30	0.33
CaO		0.04	0.01	18.49	0.24	7.04	5.19	> 14.0	0.15
Na ₂ O		0.03	0.02	0.02	0.34	0.02	0.03	0.11	0.58
K ₂ O		0.06	0.06	0.06	0.96	0.06	0.15	0.30	1.40
TiO ₂		0.01	0.01	0.01	0.23	0.01	0.05	0.05	0.18
P ₂ O ₅		0.01	0.07	0.04	0.08	0.11	0.06	0.05	0.04
CO ₂		0.01	3.58	14.82	0.08	5.56	5.40	N/A	N/A
Ba		264000	20050	1060	2710	142000	13765	N/A	N/A
Sr		3410	166	395	35	1825	369	481	23
Rb		0.2	0.5	1.8	19.2	0.9	2.3	N/A	N/A
Mn		43	43	3955	112	1630	1419	4972	39
Cs		0.1	< 0.1	< 0.1	0.4	0.3	0.1	N/A	N/A
Nb		< 2.4	< 2.4	< 2.4	3.1	< 2.4	< 2.4	N/A	N/A
Hf		< 10	< 10	< 10	< 10	< 10	< 10	N/A	N/A
Ta		0.4	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	N/A	N/A
Y		0.7	3.4	3.9	8.0	8.3	4.0	6.0	2.5
Sc		0.5	0.4	1.4	11.8	3.2	1.7	N/A	N/A
Ir		< 5	< 5	< 5	< 5	< 5	< 5	N/A	N/A
B		< 10	< 10	< 10	50	< 10	< 10	N/A	N/A
Br		< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	N/A	N/A
Be		< 3	< 3	< 3	< 3	< 3	< 3	N/A	N/A
Li		< 3	< 3	< 3	4	< 3	< 3	N/A	N/A
ΣREE		16.43	20.63	30.53	44.81	48.93	14.50	N/A	N/A

Median values were chosen to remove the effect of outliers. *n*: number of samples analyzed.

¹Carbonate and pyrite-sphalerite semimassive and stringer ore geochemistry is from historic company assays.

Analyses and methods differ from thesis samples.

²Cr-steel mill used in crushing and pulverizing of samples.

Table 3.4. Pearson Correlation matrix for significant trace elements within massive sulfide ore from Zone I, Glacier Creek deposit

	Zn	Pb	As	Sb	Au	Ag	Cd	Mn	Hg	Ba	Sr	Rb	Cu	Fe	Tl	Sn	In	W	Co	Ni	Se	Bi	Mo	V	Cr	Cs	K	CO2	Mn	CaO
Zn	1.00																													
Pb	0.46	1.00																												
As	0.08	0.06	1.00																											
Sb	0.44	0.40	0.44	1.00																										
Au	0.31	0.35	0.64	0.47	1.00																									
Ag	0.14	0.35	0.69	0.67	0.76	1.00																								
Cd	0.89	0.35	-0.04	0.20	0.16	0.00	1.00																							
Mn	0.09	-0.27	-0.32	-0.34	-0.26	-0.33	0.41	1.00																						
Hg	0.73	0.66	0.15	0.61	0.27	0.37	0.59	-0.12	1.00																					
Ba	0.42	0.57	-0.03	0.42	0.10	0.21	0.15	-0.44	0.45	1.00																				
Sr	0.52	0.61	-0.06	0.45	0.19	0.25	0.26	-0.33	0.50	0.96	1.00																			
Rb	-0.33	-0.20	-0.19	-0.22	-0.21	-0.23	-0.27	-0.14	-0.32	-0.35	-0.37	1.00																		
Cu	-0.37	-0.28	0.36	0.00	0.35	0.22	-0.33	-0.10	-0.32	-0.41	-0.45	-0.09	1.00																	
Fe	-0.51	-0.55	-0.04	-0.26	-0.23	-0.36	-0.44	0.06	-0.63	-0.55	-0.59	0.11	0.51	1.00																
Tl	-0.21	-0.06	0.28	0.26	0.20	0.18	-0.28	-0.33	-0.12	-0.13	-0.16	0.67	0.22	0.21	1.00															
Sn	-0.04	-0.11	-0.13	-0.04	-0.05	0.02	-0.07	-0.14	-0.01	-0.11	-0.09	0.04	0.29	0.17	-0.08	1.00														
In	0.10	-0.15	0.22	0.35	0.17	0.19	0.11	0.15	-0.06	-0.02	0.00	-0.19	0.48	0.29	0.25	0.24	1.00													
W	0.24	-0.10	0.09	0.06	-0.12	-0.06	0.13	-0.04	0.28	0.13	0.07	-0.08	-0.11	-0.22	-0.14	0.36	-0.13	1.00												
Co	-0.20	-0.28	0.33	-0.01	0.18	-0.02	-0.18	-0.06	-0.28	-0.26	-0.31	-0.07	0.67	0.55	0.34	-0.03	0.58	-0.07	1.00											
Ni	-0.31	-0.28	-0.11	-0.04	-0.24	-0.16	-0.25	0.02	-0.22	-0.28	-0.30	0.20	0.14	0.44	-0.02	0.04	0.02	-0.12	0.05	1.00										
Se	0.27	0.01	-0.21	-0.09	-0.18	-0.26	0.37	0.32	-0.02	-0.11	-0.03	-0.05	-0.18	0.09	-0.39	0.16	-0.07	0.05	-0.18	0.31	1.00									
Bi	0.30	-0.08	0.06	0.04	0.12	0.02	0.48	0.26	0.28	-0.19	-0.07	-0.16	0.07	-0.03	0.07	-0.03	0.17	-0.08	0.26	-0.18	0.02	1.00								
Mo	-0.30	-0.37	0.12	-0.04	0.04	-0.10	-0.32	0.04	-0.31	-0.43	-0.45	-0.01	0.61	0.70	0.11	0.16	0.27	0.11	0.55	0.58	0.08	-0.04	1.00							
V	-0.34	-0.13	-0.10	0.03	-0.11	0.00	-0.30	-0.24	-0.25	-0.26	-0.28	0.92	-0.01	0.07	0.71	0.15	-0.03	-0.12	-0.10	0.17	-0.09	-0.19	-0.02	1.00						
Cr	-0.45	-0.27	0.21	-0.30	-0.18	0.09	-0.41	-0.16	-0.28	-0.28	-0.35	0.32	-0.14	-0.08	-0.07	-0.02	-0.58	0.12	-0.35	0.29	0.01	-0.34	-0.10	0.25	1.00					
Cs	-0.35	-0.22	-0.21	-0.24	-0.23	-0.26	-0.29	-0.13	-0.34	-0.34	-0.37	0.97	-0.12	0.11	0.58	0.01	-0.23	-0.08	-0.06	0.27	0.08	-0.18	0.02	0.87	0.36	1.00				
K	-0.31	-0.19	-0.18	-0.22	-0.21	-0.23	-0.26	-0.15	-0.30	-0.32	-0.35	1.00	-0.09	0.10	0.69	0.03	-0.20	-0.07	-0.07	0.16	-0.08	-0.15	-0.03	0.91	0.30	0.95	1.00			
CO ₂	0.05	-0.29	-0.33	-0.34	-0.30	-0.35	0.37	0.95	-0.15	-0.49	-0.39	-0.16	-0.12	0.17	-0.29	-0.16	0.15	-0.06	0.00	0.01	0.23	0.32	0.06	-0.27	-0.17	-0.16	-0.16	1.00		
Mn	0.09	-0.27	-0.32	-0.34	-0.26	-0.33	0.41	1.00	-0.12	-0.44	-0.33	-0.14	-0.10	0.06	-0.33	-0.14	0.15	-0.04	-0.06	0.02	0.32	0.26	0.04	-0.24	-0.16	-0.13	-0.15	0.95	1.00	
CaO	0.11	-0.24	-0.31	-0.32	-0.29	-0.34	0.43	0.99	-0.09	-0.42	-0.31	-0.13	-0.17	0.04	-0.31	-0.14	0.16	-0.03	-0.06	0.03	0.29	0.28	0.01	-0.23	-0.16	-0.13	-0.14	0.96	0.99	1.00

Values ± 0.37 are significant at the 0.05 level (bold). Based on 26 observations.

Table 3.5. Average Electron Microprobe Analyses (wt.%) of Sphalerites within Zone I

<i>Sample</i>	<i>n</i>	Ore Type	FeS mole%	Ag	Cd	Cu	Fe	Mn	Zn	S	Total
9-08	8	Barite Ore	1.47	<0.07	0.22	0.30	0.93	0.03	64.60	33.55	99.69
9-12	4	Barite Ore	2.13	<0.07	0.13	<0.03	1.36	0.02	65.64	33.83	101.08
13-08	6	Barite Ore	1.22	<0.07	0.17	0.07	0.78	0.01	66.51	33.84	101.37
17-16	5	Barite Ore	1.94	<0.07	0.23	0.13	1.24	0.01	63.45	33.43	98.53
13-10	4	Barite-Carb Ore	1.25	0.07	0.35	0.05	0.79	0.02	66.21	33.71	101.24
17-12	6	Msv Py Ore	1.74	0.11	0.22	0.47	1.11	0.01	64.97	33.69	100.52
14-31	6	Msv Py Ore	1.85	<0.07	0.27	0.08	1.17	0.01	66.25	33.96	101.82
11-07	4	Msv Py Ore	1.63	0.07	0.18	0.12	1.04	0.01	66.15	33.75	101.34
17-10	2	Py-Sp stringers (FW)	0.82	0.09	0.21	<0.03	0.52	0.01	66.86	33.64	101.35
17-17	5	Py-Sp stringers (HW)	3.33	<0.07	0.30	<0.03	2.12	<0.01	64.52	33.87	100.82
13-04	4	Po-Ccp stringers	12.16	<0.07	1.54	0.22	7.73	0.13	57.12	33.84	100.65
14-04	6	Po-Sp stringers	11.96	<0.07	0.40	0.11	7.60	0.13	58.37	34.05	100.73
11-03	2	Msv Po Ore	11.92	<0.07	0.91	0.40	7.57	0.04	58.10	34.29	101.15
14-10	8	Carbonate Ore	11.60	<0.07	0.31	0.09	7.37	0.03	59.12	34.16	101.11

Table 3.6. Average Electron Microprobe Analyses (wt.%) of selected sulfide minerals within Zone I

	<i>n</i>	S	Zn	Cu	Pb	Sb	Ag	<i>max</i>	Se	<i>max</i>	Fe	As	<i>max</i>	Au	<i>max</i>	Bi	<i>max</i>
Chalco.	29	35.34	0.05	34.45	N/A	<0.03	<0.06	0.11	<0.03	0.04	30.32	<0.03	0.07	<0.07	0.07	N/A	N/A
Galena	18	13.56	0.86	0.07	86.80	<0.04	0.13	0.47	0.06	0.25	0.24	<0.05	0.05	N/A	N/A	<0.27	-
Pyrite	20	53.76	0.08	0.05	<0.1	<0.03	<0.06	0.07	<0.03	0.05	46.65	<0.03	0.23	<0.07	-	<0.13	-
Pyrrhotite	10	38.80	0.07	0.03	<0.1	<0.03	<0.06	0.07	<0.03	0.04	60.49	<0.03	0.06	N/A	N/A	<0.13	-
Arseno.	13	20.94	0.03	1.14	<0.1	0.19	N/A	N/A	<0.04	-	31.54	37.53	1.70	<0.11	0.75	0.21	1.00

Table 3.7. Average Electron Microprobe Analyses (wt.%) of tetrahedrite-tennantite solid solution within Zone I

<i>Sample</i>	<i>n</i>	Sb	As	Ag	Au	Bi	Zn	Fe	Cu	S	Total
9-08	6	9.97	12.86	2.52	0.14	<0.13	3.93	3.78	40.19	28.03	101.34
9-12	5	9.39	13.31	2.74	N/A	<0.13	2.77	4.73	40.09	28.02	101.07
11-07	4	19.91	5.76	6.96	N/A	0.76	4.42	3.31	34.90	26.04	102.07
<i>incl.</i>	2	25.84	1.76	10.21	N/A	0.62	4.35	3.28	31.03	25.08	102.17
17-16	2	8.89	13.60	1.70	0.06	<0.13	3.27	4.39	40.54	28.90	101.44

Table 3.8. Average Electron Microprobe Analyses of Ore-Related Barian Muscovites

<i>sample</i>	13-10	14-04	14-31	14-10	11-03	17-10	17-12	17-16	17-17	9-08	13-04
<i>n</i>	<i>1</i>	<i>6</i>	<i>5</i>	<i>1</i>	<i>2</i>	<i>7</i>	<i>2</i>	<i>3</i>	<i>4</i>	<i>10</i>	<i>10</i>
SiO ₂ wt. %	44.76	45.01	45.04	43.89	42.78	47.84	42.65	40.61	44.10	41.34	45.01
TiO ₂	0.08	0.41	0.61	0.34	0.44	0.28	0.43	<0.06	0.52	0.40	0.41
Al ₂ O ₃	33.79	31.54	32.86	31.03	32.66	29.14	30.26	30.50	31.39	31.05	31.54
FeO	1.37	3.33	1.60	3.20	1.99	2.89	4.83	1.31	2.18	0.89	3.33
MnO	<0.02	<0.02	0.02	0.02	0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
MgO	1.45	1.84	1.47	1.54	2.12	1.71	2.37	1.45	1.70	1.58	1.84
CaO	0.08	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Na ₂ O	0.56	0.44	0.34	0.52	0.55	0.39	0.33	0.68	0.43	0.45	0.44
K ₂ O	9.00	9.08	9.51	7.73	8.10	9.00	8.40	6.58	9.13	7.61	9.08
F	0.38	0.23	0.27	0.14	0.07	0.26	0.21	0.12	0.20	0.39	0.23
Cl	0.07	0.01	0.01	0.02	0.01	0.01	0.01	0.08	0.01	<0.005	0.01
BaO	3.24	3.34	3.70	8.65	6.44	3.21	4.32	7.95	3.92	6.88	3.34
Rb ₂ O	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
V ₂ O ₃	0.28	0.10	0.33	<0.02	0.12	0.17	0.33	4.23	0.11	1.12	0.10
<i>Total</i>	<i>94.88</i>	<i>95.24</i>	<i>95.63</i>	<i>97.01</i>	<i>95.27</i>	<i>94.80</i>	<i>94.03</i>	<i>93.50</i>	<i>93.60</i>	<i>91.56</i>	<i>95.24</i>
Number of cations, based on 12 (O,OH,F)											
Si	3.34	3.39	3.36	3.36	3.27	3.58	3.31	3.22	3.38	3.29	3.44
^{IV} Al	0.66	0.61	0.64	0.64	0.73	0.42	0.69	0.78	0.62	0.71	0.56
<i>T Site (4)</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>	<i>4.00</i>
^{VI} Al	2.32	2.19	2.25	2.15	2.21	2.16	2.07	2.06	2.21	2.21	2.21
Ti	0.00	0.02	0.03	0.02	0.02	0.02	0.03	-	0.03	0.02	0.02
Fe	0.09	0.19	0.10	0.20	0.13	0.18	0.32	0.09	0.14	0.06	0.16
Mn	-	-	0.00	0.00	0.00	-	-	-	-	-	-
Mg	0.16	0.21	0.16	0.18	0.24	0.19	0.28	0.17	0.19	0.19	0.20
V	0.02	0.01	0.02	-	0.01	0.01	0.02	0.27	0.01	0.07	0.01
Rb	-	-	-	-	-	-	-	-	-	-	-
<i>M Site (2-4)</i>	<i>2.59</i>	<i>2.62</i>	<i>2.57</i>	<i>2.55</i>	<i>2.61</i>	<i>2.56</i>	<i>2.71</i>	<i>2.59</i>	<i>2.58</i>	<i>2.55</i>	<i>2.60</i>
K	0.86	0.87	0.90	0.75	0.79	0.86	0.83	0.66	0.89	0.77	0.94
Ba	0.09	0.10	0.11	0.26	0.19	0.09	0.13	0.25	0.12	0.22	0.05
Na	0.08	0.07	0.05	0.08	0.08	0.06	0.05	0.10	0.06	0.07	0.06
Ca	0.01	-	-	-	-	-	-	-	-	-	-
<i>I site (1)</i>	<i>1.04</i>	<i>1.03</i>	<i>1.06</i>	<i>1.09</i>	<i>1.06</i>	<i>1.01</i>	<i>1.01</i>	<i>1.02</i>	<i>1.07</i>	<i>1.06</i>	<i>1.06</i>
F	0.09	0.05	0.06	0.03	0.02	0.06	0.05	0.03	0.05	0.10	0.04
Cl	0.008	0.002	0.001	0.002	0.001	0.001	0.001	0.010	0.001	0.000	0.00
<i>Total cations</i>	<i>7.63</i>	<i>7.66</i>	<i>7.63</i>	<i>7.64</i>	<i>7.67</i>	<i>7.57</i>	<i>7.72</i>	<i>7.61</i>	<i>7.65</i>	<i>7.61</i>	<i>7.65</i>

Dash indicates below detection limit of electron microprobe. Based on 51 analyses. *n* is number of analyses.

^{VI}Al calculated by subtracting from total Al, assuming Si + ^{IV}Al fills *T* site with 4 cations. Excess of ^{VI}Al caused by excess of Si reported (should be only 2 cations in *M* site).

Sites based on mica chemical formula $I_1M_{2-4}T_4O_{10}(OH,F,Cl)_2$, where *T* is tetrahedral site, *M* is octohedral site and *I* is the interlayer cation site.

Table 3.9 Pearson Correlation Matrix for cations in Ba-muscovite from Zone I

	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	F	Cl	Ba	V
Si	1												
Ti	-0.22	1											
Al	-0.93	0.28	1										
Fe	0.25	-0.09	-0.44	1									
Mn	0.14	0.21	-0.18	0.40	1								
Mg	-0.21	0.14	0.03	0.48	0.11	1							
Ca	-0.03	-0.20	0.11	-0.03	0.01	-0.07	1						
Na	-0.45	-0.11	0.46	-0.47	-0.40	-0.21	0.14	1					
K	0.07	0.13	0.09	0.29	0.17	0.08	0.01	-0.42	1				
F	-0.15	0.16	0.21	-0.36	-0.24	-0.03	0.16	0.03	-0.20	1			
Cl	-0.17	-0.46	0.04	-0.09	-0.15	-0.27	0.30	0.55	-0.50	-0.14	1		
Ba	-0.52	0.07	0.36	-0.40	-0.12	0.00	-0.08	0.41	-0.81	0.33	0.32	1	
V	-0.37	-0.37	0.18	-0.36	-0.31	-0.20	-0.10	0.50	-0.65	0.03	0.70	0.64	1

Values more than 0.271 different than 0 are significant at the 0.05 level (bold). Based on 51 observations.

Table 3.10. Average Electron Microprobe Analyses of (Ba,K)-Feldspar in Zone I

<i>Sample</i>	13-10	14-10	14-31	17-17
<i>n</i>	5	5	1	7
SiO ₂ wt. %	37.28	48.76	54.15	51.19
TiO ₂	<0.07	<0.07	<0.07	<0.07
Al ₂ O ₃	27.72	23.63	22.00	22.71
FeO	0.07	0.03	0.02	0.06
MnO	<0.02	<0.02	<0.02	<0.02
MgO	<0.01	<0.01	<0.01	0.03
CaO	<0.02	<0.02	<0.02	<0.02
Na ₂ O	0.41	0.64	0.87	1.22
K ₂ O	1.59	7.30	9.68	8.11
Rb ₂ O	<0.05	<0.05	<0.05	<0.05
BaO	32.64	19.41	12.98	15.47
V ₂ O ₃	<0.04	<0.04	<0.04	<0.04
<i>Total</i>	<i>99.72</i>	<i>99.77</i>	<i>99.74</i>	<i>98.86</i>
Number of cations, based on 8 (O)				
Si	2.16	2.56	2.72	2.64
Ti	-	-	-	-
Al	1.90	1.47	1.30	1.38
Fe	0.00	0.00	0.00	0.00
Mn	-	-	-	-
Mg	-	-	-	0.00
Ca	-	-	-	-
Na	0.05	0.06	0.08	0.12
K	0.12	0.49	0.62	0.53
Rb	-	-	-	-
Ba	0.74	0.40	0.26	0.31
V	-	-	-	-
<i>Total</i>	<i>4.97</i>	<i>4.98</i>	<i>4.98</i>	<i>5.00</i>
% Cn	82.01	42.00	26.61	32.50
% Or	12.90	51.21	64.60	54.86
% Ab	5.36	7.28	9.64	14.46

Dash indicates below detection limit of electron microprobe. *n* is number of analyzes.

Chemical formula: (Ba,K)[Al(Al,Si)Si₂O₈]

Table 3.11. Average Electron Microprobe Analyses of Carbonate in Zone I

<i>Sample</i>	11-03	13-10	14-10	17-17
<i>n</i>	3	4	4	3
CaO	36.68	41.00	52.43	42.86
SrO	<0.05	<0.05	<0.05	<0.05
FeO	19.68	2.43	0.12	5.30
MnO	1.05	0.97	1.11	0.73
MgO	1.00	9.37	1.21	5.23
CO ₂	42.58	44.50	43.23	43.05
<i>Total</i>	<i>100.99</i>	<i>98.28</i>	<i>98.11</i>	<i>97.18</i>
Number of cations, based on 3 (O)				
Ca	0.67	0.73	0.95	0.78
Sr	-	-	-	-
Fe	0.29	0.03	0.00	0.08
Mn	0.02	0.01	0.02	0.01
Mg	0.03	0.22	0.03	0.13
C	1.00	1.00	1.00	1.00
<i>Total</i>	<i>2.00</i>	<i>2.00</i>	<i>2.00</i>	<i>2.00</i>

Dash indicates below detection limit of electron microprobe. *n* is number of analyzes.

Table 3.12. Average Electron Microprobe Analyses of Ore-Related Chlorite

<i>sample</i>	11-03	13-04	13-10	14-04	14-10	17-10	17-12
<i>n</i>	4	7	3	4	4	6	5
SiO ₂ wt. %	27.67	27.07	26.27	25.52	24.65	24.68	25.81
TiO ₂	0.04	0.01	0.03	0.03	0.08	0.03	0.07
Al ₂ O ₃	21.02	21.81	21.62	21.49	19.37	20.19	21.71
FeO	12.30	17.90	7.93	22.51	36.47	28.78	19.95
MnO	0.32	0.33	0.24	0.74	0.23	0.51	0.30
MgO	23.51	19.49	25.59	16.17	7.24	11.82	18.10
CaO	0.02	0.03	0.03	0.01	0.01	0.01	0.01
Na ₂ O	0.01	0.01	0.01	0.02	0.02	0.01	0.01
K ₂ O	0.00	0.01	0.00	0.01	0.09	0.01	0.01
F	0.14	0.13	0.19	0.17	0.00	0.01	0.12
Cl	0.00	0.00	0.01	0.02	0.01	0.01	0.01
BaO	0.02	0.02	4.65	0.01	0.22	0.02	0.00
Rb ₂ O	-	-	0.00-	-	-	-	-
V ₂ O ₃	0.17	0.06	0.19	0.03	0.22	0.06	0.06
<i>Total</i>	85.16	86.81	86.68	86.67	88.60	86.11	86.10
Fe/Fe+Mg	0.34	0.48	0.24	0.58	0.83	0.71	0.52

11-03: massive pyrrhotite ore, 13-04: pyrrhotite-chalcopyrite stringers, 13-10: barite-carbonate ore, 14-04: pyrrhotite-sphalerite stringers, 17-10: pyrite-sphalerite stringers, 17-12: massive pyrite-rich ore

Table 3.13 Pearson Correlation Matrix for cations in chlorite from Zone I

	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	F	Cl	Ba	V
Si	1												
Ti	-0.122	1											
Al	-0.365	-0.256	1										
Fe	-0.050	0.171	0.023	1									
Mn	-0.235	-0.154	0.384	0.298	1								
Mg	0.010	-0.161	-0.062	-0.995	-0.309	1							
Ca	0.056	-0.022	-0.223	-0.186	-0.024	0.155	1						
Na	-0.177	0.294	-0.121	0.442	0.180	-0.433	0.157	1					
K	0.337	0.205	-0.058	0.251	-0.159	-0.307	0.003	0.358	1				
F	0.161	-0.012	0.010	-0.653	-0.181	0.641	-0.013	-0.257	-0.154	1			
Cl	-0.331	-0.115	0.120	0.240	0.465	-0.221	0.059	0.345	-0.080	-0.040	1		
Ba	-0.586	0.227	-0.189	-0.273	-0.145	0.275	0.441	0.103	0.010	0.047	0.052	1	
V	0.106	0.198	-0.614	0.155	-0.449	-0.108	-0.054	0.122	-0.087	-0.150	-0.111	0.028	1

Values more than 0.334 different than 0 are significant at the 0.05 level (bold). Based on 33 observations.

Table 3.14 Average Electron Microprobe Analyses of Albite in Zone I

<i>Sample</i>	13-04	14-31	17-10
<i>n</i>	<i>11</i>	<i>5</i>	<i>6</i>
SiO ₂ wt. %	66.30	67.43	67.15
TiO ₂	0.02	0.03	0.02
Al ₂ O ₃	20.69	19.51	19.31
FeO	0.10	0.05	0.04
MnO	< 0.02	< 0.02	< 0.02
MgO	< 0.01	< 0.01	< 0.01
CaO	1.37	0.31	0.22
Na ₂ O	10.66	11.30	11.32
K ₂ O	0.06	0.07	0.06
Rb ₂ O	< 0.05	< 0.05	< 0.05
BaO	< 0.05	< 0.05	< 0.05
V ₂ O ₃	< 0.04	< 0.04	< 0.04
<i>Total</i>	99.23	98.73	98.13

Number of cations, based on 8 (O)

Si	2.93	2.98	2.99
Ti	0.00	0.00	0.00
Al	1.08	1.02	1.01
Fe	0.00	0.00	0.00
Mn	-	-	-
Mg	-	-	-
Ca	0.06	0.01	0.01
Na	0.91	0.97	0.98
K	0.00	0.00	0.00
Rb	-	-	-
Ba	-	-	-
V	-	-	-
<i>Total</i>	4.99	4.99	4.99

Dash indicates below detection limit of electron microprobe.

n is number of analyses.Chemical formula: Na_{0.95}Ca_{0.05}Al_{1.05}Si₃O₈

13-04: pyrrhotite-chalcopyrite stringers; 14-31: massive pyrite-rich ore;

17-10: pyrite-sphalerite stringers

Table 3.15. Sulfur Isotope Data for Zone I and II Sulfides and Sulfates

Sample	Lens	Ore type	Mineral	$\delta^{34}\text{S}$ (CDT)
11-04	Zone I (lower) (lower) (upper) (upper) (upper)	Barite Ore	Sphalerite	1.84
11-04		Barite Ore	Pyrite	2.46
9-12		Barite Ore	Pyrite	3.80
17-16		Barite Ore	Sphalerite	3.42
17-16		Barite Ore	Pyrite	4.22
14-08		Carbonate-rich Ore	Pyrrhotite	2.25
14-08		Carbonate-rich Ore	Chalcopyrite	2.62
14-10		Carbonate-rich Ore	Sphalerite	2.58
11-07		Massive Pyrite	Pyrite-Chalcopyrite	0.12
14-29		Massive Pyrite	Sphalerite	2.64
14-29		Massive Pyrite	Pyrite	2.79
14-31		Massive Pyrite	Pyrite-Chalcopyrite	5.07
11-10		Massive Pyrrhotite	Sphalerite	1.19
11-10		Massive Pyrrhotite	Pyrrhotite	1.47
13-05		Po-Ccp stringers	Pyrrhotite-Chalcopyrite	2.08
17-10		Py-Sp stringers	Pyrite-Chalcopyrite	3.15
11-11		Argillite	Pyrrhotite	-8.51
9-14		Argillite	Pyrite	-17.28
11-20	Zone II	Barite Ore	Sphalerite	-2.85
11-20		Barite Ore	Chalcopyrite	-1.91
11-20		Barite Ore	Pyrite	-1.30
19-08		Barite-Carbonate Ore	Pyrite	-1.49
11-04	Zone I	Barite Ore	Barite	12.47
17-16		Barite Ore	Barite	14.16
9-12		Barite Ore	Barite	14.36
19-08	Zone II	Barite-Carbonate Ore	Barite	11.77
11-20		Barite Ore	Barite	10.66

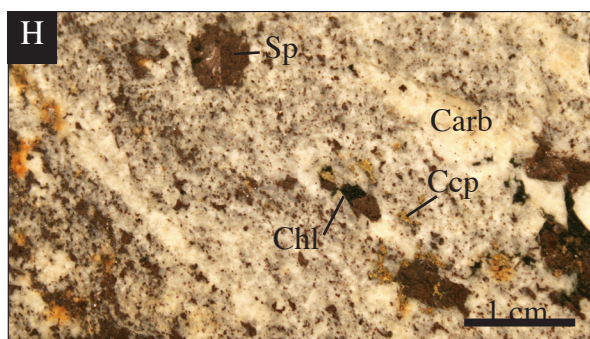
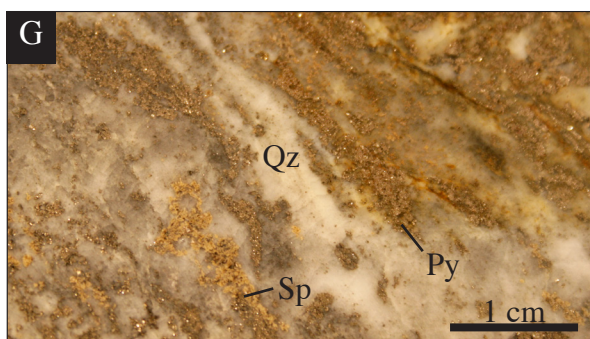
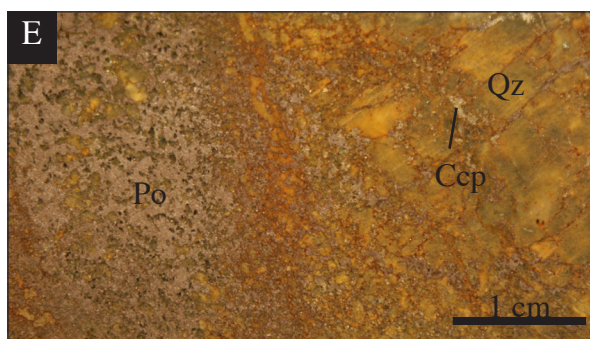
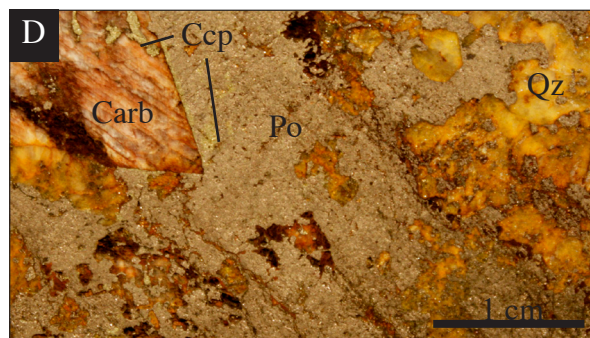
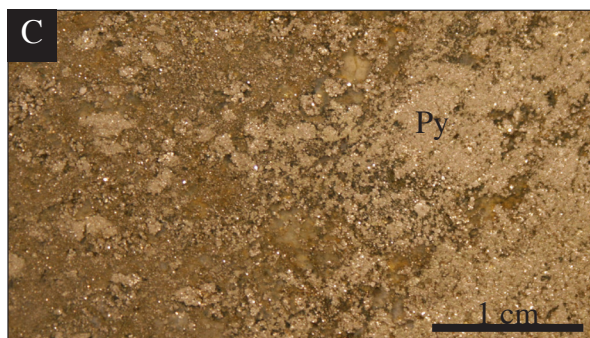
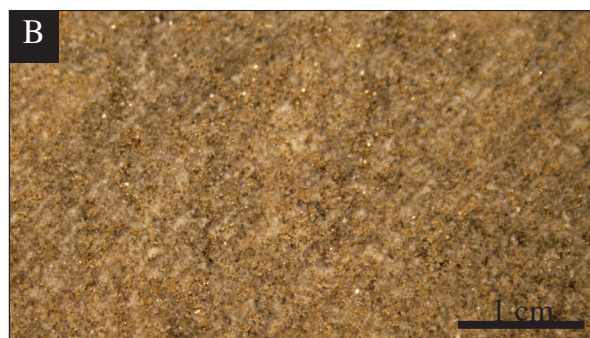
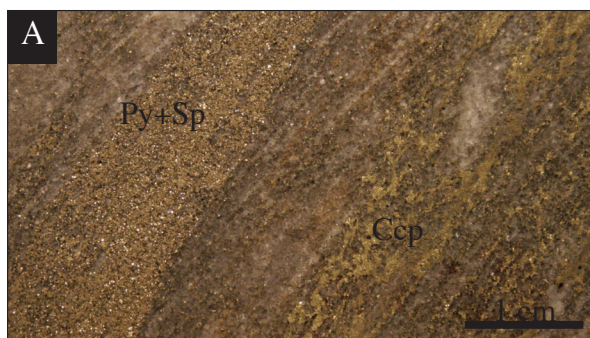




Figure 3.1. Drill core photographs showing principal ore types. Photos are of cut, wet drill core. A) Barite ore, showing weak banding of pyrite-sphalerite and locally chalcopyrite veins cutting barite-sulfide. Photo of NS9-09. B) Homogeneous massive barite ore, dominated by equigranular barite, sphalerite and pyrite. Photo of NS9-12. C) Massive pyrite ore showing two stages of mineralization or recrystallization: an early fine-grained pervasive pyrite and a later coarse-grained chalcopyrite-pyrite. Photo of NS17-12. D) Massive pyrrhotite ore showing porphyroblasts of quartz and carbonate. Chalcopyrite is concentrated around the porphyroblasts. Photo of NS11-03. E) Pyrrhotite-chalcopyrite stringers through intensely quartz-muscovite altered matrix. Photo of NS13-04. F) Clastic ore consisting of barite “sand” containing clasts of barite, sulfide, and barite needles within a carbonate matrix. Photo of NS19-07. G) Pyrite and sphalerite stringers in intensely quartz-altered rock. Photo of NS17-09. H) Carbonate ore, with relatively coarse, recrystallized, dark red sphalerite, chalcopyrite and chlorite. Photo of CMR08-14, 223.0 m.

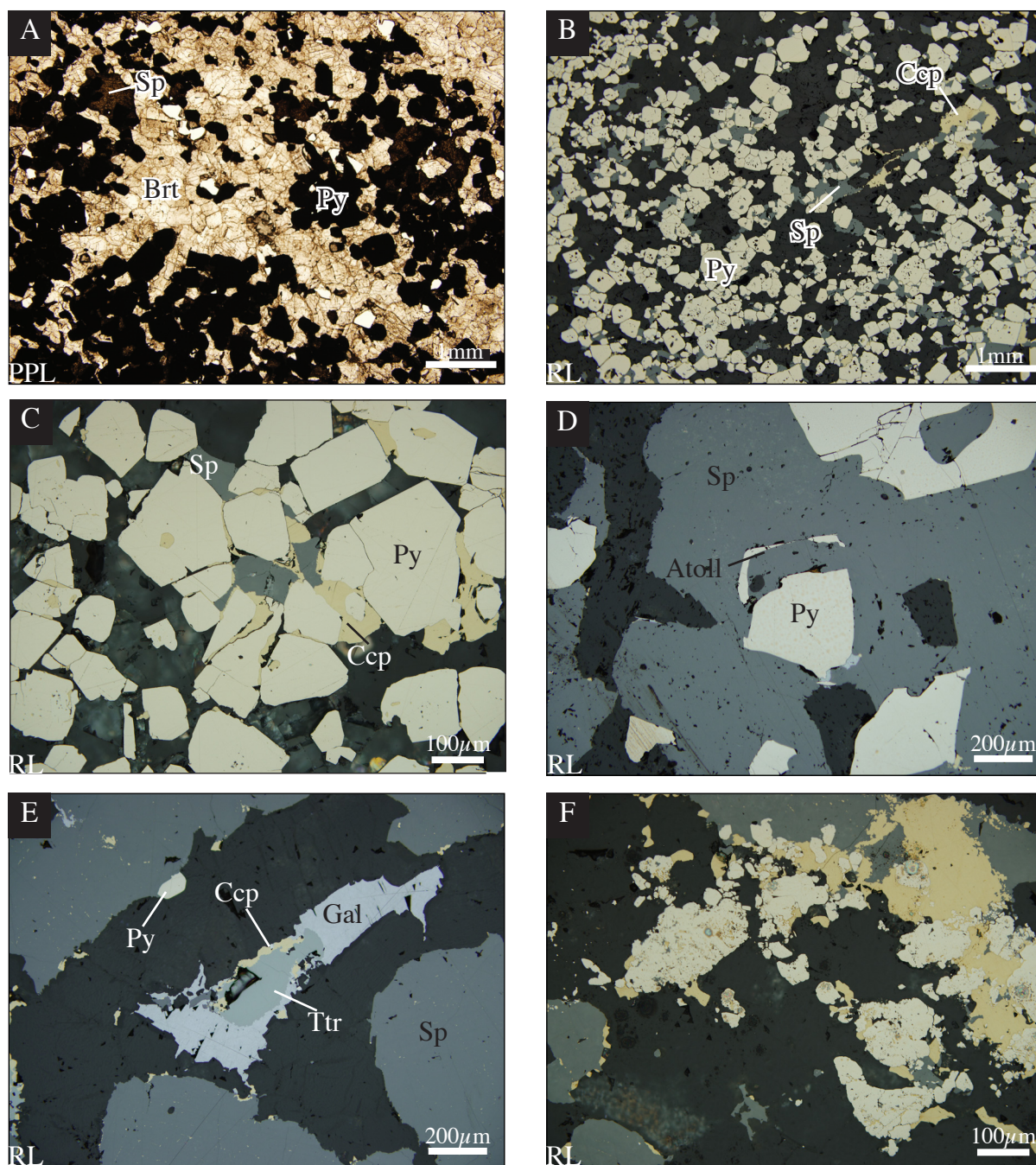


Figure 3.2. Photomicrographs of *barite ore*. A) Annealed, polygonal equigranular barite grains and red-brown sphalerite aggregates with red internal reflections. NS11-09. B) Subrounded, subhedral pyrite grains partly replaced by chalcopyrite and locally by sphalerite. NS13-09. C) Subrounded, subhedral pyrite grains and interstitial sphalerite and chalcopyrite. NS13-08. D) Pyrite atoll surrounded by sphalerite. NS11-04. E) Tetrahedrite grain intergrown with chalcopyrite and galena. NS11-04. F) Weakly recrystallized pyrite fram-boids, partly replaced by chalcopyrite NS09-09.

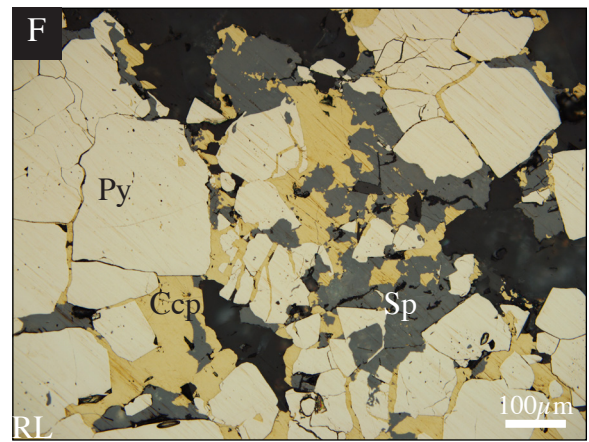
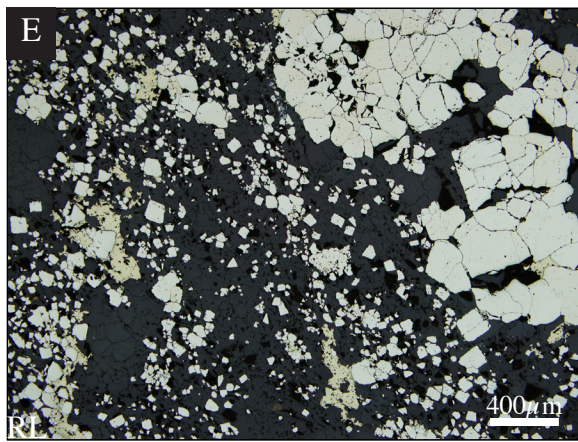
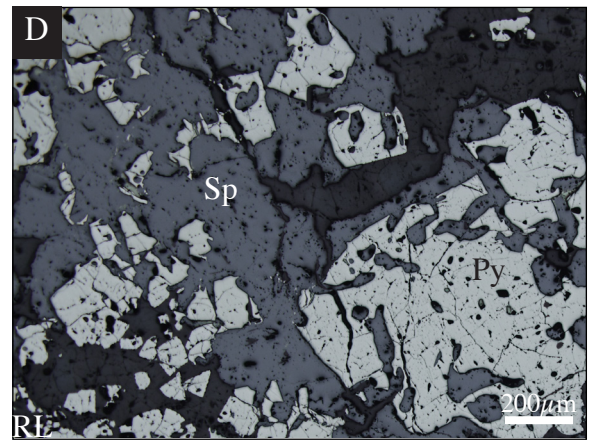
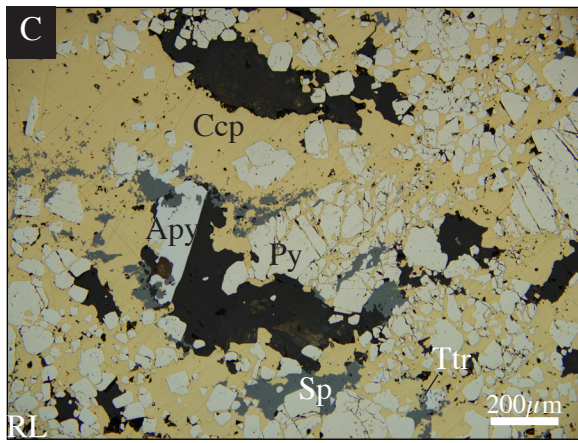
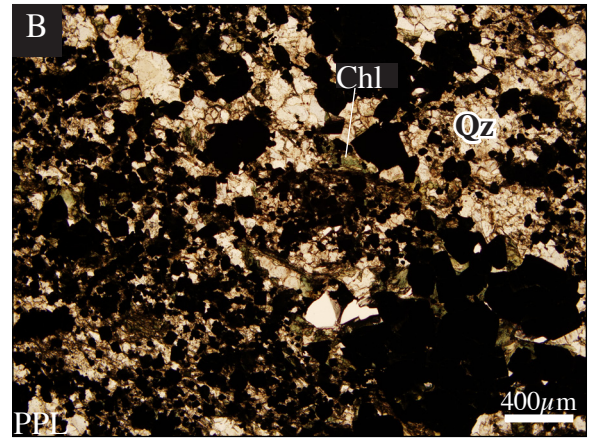
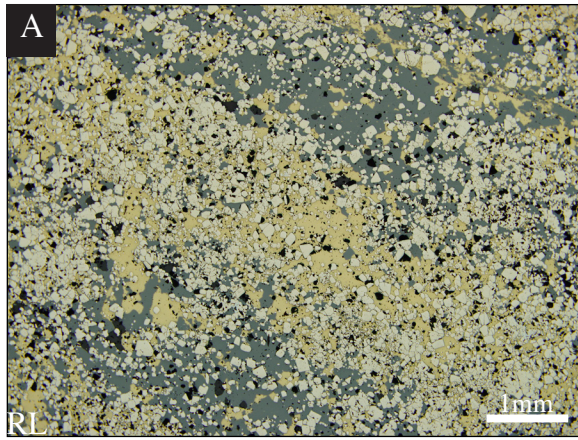


Figure 3.3. Photomicrographs of *massive pyrite ore*. A) Disseminated subhedral to anhedral pyrite in bands of massive chalcopyrite and sphalerite. NS11-07. B) Chlorite and quartz gangue. Note grain size difference of sulfides (opaque), compared to (A). NS17-12 C) Heavily “fractured” pyrite with sphalerite and pyrite replaced by chalcopyrite. A large arsenopyrite crystal is partially replaced by chalcopyrite. NS11-07. D) Sphalerite replacing pyrite and forming pyrite atoll structures. NS14-29. E) Very fine-grained to micro-crystalline, framboidal to euhedral pyrite overprinted by chalcopyrite and recrystallized quartz-pyrite. F) Sphalerite and chalcopyrite intergrown with and partly replacing and pyrite. NS09-11.

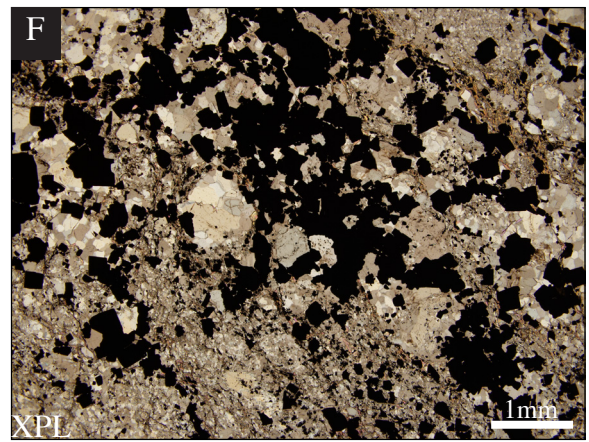
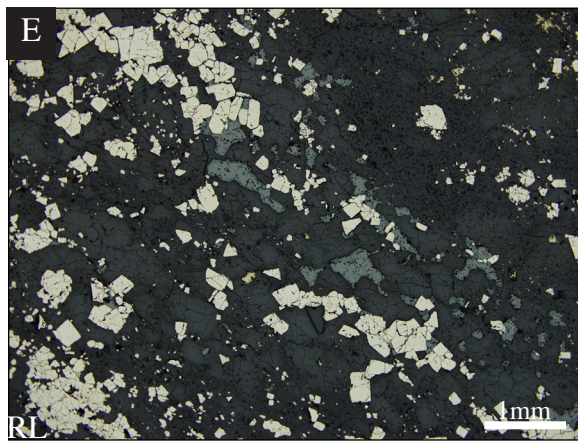
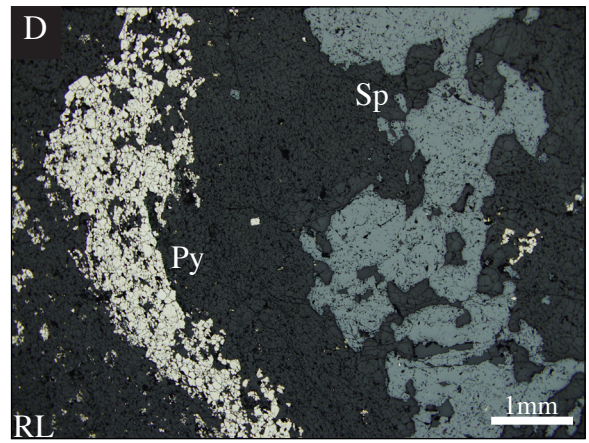
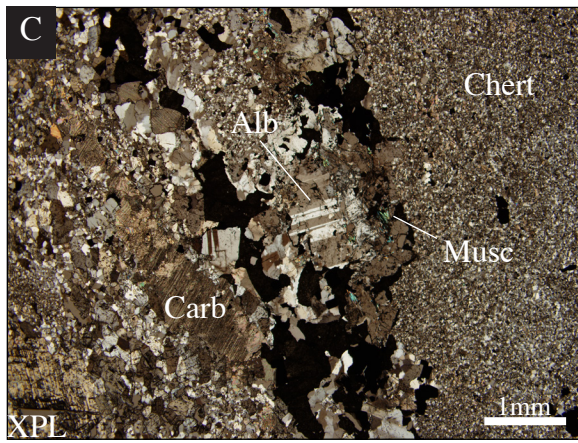
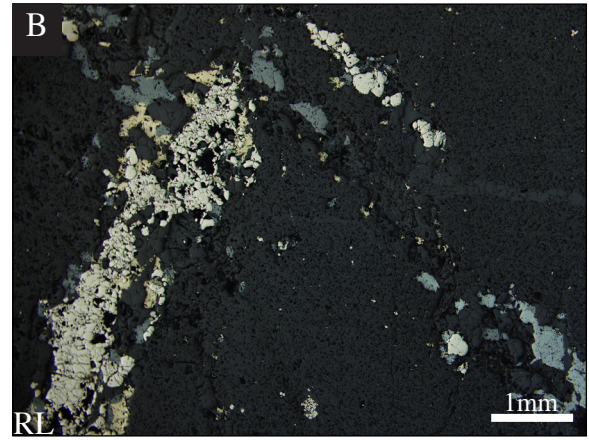
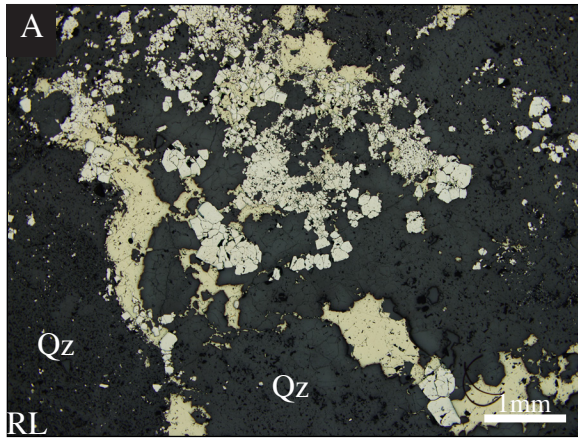




Figure 3.4. Photomicrographs of *semimassive and stringer-style pyrite-sphalerite mineralization*. A) Pyrite-chalcopyrite stringer in quartz, with variable grain size of pyrite. NS17-11. B) Pyrite-sphalerite stringers locally replaced by chalcopyrite, cutting through chert. NS11-22. C) Quartz-carbonate-albite-muscovite-sulfide stringers cutting very fine-grained chert. NS11-12. D) Pyrite stringer on left, sphalerite stringer on right, cutting through a very fine-grained, pervasively quartz-altered rock. NS17-09. E) Discontinuous pyrite and sphalerite stringer cutting through a pervasively quartz-muscovite altered volcanoclastic rock. Quartz associated with sulfides is coarser than wall rock. NS11-16. F) Quartz-sulfide stringers cutting pervasively quartz-muscovite-pyrite altered rock. Quartz associated with sulfides is coarser than wall rock. Muscovite defines foliation. NS11-16.

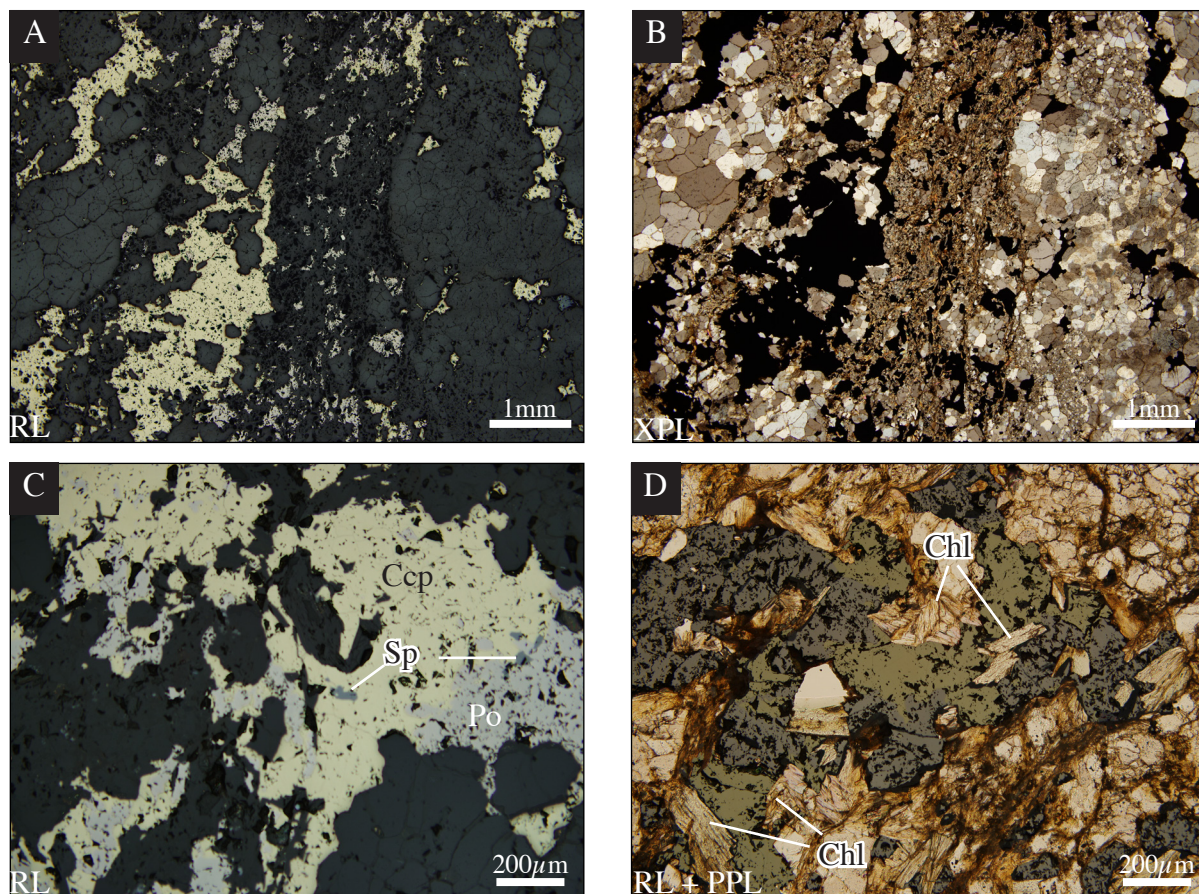


Figure 3.5. Photomicrographs of *pyrrhotite-chalcopyrite stringer-style mineralization*. A) Pyrrhotite and chalcopyrite within stringers cutting quartz-altered rock. NS13-04. B) Same photo in transmitted light. NS13-04. C) Stringer containing chalcopyrite and pyrrhotite with minor sphalerite. Note the absence of bird's eye pyrite. NS13-04. D) Very pale green sub-euhedral chlorite within pyrrhotite-chalcopyrite stringer cutting pervasively quartz-muscovite altered rock. NS14-14.

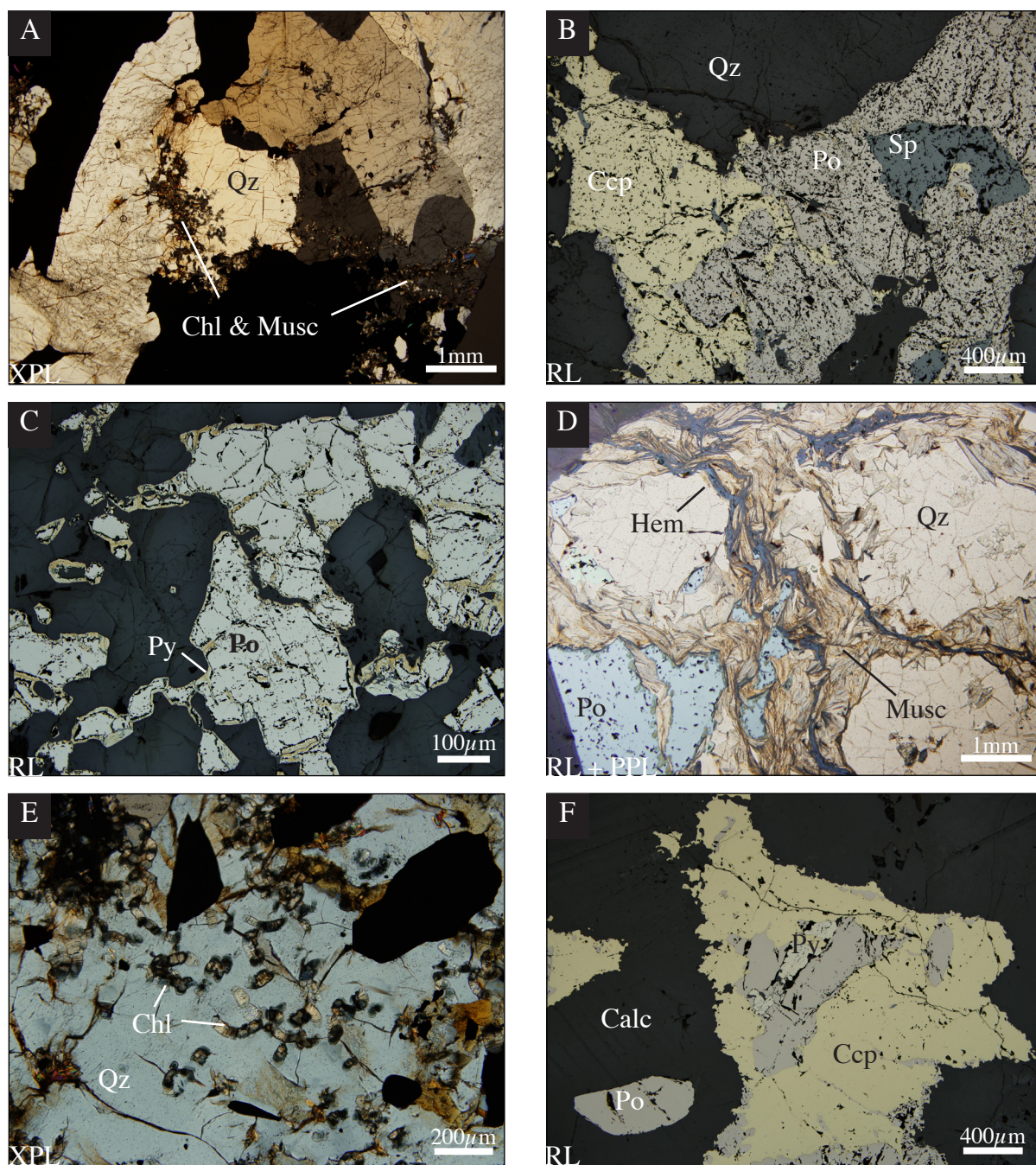


Figure 3.6. Photomicrographs of *massive pyrrhotite ore*. A) Large quartz grains with minor fine-grained chlorite and muscovite. NS11-03 B) Massive pyrrhotite, chalcopyrite and sphalerite with quartz gangue. NS11-03. C) Massive pyrrhotite showing 'birds eye' pyrite replacement along fractures and margins. NS11-03. D) Hematite is within muscovite separating large quartz grains. NS11.03. E) 'Wormy' chlorite booklets within very large quartz crystal. NS11-03. F) Pyrrhotite overgrown by and partly replaced by chalcopyrite with later pyrite. NS14-08.

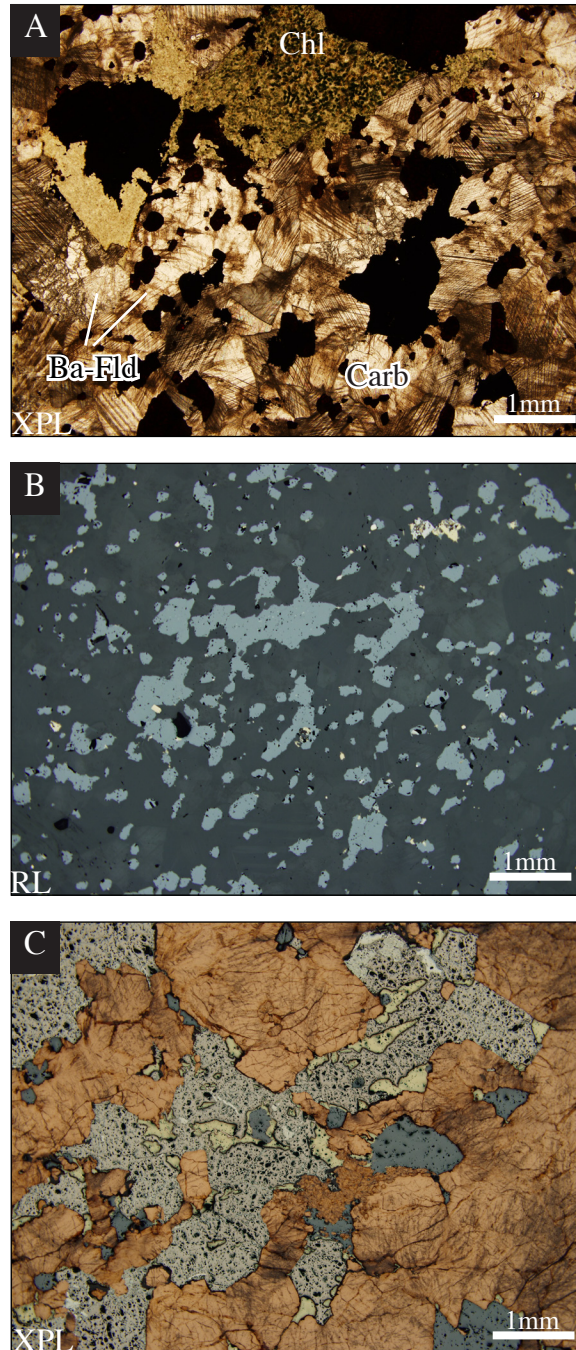


Figure 3.7. Photomicrographs of *carbonate-rich ores*. A) Carbonate-rich ore consisting of coarse carbonate, chlorite aggregates with interstitial sphalerite grains and Ba-feldspar partially replaced by carbonate. NS14-10. B) Carbonate-rich ore with rounded sphalerite grains, local chalcopyrite and trace pyrrhotite. NS14-10. C) Pyrrhotite, with minor pyrite in coarse carbonate gangue with minor chlorite. NS14-13.

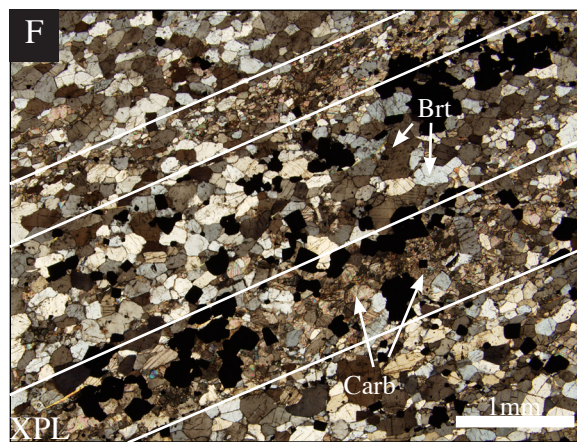
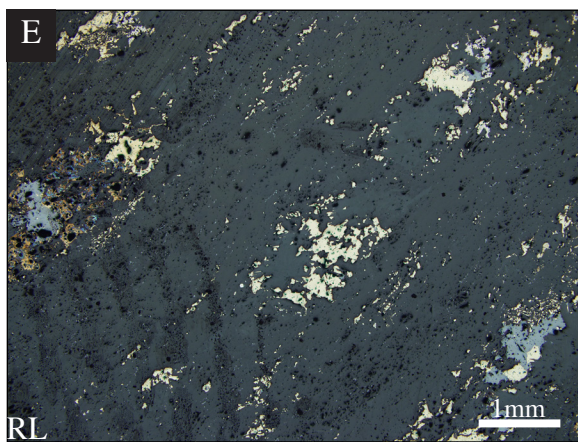
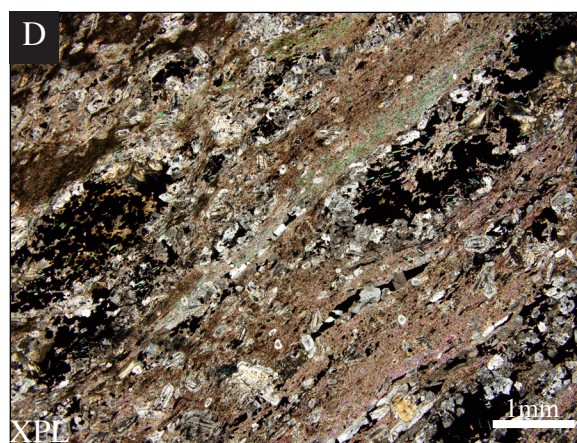
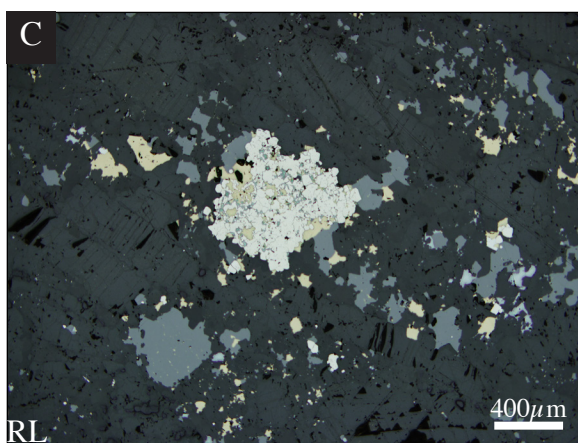
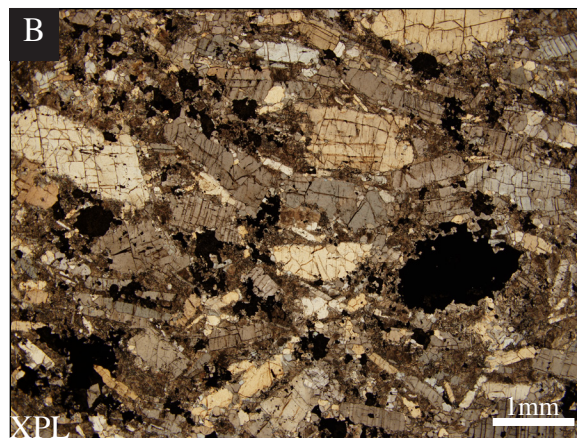
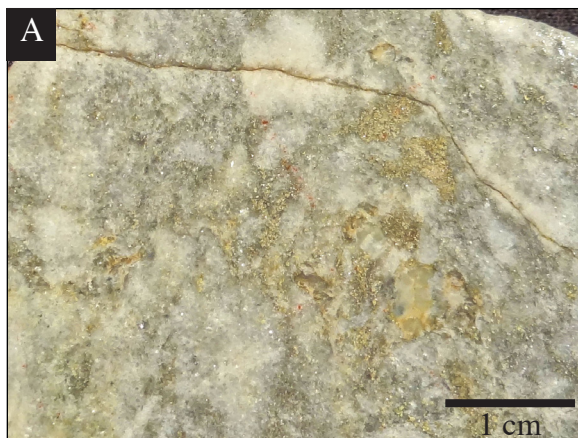


Figure 3.8. Photomicrographs of *clastic barite* (A-C), *mineralized tuffaceous rock* (D-E), and *barite-carbonate* mineralization (F). A) Drill core photo of fragmental unit with barite, carbonate and sulfide clasts, supported by a barite + sulfide matrix. NS18-06. B) Euhedral, partially broken barite crystals and sulfides within a very fine-grained carbonate matrix. NS19-07. C) Sulfide within carbonate matrix. The granular sulfides consist of weakly annealed framboidal pyrite partially replaced by chalcopyrite along with sphalerite, chalcopyrite, pyrite and galena grains. NS19-07. D) Granular sulfide-muscovite-quartz aggregates along with feldspar aggregates and individual feldspar crystals within a very fine-grained muscovite matrix. NS14-32. E) Granular chalcopyrite-pyrrhorite and minor sphalerite within a very fine-grained muscovite matrix. NS14-32. F) Finely interlayered barite and carbonate. White lines highlight carbonate layers. Ba-feldspar present in sample, but not shown. NS13-10.

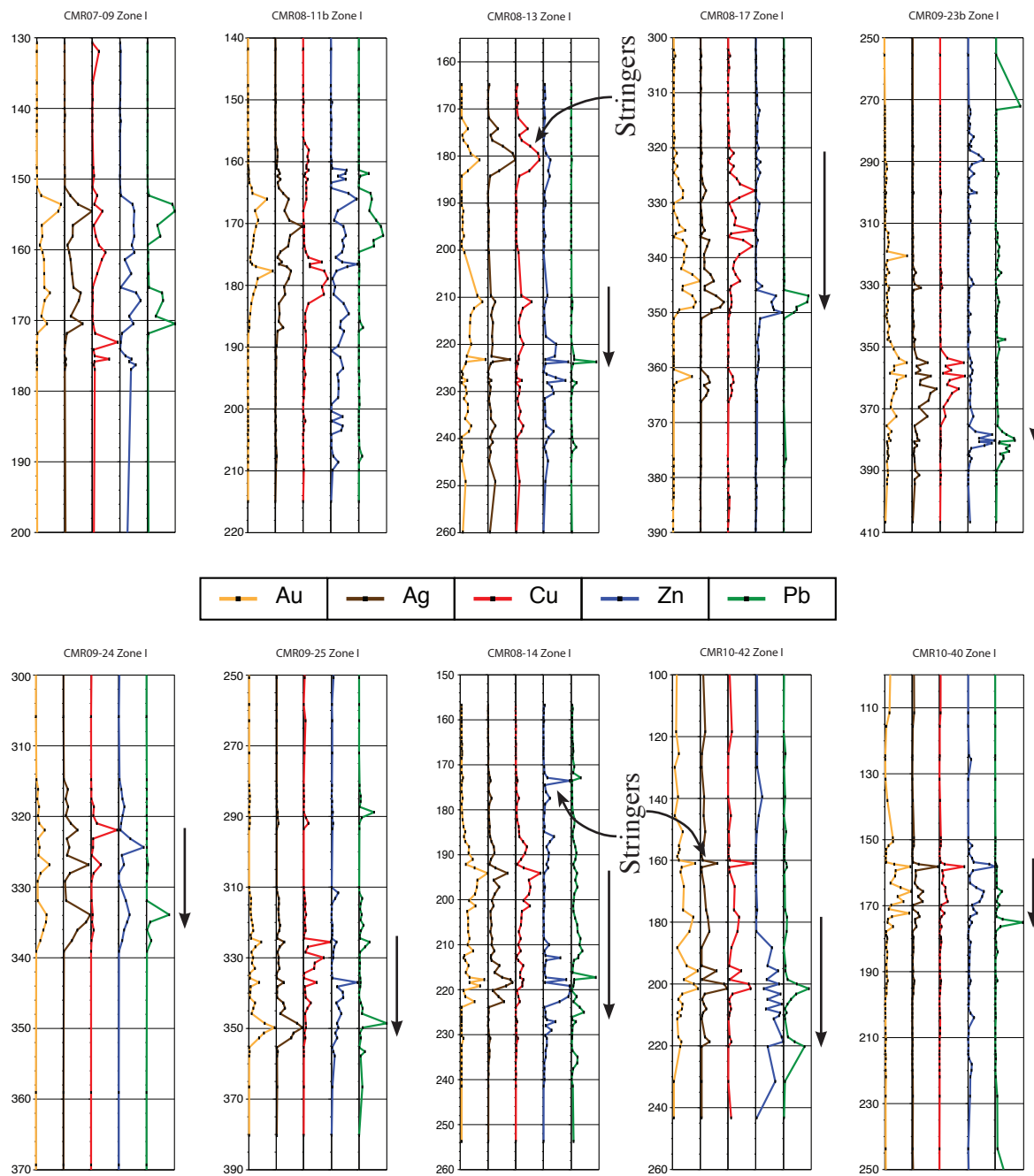


Figure 3.9. Downhole metal concentration plots of selected drillholes. Metal zonation suggests that Zone I is overturned. Arrows indicate zonation from Cu-rich to Zn-Pb-rich, but not all drill holes show a consistent metal zonation. Pb, Zn and Cu spikes are from mineralized stringers.

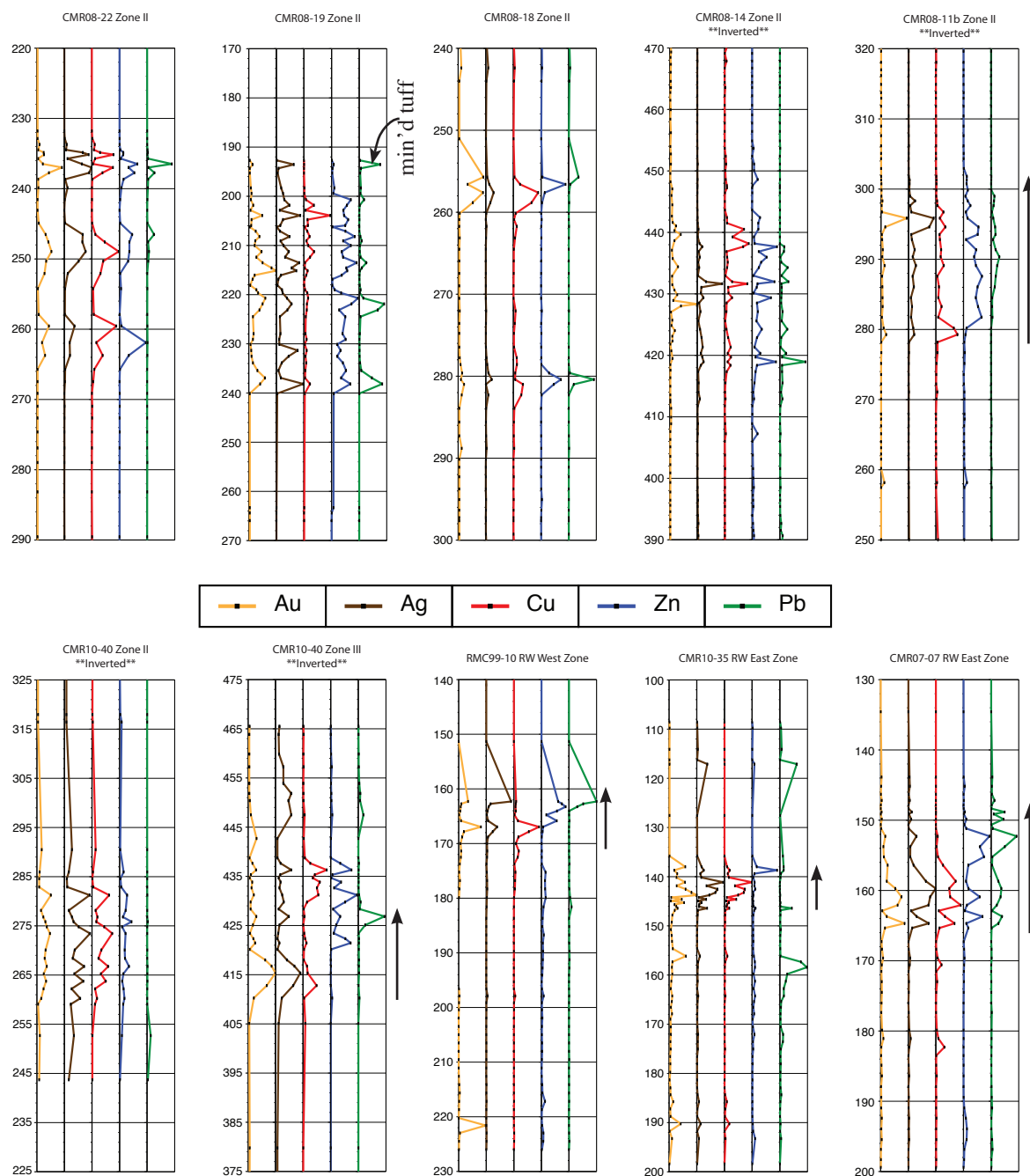


Figure 3.10. Downhole metal concentration plots of selected drillholes. Metal zonation suggests that the RW Zone and Zones II and III are upright (up drillhole), whereas Zone I is overturned (Figure 3.9). Plots for drillholes CMR08-14, CMR08-11b and CMR10-40 have been inverted because drillholes intersect the lens from stratigraphically below. Arrows indicate zonation from Cu-rich to Zn-Pb-rich, but not all drill holes show a consistent metal zonation.

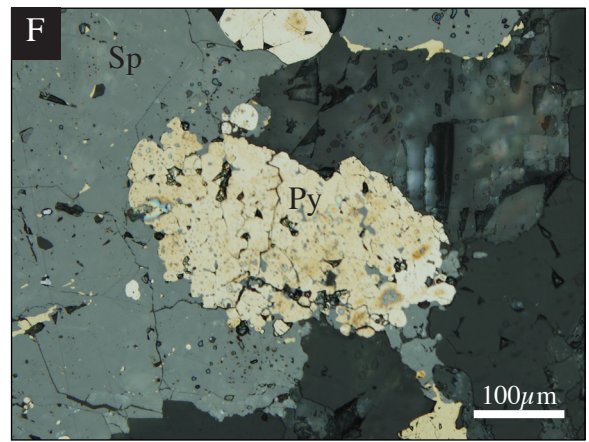
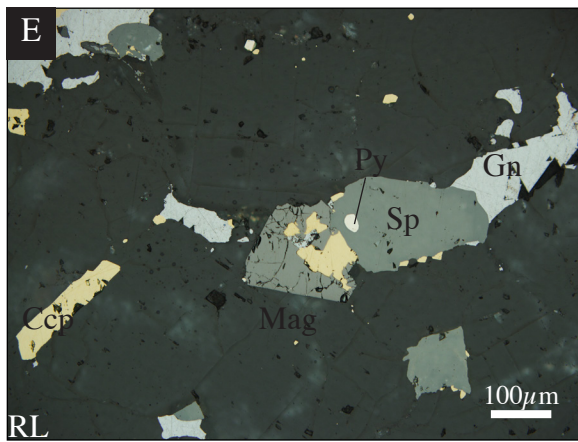
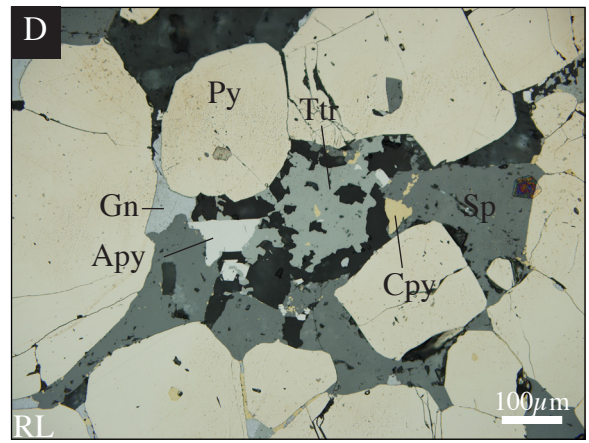
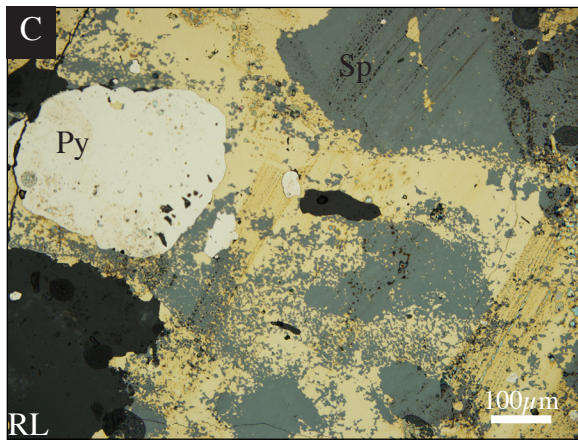
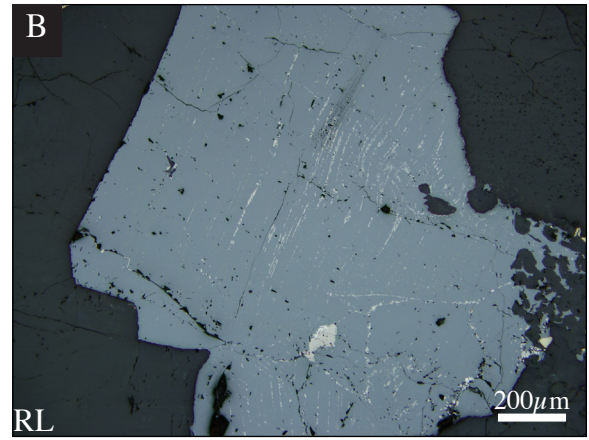
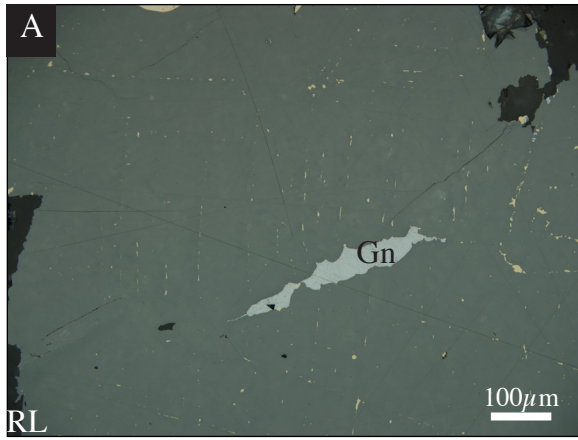




Figure 3.11. Photomicrographs of select sulfide textures. A) Chalcopyrite-disease within large sphalerite grain, in barite-rich ore. Fracture in sphalerite contains galena. NS11-04. B) Large sphalerite grain within carbonate-rich ore exhibiting “pyrrhotite-disease”. NS14-13. C) ‘Dusting’ of chalcopyrite replacing sphalerite within barite-rich ore. Pyrite shows relict colloform texture. NS09-09. D) Galena, arsenopyrite, tetrahedrite and chalcopyrite interstitial to coarse pyrite in barite-rich ore. NS11-20. E) Magnetite with galena in barite-rich ore. Chalcopyrite forming around margins of sphalerite possibly from outward remobilization of inclusions during recrystallization. Galena is concentrated in triple junctions between barite grains. NS11-05. F) Framboidal pyrite nodule within barite-rich ore on the flanks of Zone I. NS11-19

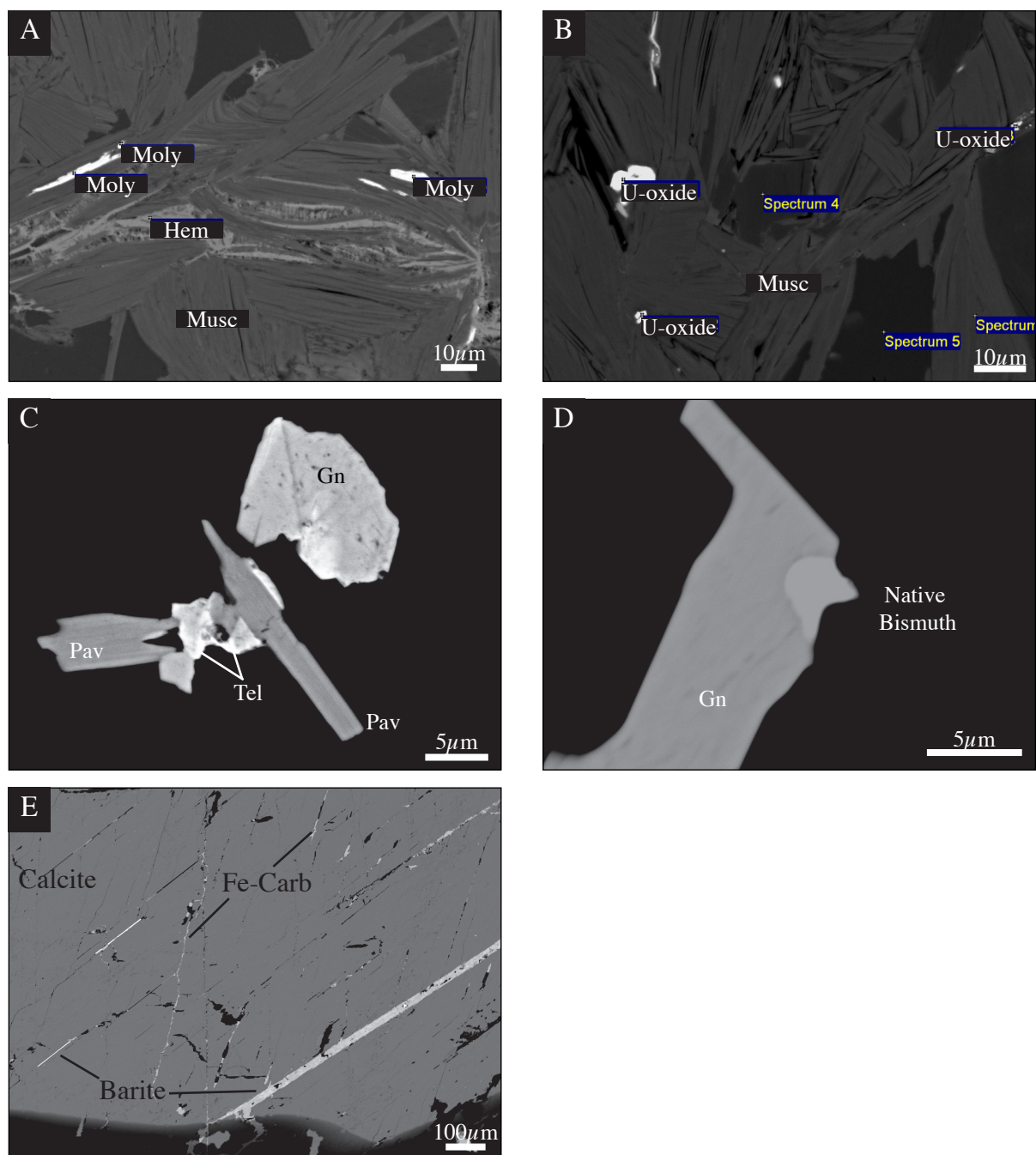


Figure 3.12. Backscattered electron images of ore-related minerals. A) Trace molybdenite in muscovite and hematite within massive pyrrhotite ore. NS11-03. B) Uranium oxide within muscovite-rich zone in massive pyrrhotite ore. NS11-03. C) Bi-telluride (tellurobismuthite) as an inclusion in or replacement of galena, and Bi-sulfosalt (pavonite-group) as spatially associated elongate laths. NS9-18. D) Native bismuth inclusion within galena. This sample has the highest Bi content at 129 ppm. NS9-18. E) Large calcite crystal from massive pyrrhotite ore, with barite and Fe-carbonate within fractures. Sample has one of the highest U contents at 25.6 ppm. NS11-03.

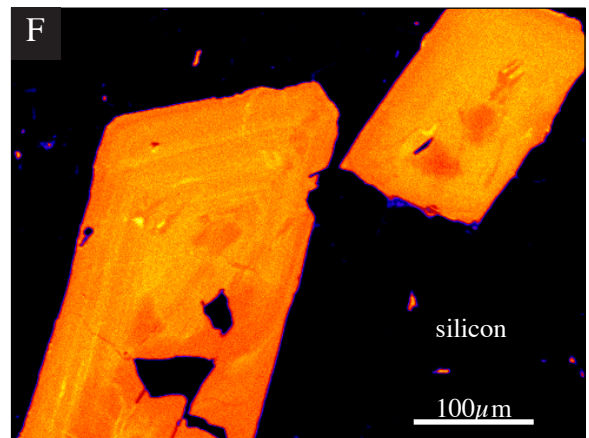
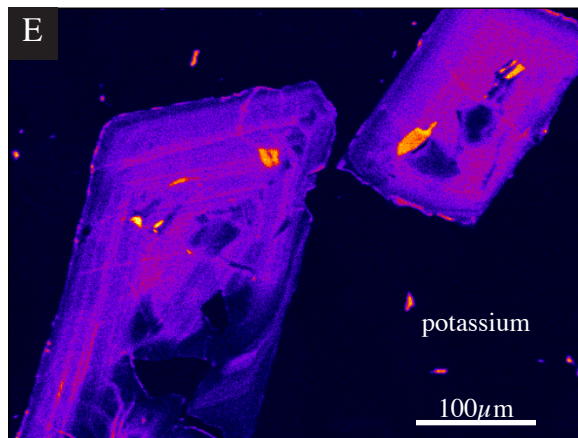
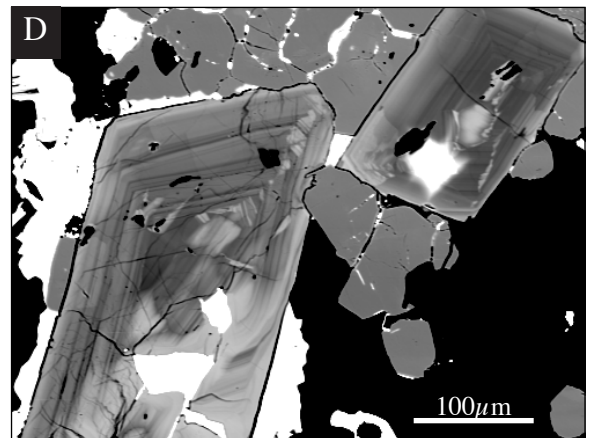
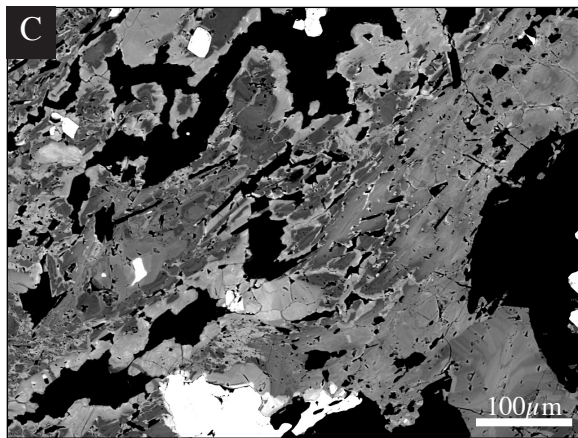
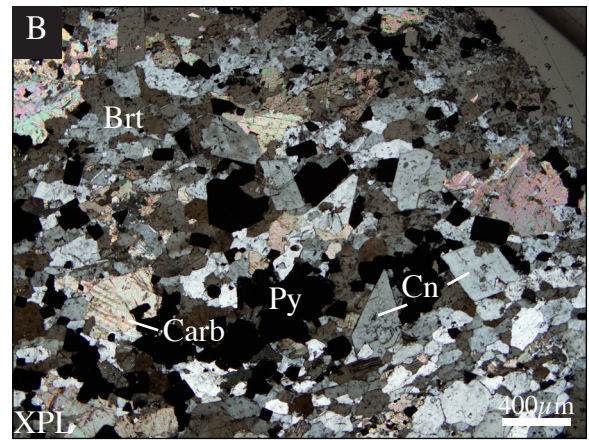
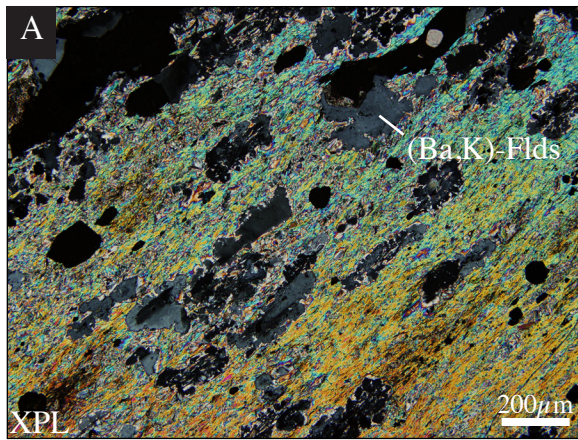




Figure 3.13. Photomicrographs of *(Ba-K)-feldspars*. A) Deformed aggregates of (Ba-K) feldspars and sulfides within a muscovite matrix. Feldspars are partially replaced by muscovite. NS17-17. B) Euhedral celsian (Ba-feldspar) disseminated throughout barite-carbonate type mineralization. NS13-10. C) Backscattered electron image of (Ba-K)-feldspars. Note the compositional variation due to Ba-K substitution. Lighter coloured rims have higher Ba/K ratios. NS17-17. D) Backscattered electron image of euhedral celsian crystals showing a high degree of compositional zonation with paler areas having a higher Ba/K ratio. NS13-10. E) Element map of K in a (Ba-K)-feldspar. Warmer (lighter) colours are higher in K. Zones of lower K are coincident with higher Ba in (D) NS13-10. F) Thermal element map of Si in a (Ba-K)-feldspar. Warmer (lighter) colours are higher Si. High Si zones are coincident with low Ba because of loss of Si during substitution of Ba for K. Compare with (D). NS13-10.

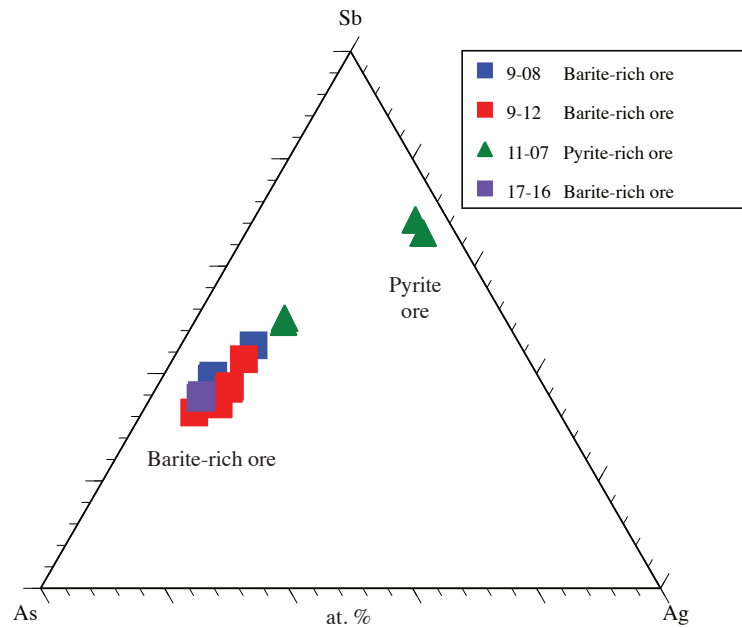


Figure 3.14. Compositional range of tetrahedrite-tennantite series minerals analyzed by electron microprobe. Compositions may vary greatly within a single sample, such as 11-07. For Figures 3.13, 3.14 and 3.15, symbols are consistent: pyrite-rich ore (triangles), barite-rich ore (squares), barite-carbonate ore (circle), carbonate-rich ore (diamonds), tuffaceous rocks (cross) and pyrrhotite-rich ore (empty diamond).

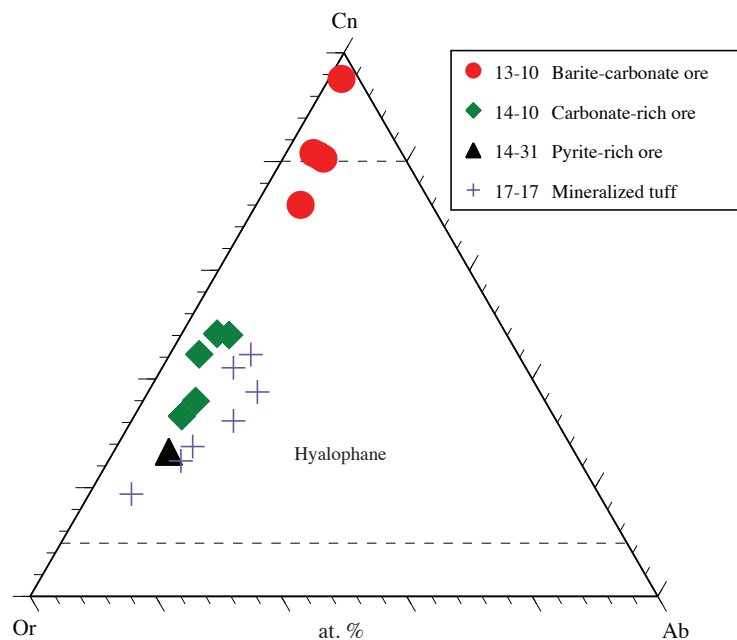


Figure 3.15. Ternary diagram showing compositional variations of (Ba,K)-feldspars in terms of Cn (Celsian)-Or (Orthoclase)-Ab (Albite) ratios. Euhedral, well-zoned crystals from barite-carbonate ore (13-10) represent true ‘celsian’, whereas the rest fall within the ‘hyalophane’ field.

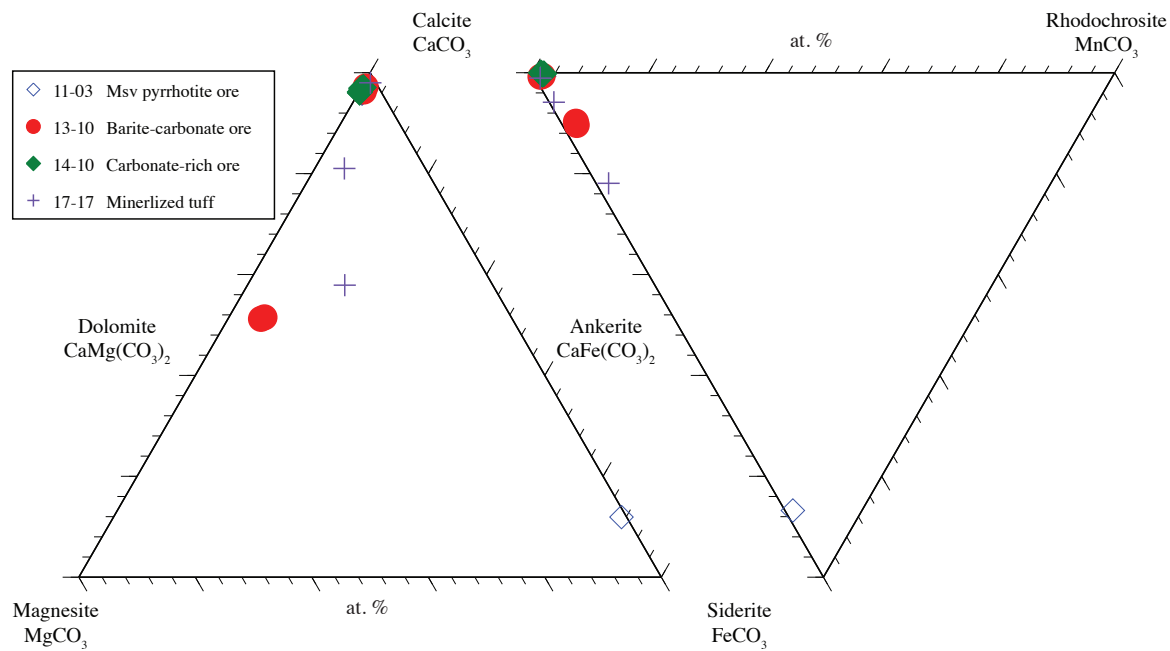


Figure 3.16. Ternary diagrams showing composition variations of carbonates from within Zone I. Most plot within the calcite field, although several grains analyzed are dolomitic and a grain from a massive pyrrhotite plots in the siderite field.

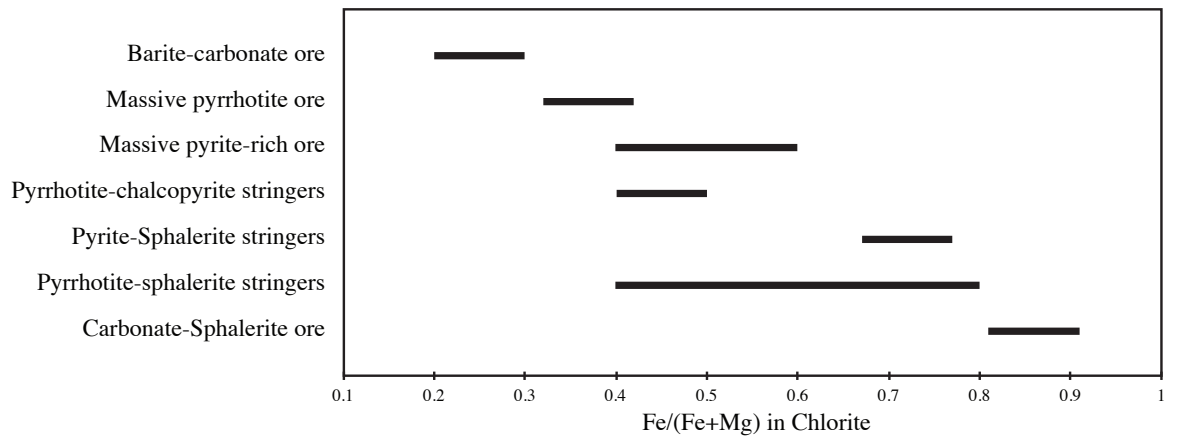
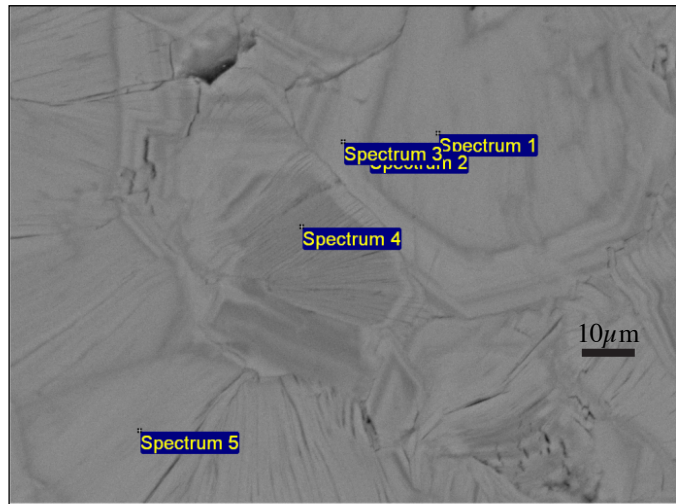


Figure 3.17. A) Backscattered electron image of zoned chlorite aggregates in carbonate-rich ore. Chlorite shows compositional zoning with brighter zones having higher Fe/Mg. NS14-10. B) Plot of Fe/(Fe+Mg) ratios of ore zone chlorite analyzed by microprobe. Chlorite tends to be more Fe-rich towards centre of Zone I lens (i.e. in drillholes CMR08-14 and -17).

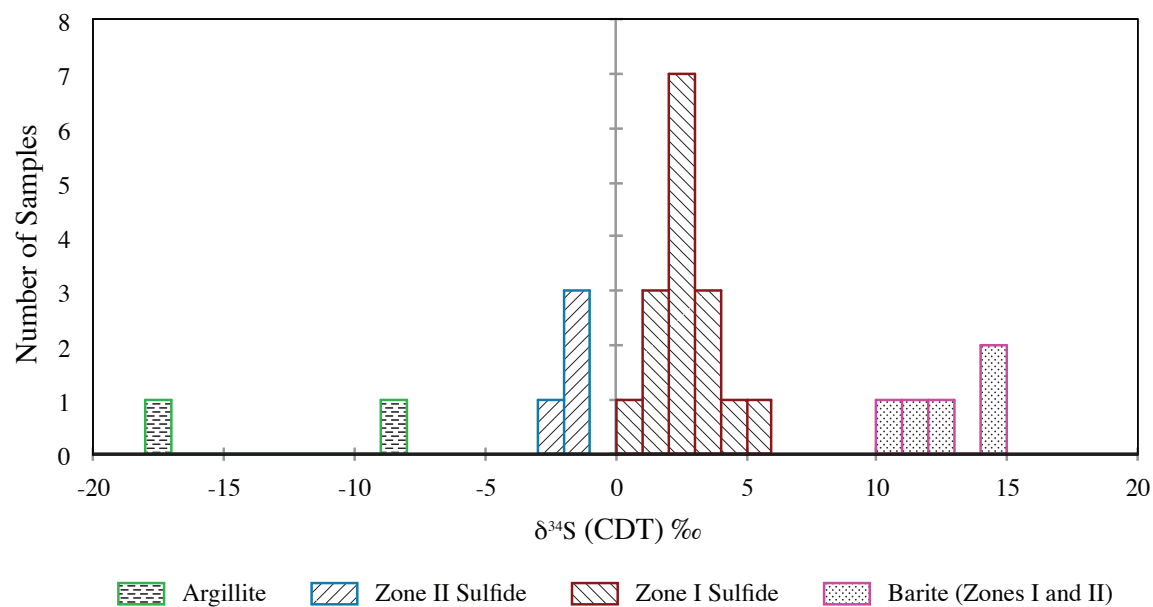


Figure 3.18. Histogram of sulfur isotope data from Zones I and II sulfides and sulfates. Zone I sulfide $\delta^{34}\text{S}$ values are generally heavier than Zone II. Average barite $\delta^{34}\text{S}$ is 10.08‰ higher than Zone I sulfides and 14.57‰ heavier than Zone II sulfides. 27 samples analyzed.

Chapter 4

ALTERATION

The major alteration zone surrounding ore at Glacier Creek is a muscovite-quartz-pyrite schist with variable amounts of carbonate, chlorite and epidote located within the inferred deposit-scale anticline. To describe the alteration surrounding the massive sulfide lenses, several questions need to be addressed: (1) What is the lithogeochemical nature of the footwall muscovite-quartz-pyrite schists and can they be correlated to known 'fresh' rock units? (2) What mass transfers occurred and can they be used to identify the hydrothermal conduits? (3) What elemental zonation patterns are present and can they be used to delineate lithological units and/or vector towards ore, and finally, (4) Do variations in the short wavelength infrared (SWIR) spectral signature of the white micas exist and can they be used to delineate lithological units or vector towards ore?

To address these questions, 30 representative samples in 7 drillholes from the footwall and hanging-wall alteration zones were chosen for detailed geochemical and petrographic analyses. Whole-rock data from Constantine Metal Resources Ltd. for ~400 samples from 43 drillholes were also used to help identify least-altered protoliths and possible fractionation trends in the host lithologies.

4.1 Alteration Mineral Assemblages and Distribution

Alteration mineral assemblages have been grouped into 4 facies (Table 4.1 and Figures 4.1 to 4.4). The dominant footwall facies is a muscovite > quartz + pyrite assemblage

(“muscovite facies”). Illite has not been observed. This facies forms a large alteration zone referred to as QSP (quartz-sericite-pyrite) schist. In general, alteration intensity increases towards ore. Muscovites throughout the deposit are barium-rich (Figure 4.3) and will be discussed below. These rocks show a simple mineralogy and, in strongly altered zones, have lost nearly all primary textures (Figures 2.12 G and 4.2 F). Within weakly altered feldsparphyric basalts, muscovite selectively replaces the igneous feldspar (Figure 2.12 D). In the moderately altered volcanoclastic rocks, muscovite replaces the matrix or clasts (Figure 4.1 B). Locally quartz alteration may also be selective, replacing clasts, amygdules or matrix material (Figure 4.1 B and C). Moderately altered rocks containing minor carbonate $\pm$ chlorite (up to 10 vol.%) form a stratabound alteration facies 20-40 m below Zone II and just below Zone III massive sulfide mineralization (“carbonate-chlorite facies”; Figure 4.4). This facies is also observed locally below Zone I (Figure 4.5). Carbonate and chlorite are also found enveloping massive sulfide lenses where the rocks are thought to be tuffaceous. This carbonate alteration may be from an earlier alteration phase or even diagenesis of the volcanic precursor. A quartz-pyrite facies occurs immediately below massive sulfide mineralization, and forms partially transposed feeder zones to the ore lenses (“quartz-pyrite facies”; Figures 4.4 and 4.5). Quartz is extensively recrystallized and forms polygonal, granoblastic texture of varying grain size. Directly underlying the center of Zone I, this quartz-pyrite dominated assemblage contains minor chlorite associated with stringers. The quartz-pyrite facies likely grades into the pyrrhotite-chalcopyrite stringer zone underlying Zone I (Figures 4.4 and 4.5). Stratigraphically below the lenses (>100 m) muscovite-quartz-pyrite alteration grades into an epidote + muscovite + quartz + pyrite/pyrrhotite alteration facies (“epidote facies”). Least altered volcanic rocks at Glacier Creek typically have a greenschist facies

metamorphic mineral assemblage of chlorite, carbonate, feldspar and locally minor quartz and epidote. These least altered rocks are typically relatively calcareous, magnetic and are cut by numerous thin calcite veinlets. Alteration zonation, with the exception of weakly transposed quartz-pyrite facies 'conduits', appears to be parallel stratigraphy and may outline previous lithologies.

4.2 Geochemistry of Alteration

Immobile Elements

Whole rock geochemical data indicate that the high-field-strength elements (HFSE) Zr, Al, Ti, Nb, Hf and Ta and to an extent the heavy rare-earth elements (HREE) (e.g. Lu) were immobile during alteration (Figure 4.10). Y and the HREEs were slightly mobile in strongly altered rocks. Some typically immobile elements, such as Sc, V and Th and the light rare-earth elements (LREE) are also mobile.

The HFSE (Zr, Y, Nb) are typically incompatible (except within some calc-alkaline suites), making them good monitors for magmatic fractionation (Gifkin et al., 2005). These elements maintain the same ratio during fractionation and through metasomatism, assuming a single source, and therefore can be used to identify magmatic affinity. Volcanic rocks around the Glacier Creek deposit all fall within the tholeiitic field, with some overlap into the transitional field on a Zr versus Y plot (Figure 4.6). All volcanic rock samples from Constantine's historic whole-rock database plot within the sub-alkaline basalt or rhyolitic fields (Figure 4.7).

Green (2001) differentiated 6 least-altered basalt units using field mapping observations and a plot of Zr/TiO_2 versus $\text{Zr}/\text{Al}_2\text{O}_3$ (Figure 4.8). This plot shows that Zr/TiO_2 ratios are a poor discriminator of the different units (and altered equivalents) because TiO_2 is partially incompatible in tholeiitic basalts (MacLean and Barrett, 1993) and therefore does not show a distinct fractionation pattern. $\text{Zr}/\text{Al}_2\text{O}_3$, however, shows a significant spread due to magmatic fractionation. Green's (2001) B2 and B3 basalts plot close together along a fractionation curve shown in Figure 4.9, as do the B4 and B5 basalts. The feldspar-phyric basalts (B6) do plot separately along a distinct, steep alteration line and even highly altered samples of B6 basalt can be easily identified chemically. Five main groupings of data are observed in this plot: the B6 feldspar-phyric basalts, a group around the B4 and B5 basalts, a group around the B3 and B2 basalts, a wide spread grouping of trachyandesitic basalts, and the rhyolites (Figure 4.9). There is considerable spread in the data, possibly due to different analytical methods as the samples were collected over several years and analyzed by different labs, and possibly from sulfide content. Some of the rocks are also volcanoclastic in nature and their geochemistry generally does not correlate well with their coherent counterparts (e.g., Gifkin et al., 2005).

Nevertheless, four main groupings of mafic-intermediate volcanic rocks can be identified in Figure 4.9: $\text{Al}_2\text{O}_3/\text{Zr}$ ratios >0.32 correspond to feldspar-phyric basalt, between 0.2 and 0.32 is B4-B5 basalt, 0.14-0.20 is B2-B3 basalt and 0.07-0.14 is trachyandesitic basalt. Using this rough guide, several important conclusions can be drawn from Figure 4.9. Samples from the overturned footwall to Zone I are chemically equivalent to the feldspar-phyric (B6) basalt, with the exception of a 10-20 m thick mafic volcanic unit, historically logged as

a massive “MZ” basalt which chemically resembles the B2/B3 basalts in the hanging wall (Figure 2.9). This unit is less altered than the adjacent feldspar-phyric basalt and quartz-sericite-pyrite schist, which both have a similar $\text{Al}_2\text{O}_3/\text{Zr}$ ratio. The massive, less altered basalt unit may represent a pre- to syn-mineralization sill/dyke that intruded below the Zone I mineralization. The pyrrhotite-chalcopyrite stringer zone stratigraphically below Zone I is greatly attenuated where this basalt unit occurs (Figure 2.9). Basalts from the immediate hanging-wall to Zone I, as well as in the footwall and immediate hanging-wall to Zone II also have $\text{Al}_2\text{O}_3/\text{Zr}$ ratios similar to the B6 basalt of Green (2001).

Several tuffaceous rocks (e.g., NS9-15, NS9-19) plot within the trachyandesite field. These intermediate tuffaceous rocks occur immediately above and below Zones I, II and III (see Chapter 3). Fresh, unaltered, coherent trachyandesites are rare in the Glacier Creek area and appear to be unrelated to mineralization.

Despite the structural complexity between Zone I and Zones II and III, it is apparent from Figure 4.9 that the feldspar-phyric basalt (B6) is the overall footwall unit to mineralization at Glacier Creek, with intermediate tuffaceous and rhyolitic units often directly hosting mineralization.

Mass Changes (Multiple-Precursor)

Several techniques have been developed for routine calculation of mass and elemental change during alteration (Gresens, 1967; Grant, 1986; MacLean and Kranidiotis, 1987; MacLean, 1990; Stanley and Madeisky, 1994). In exploration, these methods help to identify

hydrothermal pathways and may be used to vector towards ore zones. Immobile element ratios are used to overcome the issue of closure in compositional data, which mask elemental changes due to mass gains or losses (Gifkin et al., 2005; Rollinson, 1993). At Glacier Creek, mass transfer calculations provide quantitative identification of alteration facies and intensity. The multiple precursor technique of Barrett and MacLean (1994) and MacLean and Barrett (1993) has been applied to many VMS deposits in recent years and are used here. The least altered volcanic units around the Glacier Creek deposit have been identified by Green (2001), but strongly altered rocks cannot be confidently correlated with known precursor compositions. For this reason, the multiple precursor method of MacLean and Barrett (1993) is used to estimate the starting compositions, assuming that the precursors shared a common magmatic source.

For the multiple precursor method (MacLean and Barrett 1993; Barrett and MacLean, 1994), a general *fractionation curve* is drawn for genetically related volcanic units on an immobile compatible-incompatible plot (Zr vs Al_2O_3 ; Figure 4.9). For each altered sample, the precursor (least altered) Zr concentration is located at the intersection between an “alteration line”, a straight line through the sample point and the origin, and the fractionation curve. This can be accomplished graphically or by using the quadratic formula of the fractionation curve and alteration line. Fractionation curves are then identified for mobile elements. This is accomplished by plotting the mobile element concentrations against Zr. Curves and quadratic equations for best-fit lines are shown in Figure 4.11. Most mobile elements have a concave-up curve, showing a decrease in concentration with fractionation. Several elements such as P, Ti and Fe are known to increase with fractionation within mafic tholeiites, and

then decrease again with more felsic compositions. We are more concerned with differentiating basalts here, therefore, only mafic samples are plotted for these elements (i.e., rocks with $\text{Al}_2\text{O}_3/\text{Zr}$ ratios of >0.14). Precursor Zr values are input into the quadratic formula for each mobile element to identify the concentration of that element in the precursor. The computed precursor oxide concentrations are normalized to 100% and compared to reconstituted values for each altered sample. The reconstituted value is the original compositional data for the altered rock multiplied by an enrichment factor ($\text{Zr}_{\text{pre}}/\text{Zr}_{\text{alt}}$). The difference between this reconstituted value and the calculated precursor value is the mass change presented as g/100g.

Results

Mass gains within the altered rocks at Glacier Creek are dominated by Si, Fe, S and K (Table 4.3 and Figure 4.12), reflecting the predominance of quartz, pyrite, and muscovite alteration. Ca, Mg and Na show mass losses in all altered rocks. Precursor sulfur data are only available for surface samples collected by Green (2001), with a detection limit of 0.01 wt.%. Using these sulfur data, the majority of the precursor compositions calculated for altered rocks are approximately 900 ppm S, which is consistent with the average tholeiite sulfur contents given by Mathez (1976). Overall, Al, Mn, P and Ti remain unchanged during alteration. Mass changes correlate well with empirically defined alteration facies.

Samples containing minor carbonate $\pm$ chlorite alteration (“carbonate-chlorite facies”) show an overall net mass loss, dominated by Fe and Si, although the samples clearly contain quartz and pyrite altered (Figure 4.12). These samples show a significant gain in S from pyrite formation. Samples with the most intense quartz-pyrite alteration show the larg-

est net gains. These samples directly underlie the massive sulfide lenses and form the feeder zones to the ore lenses ('quartz-pyrite facies'). "Muscovite facies" samples have the largest K gains. Least altered rocks subtle quartz-muscovite-pyrite alteration show minor mass changes.

The single precursor method (Barrett and MacLean, 1994; MacLean and Barrett, 1993) was also tested on the feldspar-phyric (B6) basalts. These rocks tend to plot more consistently along a single alteration line (Figure 4.9) and are more readily correlated empirically in hand sample by the presence of feldspar phenocrysts. Although the mass change values (g/100g) vary slightly between the two methods, the general trends are identical (Figure 4.13).

Rare Earth Elements

Insufficient REE data are available for all unaltered rocks but, data obtained for this study include least-altered compositions for the dominant footwall lithology of feldspar-phyric (B6) basalt (Figure 4.14 A; samples NS9-01 and NS13-01). Although the majority of igneous feldspars have been replaced by muscovite in these rocks, the 'least altered' sample NS9-01 has a slight positive Eu anomaly (Figure 4.14 A). Unlike the other REEs, Eu^{2+} is compatible in feldspars and becomes enriched during crystal fractionation (Rollinson, 1993). Eu^{2+} may become leached by reduced hydrothermal fluids during alteration of feldspars to sericite or chlorite, resulting in a 'negative' europium anomaly with increasing alteration (Gifkin et al., 2005). This effect is illustrated in Figure 4.14 A, in altered lithologies closest to massive sulfide mineralization (i.e., from sample NS9-01 to NS9-04 and 13-03; Figure

2.9). Sample 13-03 has the same REE pattern as NS9-04 in Figure 4.14 A, but with a lower concentration due to the effect of mass gain during silicification. The REE data also show a fan-shaped spread, showing greater loss of the light REE than heavy REE in increasingly altered rocks due to the greater mobility of LREE (Figure 4.15).

Several altered samples have positive Eu anomalies, in particular samples NS9-17, NS11-23 and NS11-24, which occur along the ore horizon of Zone II, either on the flanks or directly overlying the ore. These rocks are fragmental, tuffaceous and may be, in part, exhalative. Eu^{2+} in these rocks was likely liberated from feldspar in footwall rocks, transported within reduced, acidic hydrothermal fluids (Sverjensky, 1984) and deposited at or near the seafloor (Gifkin et al., 2005). Sample 11-23 contains sulfide stringers with apparently hydrothermal albite, although no correlation is observed between Na_2O and Eu and there has been no apparent net addition of Na to the rock. This albite may be from a later event (Chapter 3). Sample 11-23 also contains minor amounts of barite, which may incorporate Eu^{2+} instead of Sr^{2+} during crystallization, incorporating Eu from the hydrothermal fluid (cf. Barrett et al., 1990). Sample 9-17 shows a strong positive Eu anomaly and a strong enrichment in LREE, also indicative of a hydrothermal fluid source (Barrett et al., 1990). Thus, positive Eu anomalies within tuffaceous and exhalative rocks are likely a positive indicator of hydrothermal fluid-seawater interaction and may help identify stratigraphic marker horizons for massive sulfide exploration. Similar ‘exhalite’ REE patterns are observed at the Windy Craggy deposit (Peter and Scott, 1999).

Trace Elements Vectors

Within massive barite ores, a near perfect correlation exists between Ba and Sr (Table 3.4) as Sr is substituted for Ba in barite. However, Ba-muscovites and Ba-feldspars do not incorporate significant Sr, and the correlation between Ba and Sr within altered rocks is poor, suggesting that most of the Ba in the altered rocks is present in the silicates. Ba values in altered samples, in general, increase towards ore horizons in both the footwall and hanging-wall. Sr values generally decrease with increasing alteration intensity as Sr^{2+} is mobilized from feldspars. The least-altered volcanic rocks have significantly more Sr than their altered equivalents (Tables 4.2 and 4.3). The ratio of Ba/Sr, therefore, provides a robust vector towards massive sulfide mineralization, reflecting Ba enrichment in muscovites and the removal of Sr from feldspars with increasing alteration intensity and removing the effect of barite within the altered samples. Ba/Sr ratios in least altered basalts are below 50 and typically less than 10 in fresh samples but approach >500 towards massive sulfide mineralization. Least altered rhyolites typically have ratios of less than 150.

Another useful ratio of gained/lost elements is $\text{Hg}/\text{Na}_2\text{O}$. Hg correlates very strongly with Zn (Table 4.4) and increases overall towards massive sulfide mineralization. Trace sphalerite occurs locally, throughout the footwall and creates localized Hg anomalies. $\text{Hg}/\text{Na}_2\text{O}$ values directly above and lateral to ore lenses are typically greater than 1000 (ppb/%) within volcanoclastic rocks. Within 25 m above and below ore lenses, $\text{Hg}/\text{Na}_2\text{O}$ ratios are typically above 100. Least-altered rocks have $\text{Hg}/\text{Na}_2\text{O} < 20$.

Other volatile elements, such as Sb and Tl are also anomalous within a 25-50 m

envelope around the ore lenses, similar to Australian deposits such as Roseberry, Hellyer and Thalanga (Large et al., 2001a). Sb and Tl concentrations greater than 2 ppm create an envelope at least 25 m above and at least 25 - 50 m below ore lenses. Least altered samples have concentrations below 1 ppm Sb and 2 ppm Tl. However, historic data have not provided accurate results for Ba, Hg, Tl or Sb. Tl correlates strongly with K and Ba, and likely resides within barian muscovites (Table 4.4). Sb correlates perfectly with Zn and As and is likely within sphalerite.

Alteration Indices

Two commonly used alteration indices for exploration in VMS environments are the Ishikawa alteration index (AI; Ishikawa et al., 1976) and the chlorite-carbonate-pyrite index (CCPI; Large et. al, 2001b):

$$AI = \frac{100 (K_2O + MgO)}{(K_2O + MgO + Na_2O + CaO)}$$

$$CCPI = \frac{100 (MgO + FeO)}{(MgO + FeO + Na_2O + K_2O)} .$$

The AI reflects the loss of Na from plagioclase and volcanic glass during the formation of metasomatic chlorite and sericite. Alone, however, Ishikawa's AI does not show the effects of hydrothermal carbonate alteration and does not distinguish between chlorite and sericite alteration (Large et al., 2001b). The CCPI, modified by Large et al. (2001) from Lentz (1999), overcomes these problems when plotted against the AI, although it does not distinguish Fe and Mg added as carbonate or Fe added as pyrite. The "alteration box plot" for the Glacier Creek massive sulfide lenses is shown in Figure 4.16. Samples from drill-

holes CMR08-11b, CMR08-13 and CMR07-09 (Figure 2.9), all of which intersect massive sulfide lenses along the barite-rich flanks, plot (left to right) from least altered to intensely muscovite-pyrite altered with proximity to ore. Very little change in the CCPI is seen for these samples, as chlorite is not a significant alteration mineral at the flanks of the lenses and most of the carbonate is calcite. Altered samples underlying the center of the lenses, from drillholes CMR08-14 and CMR08-17 (Figure 2.10) plot towards the top-right of the alteration box plot with increasing proximity to ore, reflecting increased pyrite content and minor chlorite addition.

Samples 17-03, 17-04 and 17-06 plot below the ‘least altered’ box on Figure 4.16 due to high Na₂O and K₂O concentrations, suppressing the CCPI, and high CaO concentrations (in 17-4 and 17-6) from local calcite veins and disseminations, suppressing the AI. Samples 17-10 and 17-9 would plot further to the right, closer to the ‘ore zone’, if not for the addition of Na from albite within late quartz-albite-chlorite-sulfide veinlets.

An extended alteration index specific to the Glacier Creek deposit area can be devised from elements gained over elements gained plus elements lost:

$$\text{Index} = \frac{[\text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{SiO}_2 + \text{S} + \text{Ba}] + \text{Hg} + \text{Sb} + \text{As} + \text{Zn} + \text{Cu}}{([\text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{SiO}_2 + \text{S} + \text{Ba}] + \text{Hg} + \text{Sb} + \text{As} + \text{Zn} + \text{Cu}) + 5*(\text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{Sr})}.$$

All values are calculated in wt.%, and oxides are normalized on a LOI-free basis. Elements lost have been weighted by n = 5 to create a wider spread within the calculated index values. Least altered samples have an index value of less than 0.60, with increasing values relative

to ore proximity. This index is plotted against distance from ore in Figure 4.17 to illustrate the increase in index value with proximity to ore. Samples NS13-17, NS13-18 and NS13-19 have very high Glacier Creek alteration index (GIC AI) values, but appear distal to ore, suggesting that they may be proximal to undiscovered ore. Samples from drillholes CMR08-11b and CMR08-13 are plotted downhole with SWIR data in Figure 4.20. In general, the downhole GIC AI pattern parallels the SWIR data (see below).

The Glacier Creek alteration index, along with the alteration box plot of Large et al. (2001), Ba/Sr values in altered rocks, and volatile element ratios that use Hg, Sb and Tl should provide exploration geologists with a useful toolset for vectoring towards massive sulfide lenses in the area of the Glacier Creek deposit.

4.3 Short Wave Infrared Spectroscopy

Short wavelength infrared (SWIR) spectroscopy has become increasingly prevalent and practical for mineral exploration over the last decade, since the introduction of portable field analyzers like the PIMA-II (Thompson et al., 1999). Portable SWIR spectroscopy has recently been applied to VMS deposits (Huston et al., 1999; Herrmann et al. 2001; Jones et al., 2005; Yang et al., 2004; Yang et al., 2011), with particular success identifying white-mica and chlorite compositional variations, as vectors to ore. The ASD Terraspec Pro used during this study differs from the PIMA-II analyzer in that it analyzes the full spectrum of light between 350-2500 nm, rather than 1300-2500 nm wavelength.

The absorption of light recorded by these instruments is caused by the stretching and

bending of the molecular bonds between cations such as Al, Mg, Na and Fe and molecules such as OH, H₂O, CO₃ and NH₄ (Hauff, 2005; Herrmann et al., 2001). Each cation has a unique radius and therefore a distinct molecular bond length which absorbs light at distinct wavelengths, allowing for identification of common molecules such as AlOH, FeOH and MgOH (Figure 4.18; Post and Noble, 1993). Minerals that contain these bonds, such as chlorite, muscovite, carbonate and epidote produce very characteristic reflectance patterns and can therefore typically be identified using SWIR spectroscopy (Figure 4.18).

This method is particularly sensitive to compositional variations in white mica (muscovite) and chlorite due to the strong absorption features created by AlOH, FeOH and MgOH bonds. White micas are characterized by AlOH bonds that cause a sharp, deep absorption feature between 2180 and 2228 nm (Herrmann et al., 2001). Variations in the proportions of octahedral versus tetrahedral AlOH in white mica, typically caused by elemental substitutions of Fe, Mg (Tschermak substitution) or Na, will cause shifts in the wavelength of the AlOH absorption feature (Herrmann et al., 2001). These variations are diagnostic of the composition of the white mica, in which higher proportions of Al^{VI} (sodic compositions) cause absorption at shorter wavelengths (2180-2195 nm), typical potassic muscovite absorbs at moderate wavelengths (2200-2208 nm), and white mica with lower proportions of Al^{VI} (phengitic compositions Fe-Mg) absorb at higher wavelengths (2216-2228 nm; Herrmann et al., 2001). Chlorite is also easily identified with SWIR spectroscopy, using diagnostic FeOH (2235-2255 nm) and MgOH (2320-2360 nm) absorption features, both of which increase with increased Fe-content of chlorite (Figure 4.18; Herrmann et al., 2001; Jones et al., 2005). Several SWIR studies on VMS deposits have shown a trend from more Fe-chlorite signatures

distal to ore, to more Mg-chlorite signatures proximal to ore (Herrmann et al., 2001; Jones et al., 2005). There is an overlap around 2340 nm of MgOH and a secondary AlOH feature. Therefore, in samples with mixed chlorite and white mica, the MgOH feature is unreliable, and the FeOH feature is used to determine the character of the chlorite. Many minerals containing OH and H₂O will also absorb light around 1400 nm and 1900-2000 nm (e.g., inter-layer H₂O in illite and chlorite).

Typically at least 5% of an infrared-active mineral is required in order to be detected within a sample. In samples with multiple active minerals, at least 10% is required and, in the case of less reflective minerals such as chlorite and carbonate, at least 20% is required (Thompson et al., 1999). At Glacier Creek, minor chlorite and carbonate exist within mineralization-proximal alteration assemblages, however, these minerals are typically in very low abundance (<5%) and are not observed within the SWIR spectral data. Least altered samples do contain abundant (>50%) chlorite, however, and the transition to muscovite-quartz-pyrite alteration can be observed in the spectral signature.

Several studies have also attempted to quantify the abundance of white mica and chlorite based on the intensity of AlOH and FeOH absorption features respectively, but generally the method is not able to quantify mineral abundance (Herrmann et al., 2001; Yang, 2011).

Glacier Creek SWIR

At Glacier Creek, as described above, there is a general transition from chlorite +

carbonate $\pm$ epidote $\pm$ quartz $\pm$ pyrite altered mafic volcanic rocks to strongly altered, pervasive muscovite + quartz + pyrite altered mafic volcanic and volcanoclastic rocks towards massive sulfide mineralization. The sharp increase in muscovite content can be seen in the SWIR spectral data (Figure 4.19). FeOH absorption features decrease slightly in wavelength from ~ 2257 to ~ 2250 nm and give way to increasingly prominent AlOH features. The decrease in FeOH wavelength indicates a shift from more Fe-chlorite to more Mg-chlorite in muscovite-dominated alteration facies. However, the dominant feature of the spectra is the AlOH absorption from 2201 to 2221 nm, suggesting a K-muscovite to phengitic composition for white micas. This variation does not appear to reflect the bulk compositions of the rocks but does appear to relate to proximity to ore. A general increase in the wavelength of the AlOH absorption feature occurs towards massive sulfide and feeder-zone (“quartz-pyrite” facies alteration) mineralization. Figure 4.20 shows AlOH wavelengths, plotted downhole in 6 drillholes, for samples of muscovite-altered rock showing good absorption features. The general trend is an increase in the wavelength of the AlOH absorption towards mineralization, both above and below the ore, with proximal samples typically having absorption features at wavelengths greater than 2209 nm. The effect occurs within approximately 30 m of mineralization, making it a useful vector within pervasively muscovite-altered zones.

However, the spectral response of muscovite altered rocks is different for different deposits. At Roseberry, Highway-Reward, Western Tharsis, and Myra Falls (Herrmann et al., 2001; Jones et al, 2005), the AlOH absorption features either relate to lithology (Roseberry) and not to alteration intensity and ore proximity, or show a decrease in wavelength, indicating more sodic muscovite towards mineralization. The Glacier Creek AlOH response

is similar to that of the Hellyer deposit in Tasmania (Herrmann et al., 2001), which shows longer AlOH absorption feature wavelengths and a more phengitic nature towards the center of the alteration pipe. Huston et al. (1999) used the ratio of the relative depth of FeOH and AlOH absorption features as a proxy for the chlorite/white mica ratio around the Panorama VMS district. However, at Glacier Creek, the chloritic alteration facies does not contain sufficient muscovite and the muscovite facies does not contain sufficient chlorite to make this comparison.

Comparison of Spectral Data to White Mica Chemistry

In general, with proximity to ore, the Na, K and Al contents of muscovite decrease as Fe+Mg and Ba increase. Overall, ore-related muscovites contain up to twice as much Ba as those found within the alteration zones (Tables 3.8 and 4.4). Figure 4.21 shows that samples that have AlOH absorption features with longer wavelengths have higher Fe+Mg (phengitic), lower Na/(Na+K) (paragonitic) and higher Ba. The scatter is likely due to the zonation seen within individual muscovites (Figure 4.3), and the fact that the probe data show composition from individual crystals whereas the SWIR data are an average for the sample.

Stanton and Roy (1961) predicted the possibility of correlating the Al in tetrahedral sites with the ratio of the Si-O band around 2114 nm to the band around 1869 nm, however, this feature is not observed in the Glacier Creek samples, and is rarely seen (Post and Noble, 1993). Otherwise, this would be a useful method of tracking Ba content within the micas assuming its substitution affects tetrahedral Al, as discussed in Chapter 3.

Summary

Four alteration facies are recognized at Glacier creek: a prevalent, semiconformable muscovite > pyrite + quartz facies (“muscovite”), local stratabound muscovite + quartz + pyrite > carbonate $\pm$ chlorite facies (“carbonate $\pm$ chlorite”), a quartz > pyrite/pyrrhotite + muscovite facies (“quartz-pyrite”) associated with cross-cutting veins and stringers, and a more distal epidote > muscovite > quartz + pyrite/pyrrhotite facies (“epidote”) that likely grades into the background greenschist metamorphic assemblage. The laterally extensive alteration zone is typical of VMS deposits with permeable volcanoclastic footwalls (Franklin et al., 2005; Large et al., 2001c). The quartz-pyrite facies resembles the ‘siliceous core’ to pipe-like footwall alteration at the Hellyer deposit, Tasmania (Gemmell and Large, 1992; Gemmell and Fulton, 2001). This more pipe-like facies grades into the pyrrhotite-chalcopyrite stringer mineralization facies below Zone I.

Mass gains and losses, trace element geochemistry and short-wave infrared spectroscopy on altered rocks provide useful vectors to ore at Glacier Creek. In particular, mass gains of S, Fe, Si and K with coincident loss of Ca, Na and Mg, along with trace element gains of Tl, Sb, Hg, Ba, Zn, Cu, As and loss of Sr correlate with proximity to ore. REE geochemistry also provides useful information about alteration intensity and proximity to mineralization. REE data, especially the presence of a positive Eu anomaly, identify tuffaceous and exhalative rocks that mark the ore horizon. White mica (muscovite) compositional variations within the alteration zones are qualitatively measurable using short wavelength infrared spectroscopy. In general, as Na, K and Al contents of muscovite decrease and Fe+Mg and Ba contents increase towards ore, the AlOH absorption feature wavelength increases.

This trend parallels the downhole variations in the Glacier Creek alteration index.

Table 4.1. Dominant Alteration Facies of the Glacier Creek VMS deposit

Alteration Facies	Mineral Assemblage	Description
“Quartz-Pyrite”	Quartz > Pyrite + Muscovite	Underlies massive sulfide and forms feeder zones
“Muscovite”	Muscovite > Quartz + Pyrite	Dominant, pervasive footwall alteration
“Carbonate-Chlorite”	Quartz + Muscovite + Pyrite > Carbonate ± Chlorite	Up to 10% carbonate ± chlorite. Stratabound footwall and ore horizon alteration.
“Epidote”	Epidote > Muscovite > Quartz + Pyrite/ Pyrrhotite	Distal alteration/metamorphism

Table 4.2. Median concentrations of elements in different alteration facies at the Glacier Creek deposit.

Element	Unit	'Quartz-Pyrite'	'Muscovite'	'Carbonate-Chlorite'	'Epidote' ¹	'Least-Altered' (B6) Basalt
	<i>n</i>	8	9	5	4	4
SiO ₂	wt.%	61.19	54.26	48.16	50.87	42.71
Al ₂ O ₃		10.51	14.73	15.45	11.30	16.83
Fe ₂ O ₃		13.54	14.04	11.76	> 14.30	15.19
MnO		0.01	0.01	0.05	0.12	0.21
MgO		0.47	0.72	1.52	6.44	5.43
CaO		0.29	0.40	1.19	0.97	0.90
Na ₂ O		0.24	0.45	0.71	2.32	3.26
K ₂ O		2.85	4.49	3.28	0.63	1.49
TiO ₂		0.62	0.89	1.47	0.44	0.81
P ₂ O ₅		0.07	0.09	0.09	0.27	0.15
LOI		8.19	8.16	7.07	9.52	9.13
Total		98.20	99.00	97.99	99.89	98.34
CO ₂		0.10	0.06	1.12	N/A	0.89
S		10.35	9.99	9.41	N/A	5.50
F		0.01	0.01	0.01	N/A	0.02
Ba	ppm	4487	4706	13070	N/A	702.50
Sr		35	47	77	44	105.50
Rb		43	71	46	11	31.00
Cs		1.1	1.6	1.1	N/A	0.75
V		239	307	325	257	271.50
Sc		27.05	40.15	39.80	N/A	42.70
Hf		0.9	1.1	2.8	N/A	1.25
Zr		38	47	120	114	44.00
Y		12	18	26	27	21.00
Cu		232	163	271	87	226.50
Pb		16	9	14	39	12.25
Zn		262	458	1050	226	284.00
Hg	ppb	128	39	151	N/A	2.50
Au	ppb	27	15	14	30	0.50
Ag	ppm	0.7	1.3	0.8	0.2	0.25
Cd		1.5	2.6	5.8	< 1	0.75
As		80	63	51	< 5	12.00
Sb		3.3	3.0	3.6	10	0.75
Sn		< 1	< 1	< 1	20	0.50
Co		32.1	41.9	37.1	63.5	57.05
Ni		33	52	32	57	61.00
Mo		9	5	3	13	1.00
Cr ²		129.0	139.0	74.5	121.0	206.50
Tl		2.26	4.63	1.93	N/A	1.31
Th		0.48	0.68	1.65	N/A	0.44
W		9.50	2.55	0.50	< 10	0.50
La		3.04	3.92	5.17	N/A	4.19
Ce		6.31	8.02	16.30	N/A	9.09
Pr		0.87	1.09	2.05	N/A	1.24
Nd		3.69	4.68	8.83	N/A	5.67
Sm		1.19	1.35	2.34	N/A	1.79
Eu		0.28	0.31	0.64	N/A	0.46
Gd		1.59	1.70	3.18	N/A	2.71
Tb		0.31	0.39	0.58	N/A	0.54
Dy		1.96	2.86	3.80	N/A	3.64
Ho		0.43	0.67	0.86	N/A	0.81
Er		1.31	2.08	2.70	N/A	2.49
Tm		0.21	0.32	0.43	N/A	0.37
Yb		1.38	2.12	3.03	N/A	2.45
Lu		0.22	0.34	0.50	N/A	0.39
ΣREE		23.79	28.67	51.99	N/A	36.50

Median values were chosen to remove the effect of outliers. *n*: number of samples analyzed.

For 'Chlorite' facies alteration geochemistry see semimassive and stringer ore types in Table 3.3.

¹'Epidote' facies geochemistry is from historic company assays. Analyses and methods differ from thesis samples.

²Cr-steel mill used in crushing and pulverizing of samples.

'Least-Altered' samples are of the feldspar-phyrlic (B6) basalt

Table 4.3. Calculated Mass Changes for Altered Rocks

Sample	Ba (ppm)	Sr (ppm)	Al ₂ O ₃	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	P ₂ O	SiO ₂	TiO ₂	S	NET	Facies
NS11-01	10.09	-195.71	0.31	-8.89	13.10	-0.44	1.70	-0.01	1.52	0.04	15.71	0.55	8.08	31.77	Least Altered
NS13-01	565.42	37.30	0.36	4.10	1.76	1.39	-0.75	0.13	-0.64	0.09	7.39	0.46	4.65	15.00	Least Altered
NS9-01	763.59	-295.81	-0.52	-10.32	20.10	1.18	3.62	0.26	-5.22	0.20	0.53	0.54	4.30	14.54	Least Altered
NS9-02	1813.59	-238.51	0.29	-10.29	5.28	3.98	-2.41	0.04	-2.81	0.05	-1.06	0.46	9.77	-2.03	Least Altered
NS9-03	812.40	-173.88	-0.15	-8.59	-2.58	0.86	-0.84	-0.07	-1.25	0.06	-12.10	0.30	14.05	-23.51	Least Altered
NS9-04	716.39	-178.57	0.15	-9.71	14.45	1.20	0.45	-0.03	-0.99	0.05	-5.88	0.36	12.39	11.01	Least Altered
NS13-02	-107.23	-177.83	-0.10	-9.00	5.65	-0.21	1.20	0.01	-0.57	0.01	-4.73	0.14	5.51	-3.04	Least Altered
NS11-27	923.77	-261.34	0.06	-9.38	30.56	-0.03	6.00	0.41	-4.74	0.01	-2.33	0.21	7.51	33.65	Carbonate ± Chlorite Facies
NS13-15	2599.08	-162.35	0.26	-7.18	2.61	2.22	-3.33	-0.06	-3.25	-0.13	-12.45	-0.28	25.96	-12.82	Carbonate ± Chlorite Facies
NS13-14	3809.78	-214.91	-0.04	-9.33	-5.09	3.85	-4.69	-0.16	-4.20	-0.01	-8.18	0.25	9.49	-24.38	Carbonate ± Chlorite Facies
NS11-23	14267.94	-24.29	0.40	-5.34	-9.15	2.95	-5.12	-0.12	-2.88	-0.26	-7.96	-0.37	12.66	-20.78	Carbonate ± Chlorite Facies
NS11-14	11796.73	-131.53	0.69	-5.63	-9.25	2.80	-4.26	-0.11	-3.17	-0.13	1.51	-0.67	0.50	-12.63	Carbonate ± Chlorite Facies
NS11-02	2999.64	-274.75	0.48	-10.65	-1.71	6.58	-5.78	-0.22	-4.72	-0.02	13.35	0.42	4.43	2.77	Muscovite Facies
NS11-15	9256.11	-164.67	0.13	-8.29	0.67	3.36	-5.61	-0.17	-3.12	-0.08	5.94	-0.12	13.75	3.53	Muscovite Facies
NS11-26	3625.91	-151.05	0.43	-7.08	-2.01	3.28	-4.99	-0.14	-3.26	-0.14	24.67	-0.79	17.22	19.96	Muscovite Facies
NS13-03	3124.89	-213.28	0.04	-9.66	11.48	5.07	-5.10	-0.18	-3.64	-0.11	15.56	0.40	21.77	28.04	Muscovite Facies
NS13-07	7720.69	-259.91	0.48	-10.26	24.65	6.26	-5.95	-0.22	-4.44	-0.08	6.28	0.43	11.72	39.81	Muscovite Facies
NS13-17	2503.34	-224.48	-0.20	-9.14	16.17	4.22	-5.84	-0.19	-4.25	-0.04	33.32	0.03	12.62	52.95	Muscovite Facies
NS9-05	1758.15	-249.79	-0.15	-9.03	0.29	4.83	-5.75	-0.20	-4.37	-0.01	21.72	0.22	2.73	15.34	Muscovite Facies
NS11-24	7034.00	-232.13	0.03	-9.61	0.07	4.44	-5.59	-0.19	-4.29	-0.03	57.93	0.33	8.40	51.40	Quartz-Pyrite Facies
NS11-25	5801.38	-236.98	-0.38	-9.64	27.45	4.76	-5.80	-0.19	-4.29	0.01	95.00	0.26	16.34	133.83	Quartz-Pyrite Facies
NS13-06	8384.32	-253.48	0.18	-10.26	16.71	6.17	-5.93	-0.21	-4.46	-0.07	71.36	0.46	18.49	92.12	Quartz-Pyrite Facies
NS13-12	9231.87	-177.32	-0.05	-9.64	8.17	4.33	-5.90	-0.20	-3.15	-0.02	28.99	0.28	39.16	35.57	Quartz-Pyrite Facies
NS13-13	5314.74	-251.00	0.03	-9.84	11.86	4.49	-3.47	-0.15	-4.45	0.01	64.58	0.34	12.37	76.67	Quartz-Pyrite Facies
NS13-16	5734.21	-218.55	-0.04	-9.17	12.62	4.03	-5.93	-0.18	-4.10	-0.02	47.25	0.19	3.99	61.67	Quartz-Pyrite Facies
NS13-18	10194.31	-195.47	-0.14	-8.81	46.43	3.77	-5.80	-0.19	-3.64	-0.02	69.78	0.19	4.14	141.87	Quartz-Pyrite Facies
NS13-19	1079.33	-155.67	0.46	-7.36	3.36	3.58	-5.28	-0.15	-3.35	-0.10	32.04	-0.51	0.64	35.28	Quartz-Pyrite Facies

Zr used as immobile element monitor for calculations. Multiple precursor method of Barrett and MacLean (1993) used for calculations.

Table 4.4. Pearson Correlation Matrix for Major, Minor and Trace elements in Altered Rocks

	CaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	Na ₂ O	SiO ₂	CO ₂	S	F	Ba	Sr	V	Zn	As	Sb	Hg	Tl
CaO	1.00																	
Fe ₂ O ₃	-0.22	1.00																
K ₂ O	-0.19	-0.43	1.00															
MgO	0.21	0.40	-0.63	1.00														
MnO	0.33	0.43	-0.55	0.92	1.00													
Na ₂ O	0.37	-0.03	-0.52	0.55	0.34	1.00												
SiO ₂	-0.27	-0.59	0.30	-0.82	-0.79	-0.46	1.00											
CO ₂	0.98	-0.19	-0.19	0.17	0.28	0.36	-0.25	1.00										
S	-0.42	0.62	0.09	-0.44	-0.40	-0.40	0.11	-0.35	1.00									
F	0.05	-0.42	0.17	0.24	0.09	0.29	-0.13	-0.02	-0.52	1.00								
Ba	-0.02	-0.36	0.37	-0.49	-0.42	-0.25	0.39	-0.05	0.12	0.12	1.00							
Sr	0.73	-0.30	-0.16	0.17	0.18	0.58	-0.22	0.69	-0.38	0.21	0.33	1.00						
V	-0.03	-0.39	0.31	0.06	-0.10	0.21	-0.10	-0.08	-0.37	0.40	0.16	0.22	1.00					
Zn	0.16	-0.22	0.21	-0.13	-0.09	-0.03	0.03	0.08	-0.01	0.39	0.66	0.48	0.21	1.00				
As	0.05	-0.21	0.23	-0.31	-0.25	-0.21	0.24	-0.02	0.14	0.26	0.64	0.31	0.03	0.92	1.00			
Sb	0.17	-0.22	0.21	-0.13	-0.08	-0.03	0.03	0.09	-0.02	0.39	0.64	0.47	0.20	0.99	0.93	1.00		
Hg	0.15	-0.18	0.19	-0.17	-0.12	-0.05	0.06	0.07	0.05	0.34	0.67	0.46	0.17	0.98	0.93	0.99	1.00	
Tl	-0.07	-0.36	0.55	-0.41	-0.37	-0.33	0.30	-0.10	0.05	0.48	0.55	0.03	0.06	0.57	0.63	0.56	0.56	1.00

Values ± 0.355 are significant at the 0.05 level (bold). Based on 29 observations.

Table 4.5. Average Electron Microprobe Analyses of Barian-Muscovites within Altered Rock

<i>sample</i>	11-14	17-07	17-06	11-13	11-16	14-15	11-24	14-14
<i>n</i>								
SiO ₂ wt. %	46.11	47.46	46.38	46.59	45.91	46.53	47.62	44.97
TiO ₂	0.33	0.44	0.33	0.42	0.64	0.33	0.30	0.61
Al ₂ O ₃	34.14	33.05	35.13	33.67	32.20	33.32	33.42	34.59
FeO	1.30	0.58	1.88	1.19	1.42	1.37	0.59	0.63
MnO	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00
MgO	1.44	1.95	0.73	1.46	1.85	1.44	1.66	1.47
CaO	0.01	0.03	0.03	0.01	0.01	0.00	0.01	0.03
Na ₂ O	0.61	0.47	0.76	0.41	0.53	0.53	0.55	0.58
K ₂ O	9.21	9.39	9.68	9.64	9.08	9.65	9.91	8.85
F	0.23	0.40	0.15	0.09	0.33	0.22	0.31	0.40
Cl	0.00	0.01	0.02	0.00	0.03	0.01	0.01	0.01
BaO	3.20	3.04	1.28	2.68	3.71	2.18	1.61	4.54
Rb ₂ O	-	-	-	-	-	-	-	-
V ₂ O ₃	0.16	0.08	0.08	0.17	0.26	0.12	0.15	0.11
<i>Total</i>	96.64	96.72	96.40	96.29	95.84	95.61	96.02	96.63
Number of cations, based on 12 (O,OH,F)								
Si	3.37	3.45	3.36	3.40	3.41	3.42	3.45	3.31
^{IV} Al	0.63	0.55	0.64	0.60	0.59	0.58	0.55	0.69
<i>T Site (4)</i>	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00
^{VI} Al	2.31	2.28	2.36	2.30	2.22	2.30	2.31	2.32
Ti	0.02	0.02	0.02	0.02	0.04	0.02	0.02	0.03
Fe	0.08	0.03	0.11	0.07	0.09	0.08	0.04	0.04
Mn	-	-	-	-	-	-	-	-
Mg	0.16	0.21	0.08	0.16	0.20	0.16	0.18	0.16
V	0.009	0.004	0.005	0.010	0.015	0.007	0.009	0.006
Rb	-	-	-	-	-	-	-	-
<i>M Site (2-4)</i>	2.57	2.55	2.58	2.56	2.57	2.57	2.55	2.56
K	0.86	0.87	0.90	0.90	0.86	0.90	0.92	0.83
Ba	0.09	0.09	0.04	0.08	0.11	0.06	0.05	0.13
Na	0.09	0.07	0.11	0.06	0.08	0.08	0.08	0.08
Ca	-	0.00	0.00	-	-	-	-	0.00
<i>I site (1)</i>	1.04	1.03	1.04	1.03	1.04	1.04	1.04	1.05
F	0.05	0.09	0.03	0.02	0.08	0.05	0.07	0.09
Cl	-	0.001	0.003	-	0.003	0.001	0.001	0.001
<i>Total cations</i>	7.61	7.58	7.62	7.60	7.61	7.61	7.59	7.60

Dash indicates below detection limit of electron microprobe. Based on 51 analyses. *n* is number of analyses.

^{VI}Al calculated by subtracting from total Al, assuming Si + ^{IV}Al fills *T* site with 4 cations. Excess of ^{VI}Al caused by excess of Si reported (should be only 2 cations in *M* site).

Sites based on mica chemical formula $I_1M_{2-4}T_4O_{10}(OH,F,Cl)_2$, where *T* is tetrahedral site, *M* is octohedral site and *I* is the interlayer cation site.

Table 4.6. Pearson Correlation Matrix for Cations in Ba-muscovites from Altered Rocks

	Si	Ti	Al	Fe	Mn	Mg	Ca	Na	K	F	Cl	Ba	V	Total
Si	1													
Ti	-0.36	1												
Al	-0.89	-0.01	1											
Fe	-0.16	-0.19	0.19	1										
Mn	-0.01	-0.15	0.08	0.15	1									
Mg	0.44	0.33	-0.71	-0.64	-0.15	1								
Ca	0.01	0.23	0.00	-0.23	0.27	0.09	1							
Na	-0.41	-0.22	0.58	0.49	0.09	-0.74	-0.05	1						
K	0.63	-0.71	-0.33	0.25	0.05	-0.23	-0.21	-0.02	1					
F	-0.01	0.45	-0.17	-0.56	-0.14	0.54	0.47	-0.18	-0.45	1				
Cl	-0.21	0.22	0.13	0.19	0.24	-0.08	0.41	0.24	-0.10	0.20	1			
Ba	-0.52	0.72	0.15	-0.36	-0.19	0.45	0.01	-0.27	-0.89	0.42	-0.03	1		
V	0.15	0.29	-0.40	0.20	0.04	0.33	-0.12	-0.25	-0.01	0.02	0.16	0.14	1	
Total	-0.34	0.40	0.14	-0.23	-0.13	0.26	0.32	0.13	-0.46	0.86	0.41	0.43	0.07	1

Values ± 0.316 are significant at the 0.05 level (bold). Based on 37 observations.

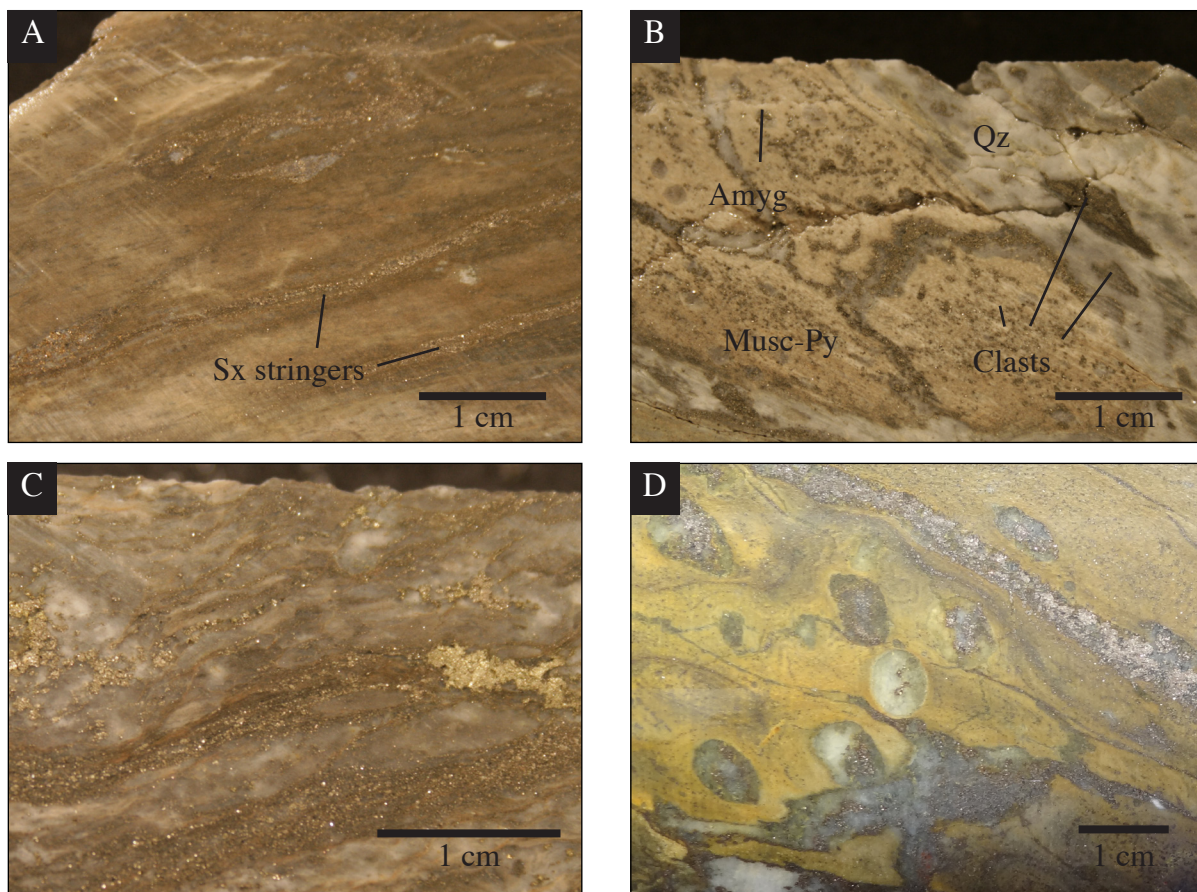


Figure 4.1. Drill core photographs of common alteration textures and facies. All samples have basaltic composition (see Figure 4.7). A) Pervasive muscovite (70%) and quartz alteration. Trace carbonate is present within thin sulfide stringers. Primary textures have been destroyed, although the rock appears fragmental (NS13-14). B) Selective alteration by quartz flooding of the matrix to fragmental basalt. Muscovite and pyrite replace clasts which may have had curvilinear margins. Quartz-amygdules can be seen in large clasts (NS11-26). C) Quartz-dominated (>60%) alteration abundant sulfide from a feeder-zone. The muscovite-sulfide network cuts pervasive quartz alteration (NS13-16). D) Pervasive to patchy epidote-muscovite-quartz dominated alteration cut by pyrrhotite stringer. Sample from approximately 85 m below Zone II (NS19-14).

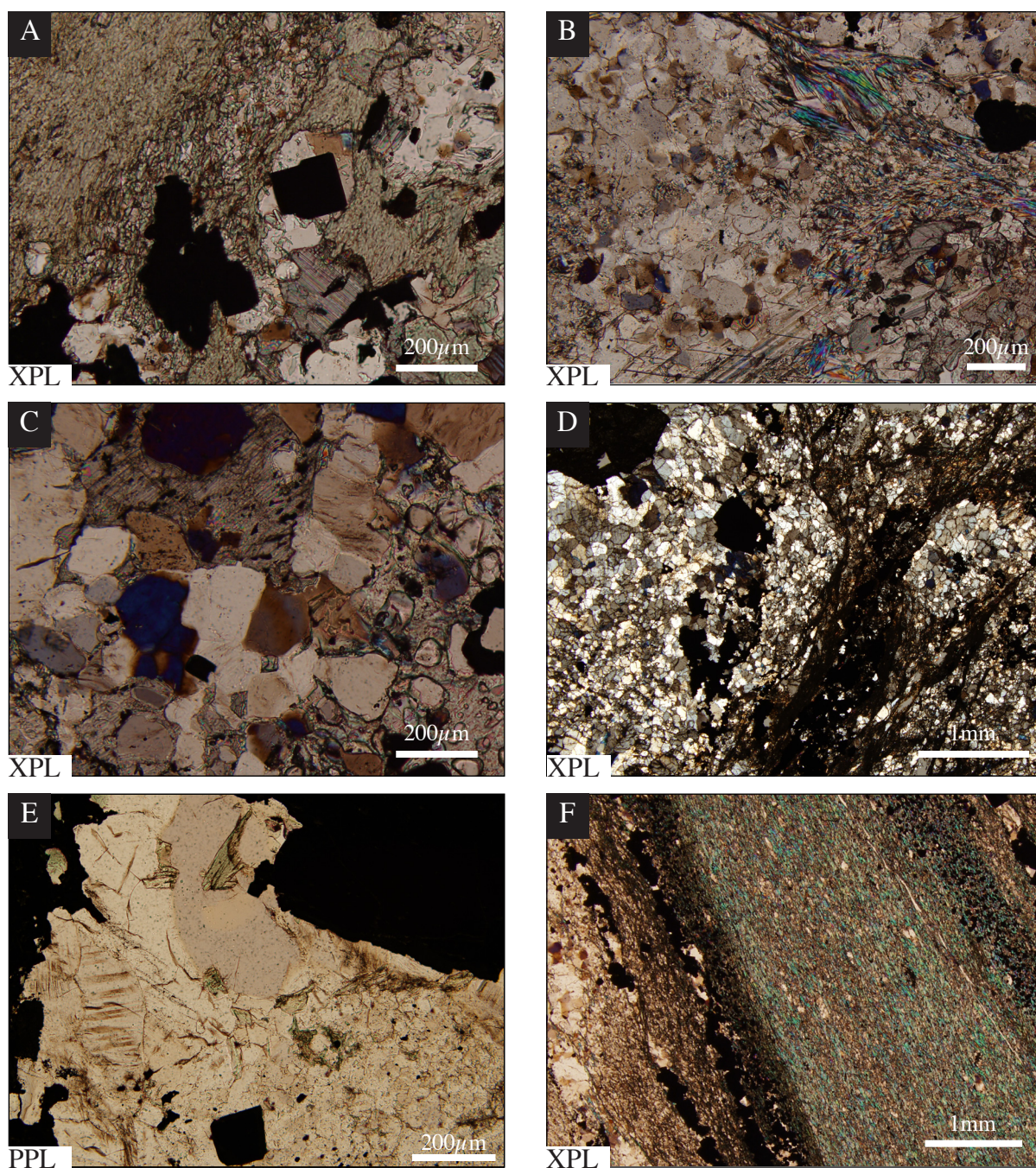


Figure 4.2. Photomicrographs of select alteration styles and minerals. A) Chlorite-carbonate alteration in tuffaceous rock stratigraphically overlying Zone I (NS14-17). B) Quartz-muscovite-carbonate alteration stratigraphically overlying Zone II and underlying Zone III (NS11-23). C) Quartz-carbonate texture from stratigraphically below Zone II (NS11-16). D) Quartz dominated alteration, with sericite-sulfide stringers (NS17-09). E) Quartz-muscovite-chlorite alteration in stringer zone stratigraphically underlying Zone I (NS17-11). F) Pervasive muscovite with selective quartz alteration (NS13-19).

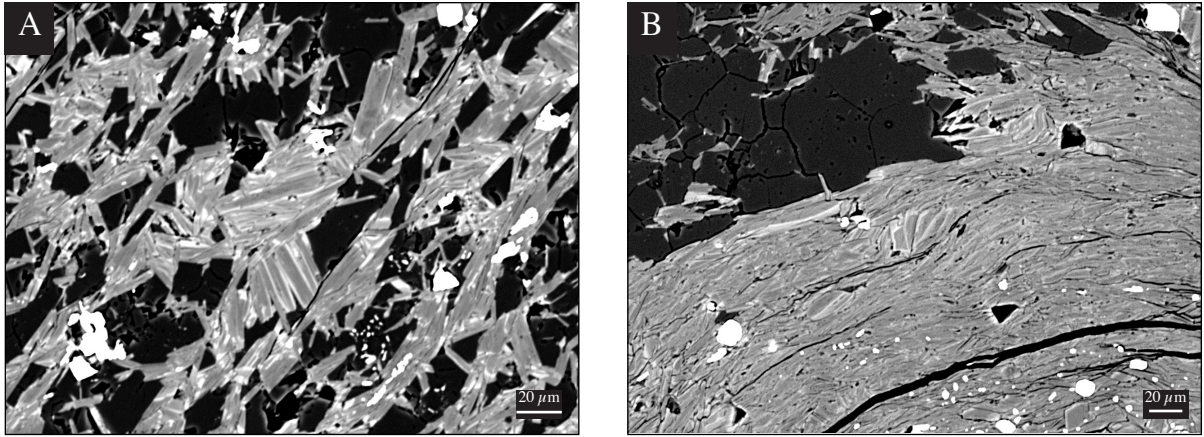


Figure 4.3. Backscattered electron images of barian-muscovite from alteration zone between Zones I and II.

Muscovites show compositional zonation, commonly with Ba-rich rims. A) Sample NS11-14. B) Sample NS13-19.

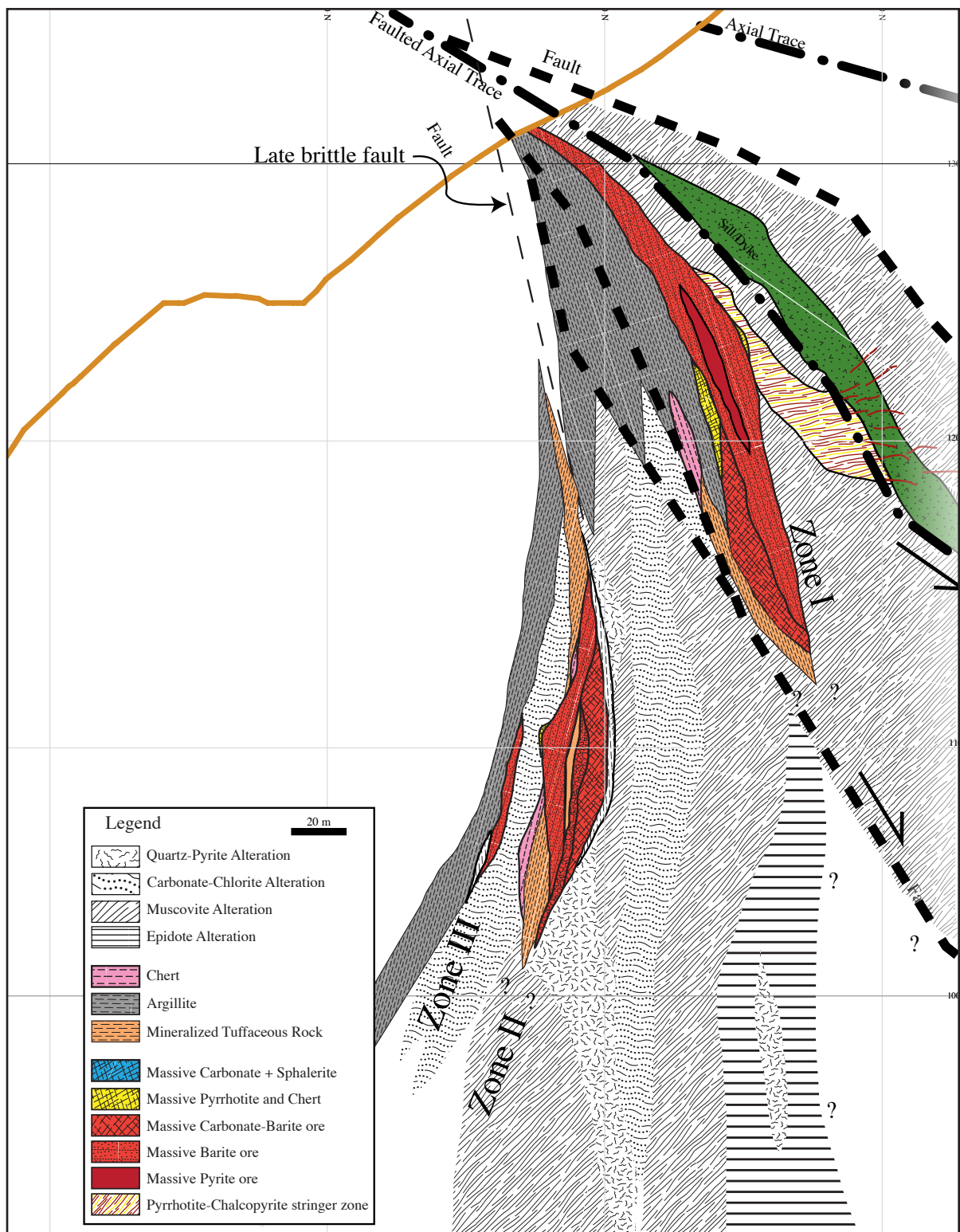


Figure 4.4. Cross-section through the southwall at 421200E, showing dominant alteration facies (cf. Figure 2.9).

Quartz-Pyrite: quartz + pyrite > muscovite; Carbonate-Chlorite: quartz + muscovite + pyrite > carbonate ± chlorite; Muscovite: muscovite > quartz + pyrite; Epidote: epidote > muscovite > quartz + pyrite/pyrrhotite.

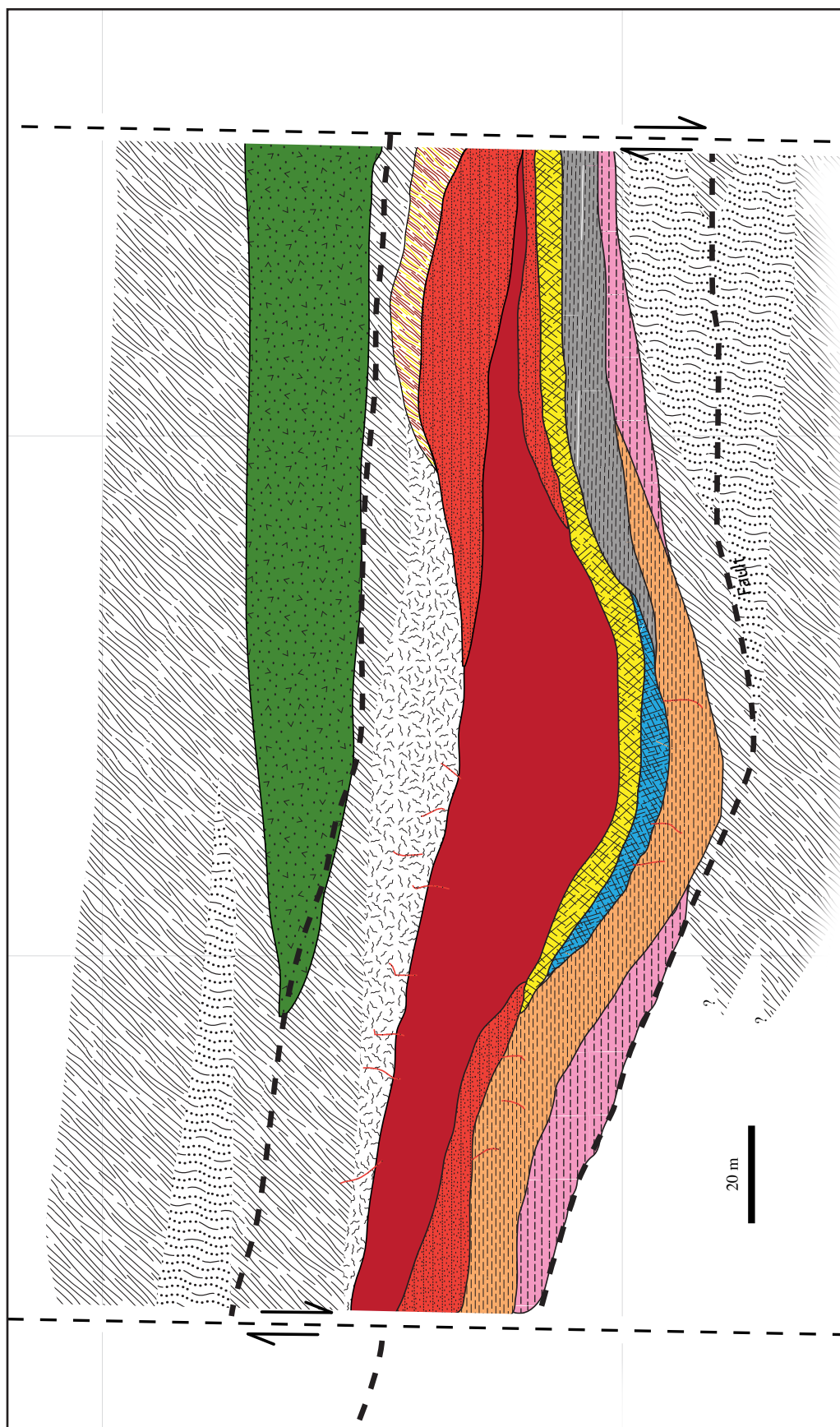


Figure 4.5 Long-section through Zone I showing dominant alteration facies (c.f. Figure 2.10). See Figure 4.4 for legend and details.

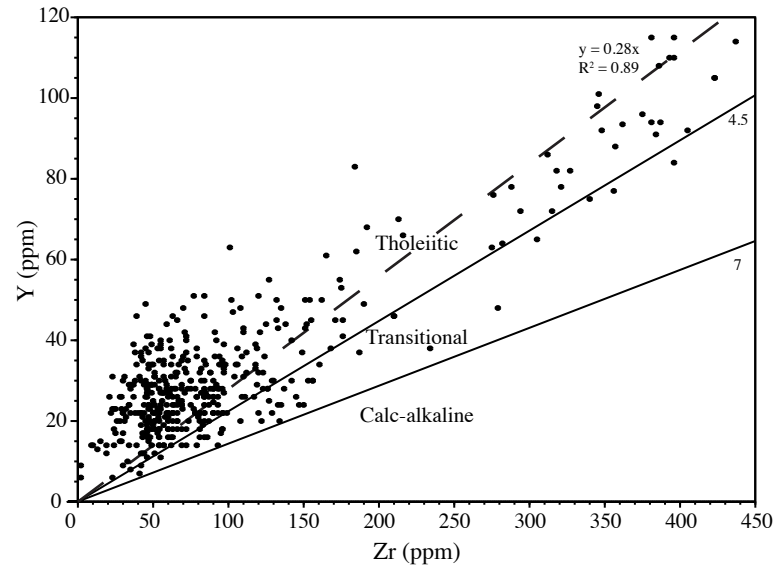


Figure 4.6. Zr/Y ratios of altered and least-altered volcanic host rocks from the Glacier Creek area. Zr/Y ratios average 3.57, with most samples plotting in the tholeiite field. Data are from this study and 438 whole-rock analyses from the historic database. After Barrett and MacLean (1994).

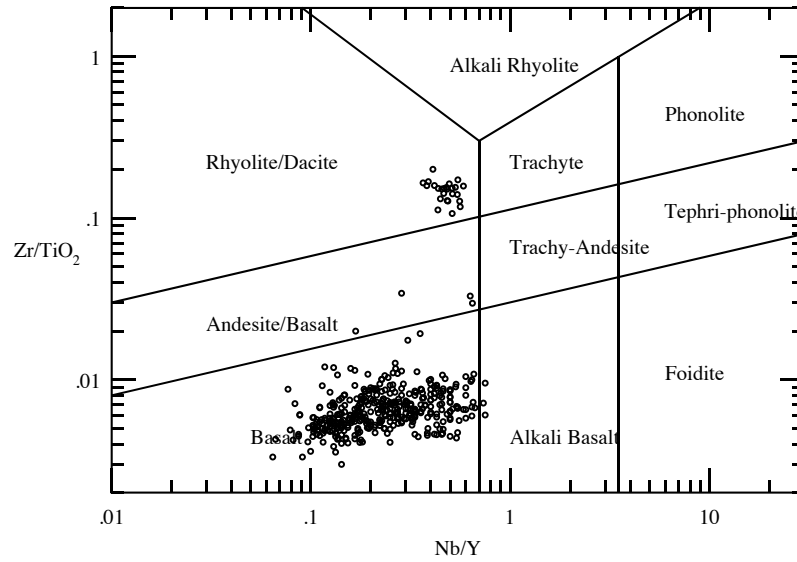


Figure 4.7. Zr/TiO_2 versus Nb/Y plot of Winchester and Floyd (1977) updated by Pearce (1996). Samples plot either within the sub-alkaline basalt field or the rhyolite field. A few outliers may be clastic. Data are from this study and 438 whole rock analyses from historic database

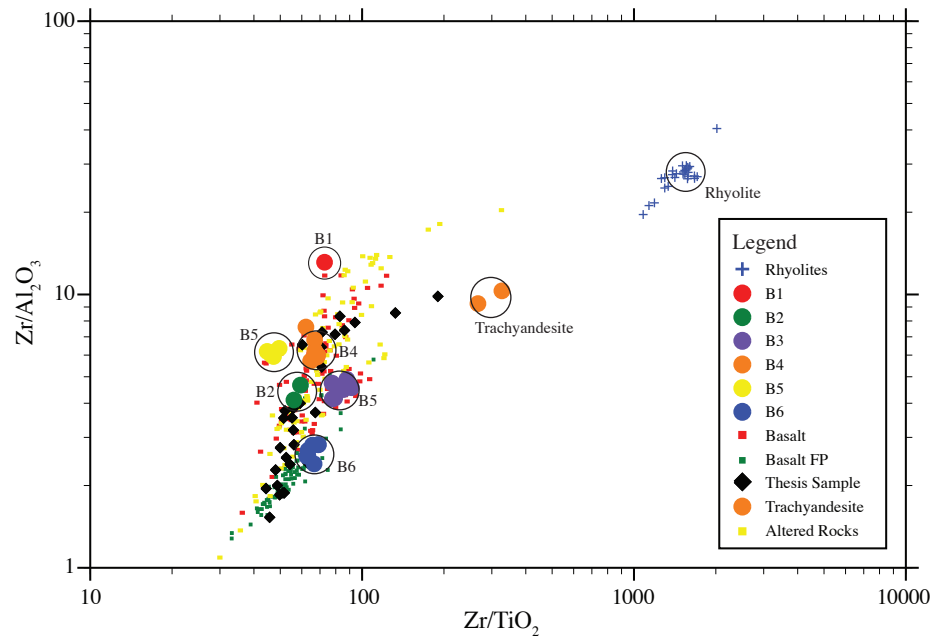


Figure 4.8. Geochemical classification plot of volcanic rocks at Glacier Creek, modified from Green (2001).

Least-altered volcanic rock samples were initially divided by Green (2001) based on field observations and are distinctly grouped on this plot. Altered samples and undifferentiated basalt from historic database and thesis samples, however, cannot be easily divided. See text for discussion. Data plotted on a LOI-free basis.

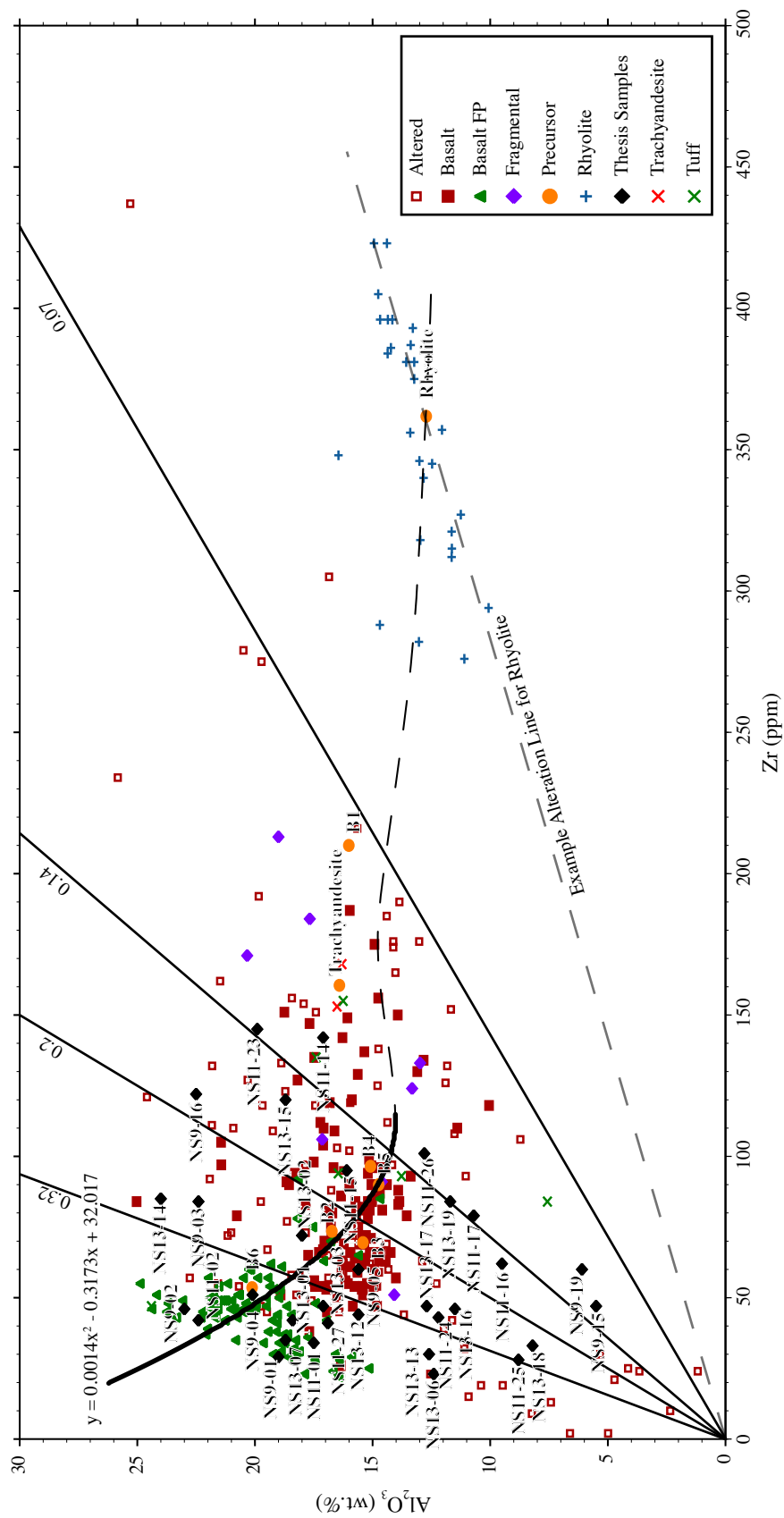




Figure 4.9. Plot of Glacier Creek volcanic rock compositions in terms of Zr (immobile/incompatible) versus Al_2O_3 (immobile/compatible) modified from Green (2001), historic database and this study. Solid lines through the origin separate data based on population densities that group around known precursor values. Feldspar-phyric basalts typically plot above a $\text{Al}_2\text{O}_3/\text{Zr}$ ratio of 0.32. Basalts similar in composition to B2/B3 basalts identified by Green (2001) plot between 0.2 and 0.32, B4/B5 plot between 0.14 and 0.2, trachyandesites and many tuffs plot between 0.07 and 0.14, and rhyolites all plot below a 0.07 slope. The fractionation trend for precursor ratios is shown. The solid segment of the fractionation trend passes through the bulk of mafic volcanic samples found at Glacier Creek ($\text{Al}_2\text{O}_3/\text{Zr}$ ratios >0.14) and can be expressed as the quadratic equation: $y = 0.0014x^2 - 0.3173x + 32.017$. The dashed line is an approximation of the fractionation trend. Samples that plot above or below the fractionation trend, along a path emanating from the origin, have been altered and their distance from the curve represents loss or gain of mass relative to their precursor (e.g., alteration line). Rock types are as logged in database. Precursor data are averaged from Green (2001). Data presented on a LOI-free basis.

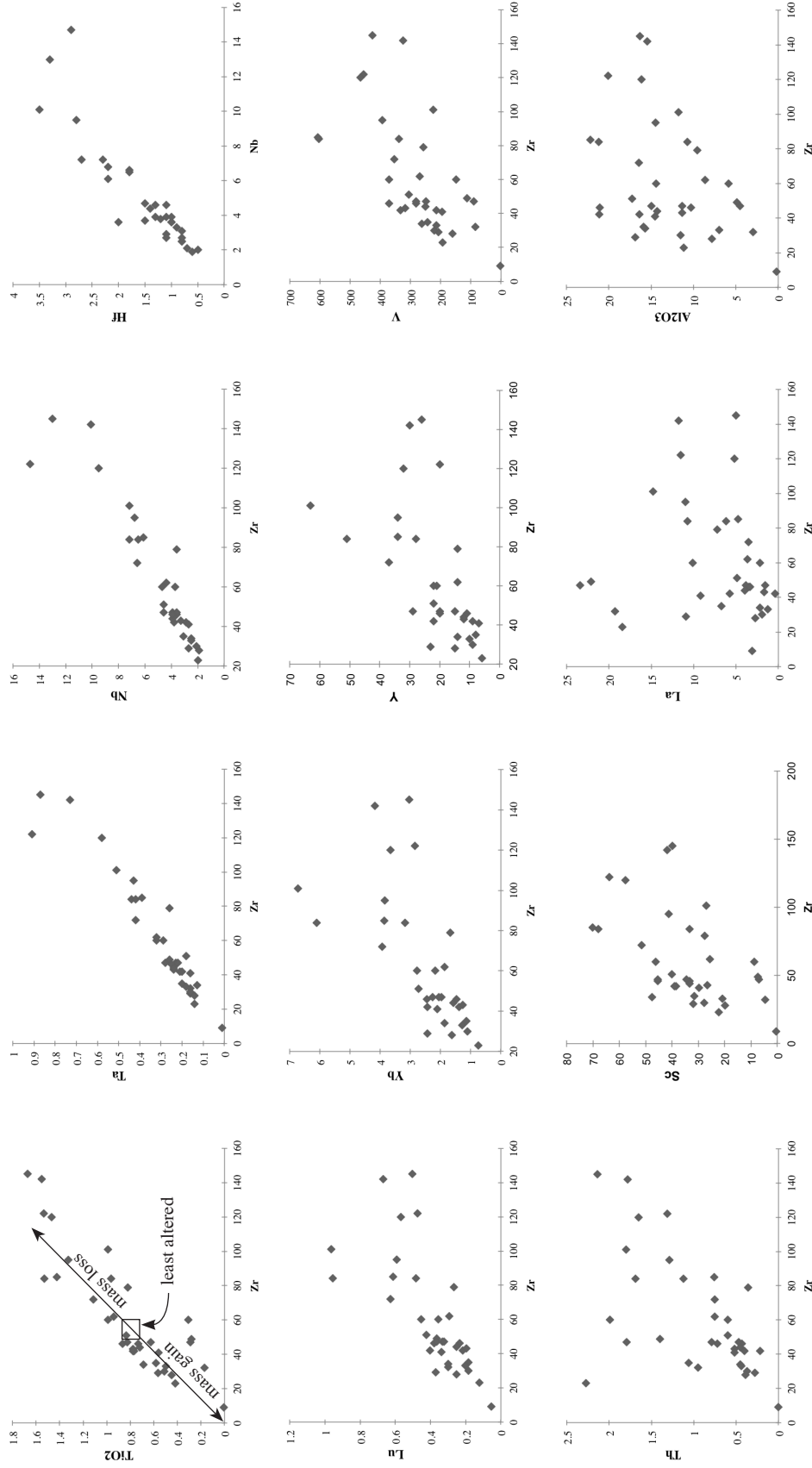


Figure 4.10. Immobility element plots for altered rocks from this study. TiO₂, HREE (Lu, Yb), Ta, Nb and Hf are immobile within the Glacier Creek alteration zone. Hf and Zr have a high affinity for one another and appear to be immobile whereas Sc, V, Th, and LREEs are mobile. Y and Yb are slightly mobile. Al₂O₃ is immobile but compatible and shows a spread due to fractionation, whereas TiO₂ is incompatible within tholeiitic basalts. Data from samples analyzed during this study only. Least altered range for Zr versus TiO₂ is from Green (2001).

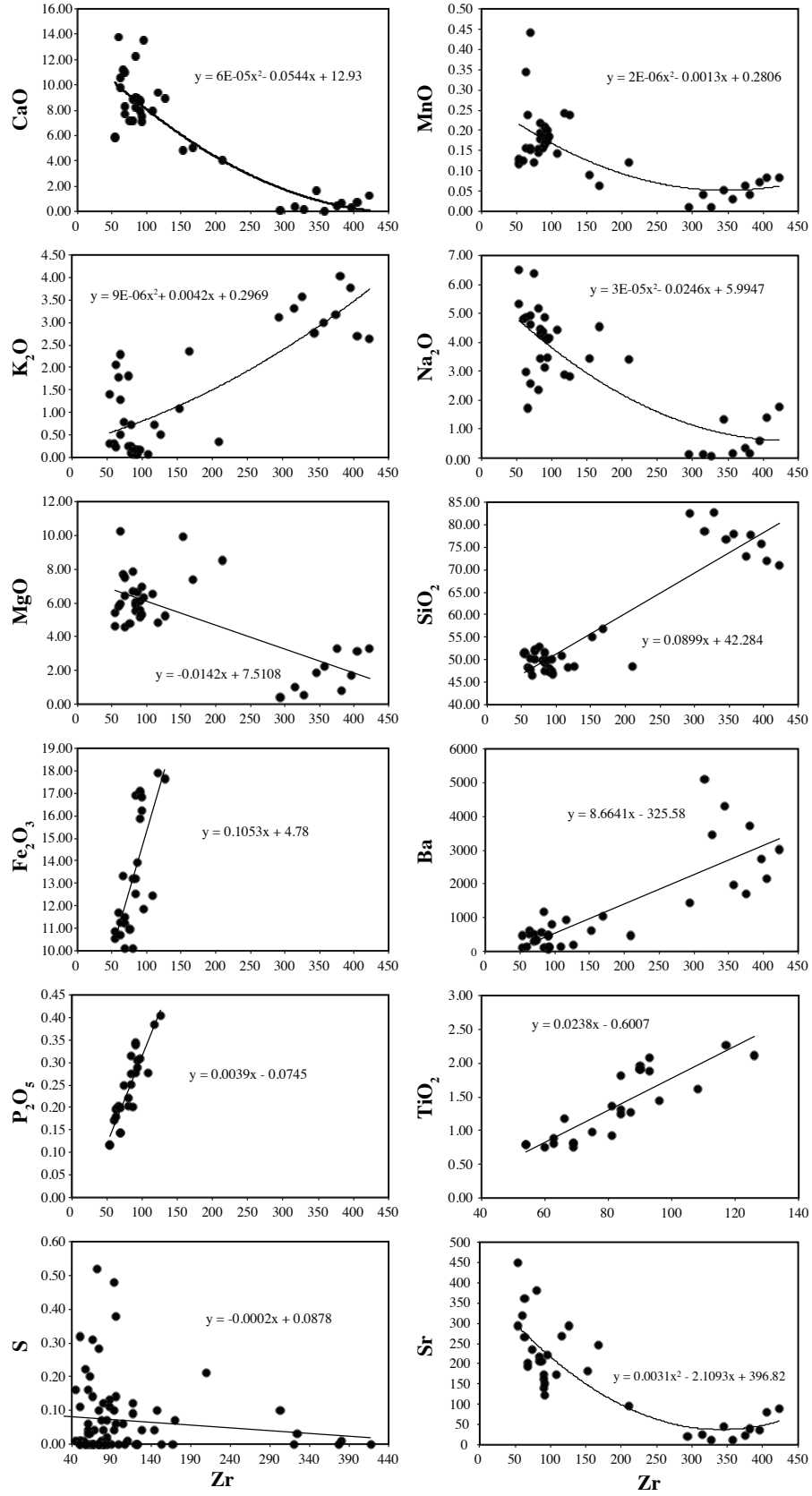




Figure 4.11. Mobile elements plotted against Zr for mass transfer calculations. Trendlines are interpreted to represent fractionation trends, and reflect multiple precursor oxide values for different rock types. Polynomial equations for each trend were used to calculate precursor values for each rock type, regardless of degree of alteration. Typically mobile elements should show a concave-up curve with a negative slope as these elements decrease with increased Zr. P_2O_5 , TiO_2 and Fe_2O_3 increase with Zr within the basalt to basaltic andesite range; only this range is shown for these elements. SiO_2 , K_2O , Ba and S also increase with Zr, however, this also reflects alteration. Data presented on a LOI-free basis.

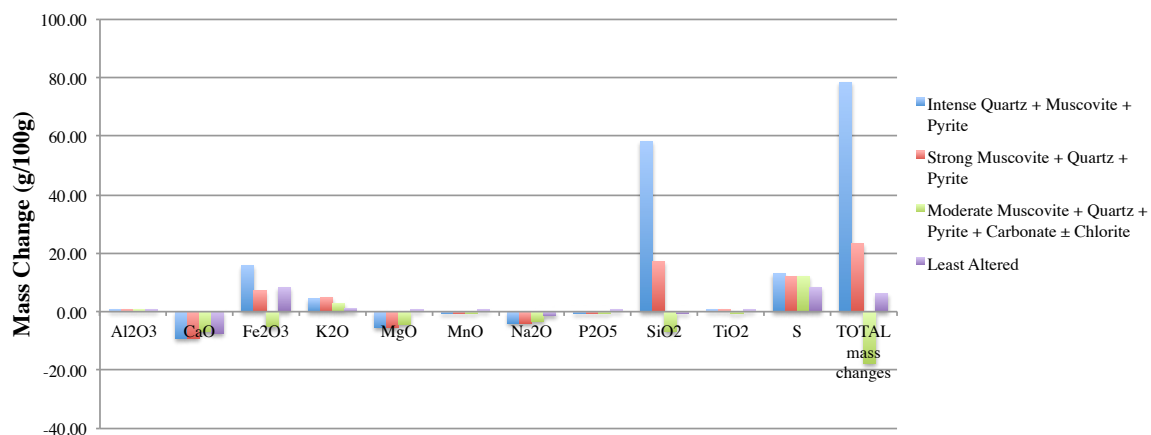


Figure 4.12. Average mass changes of major elements for representative alteration facies based on results from 30 altered samples and using Zr as immobile monitor. Intense Quartz + Muscovite + Pyrite alteration outlines principal hydrothermal fluid conduits beneath ore zones (Figures 2.9 and 2.10). Al, Mn, P and Ti are relatively immobile. There is a general loss of Ca, Mg and Na within all altered rocks, and a general gain in K, SiO₂ and Fe₂O₃. Carbonate ± chlorite altered rocks show a loss of Fe and Si. Least altered samples show a minor gain in Fe and K from muscovite and pyrite.

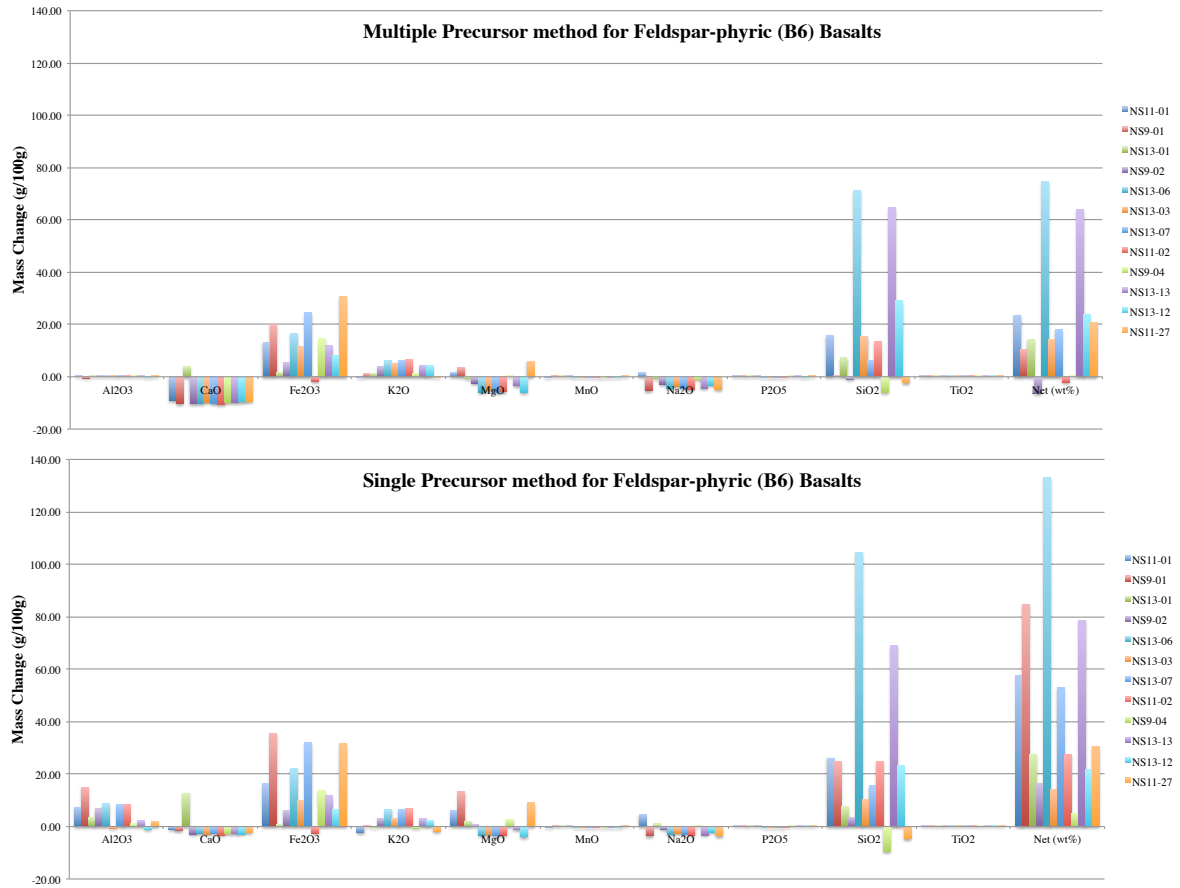


Figure 4.13. Comparison between single and multiple precursor mass balance calculations for the feldspar-phyric basalts. Total mass change values do not match, but general trends are identical. Precursor values used for the single precursor method are from the average composition of B6 basalt reported by Green (2001).

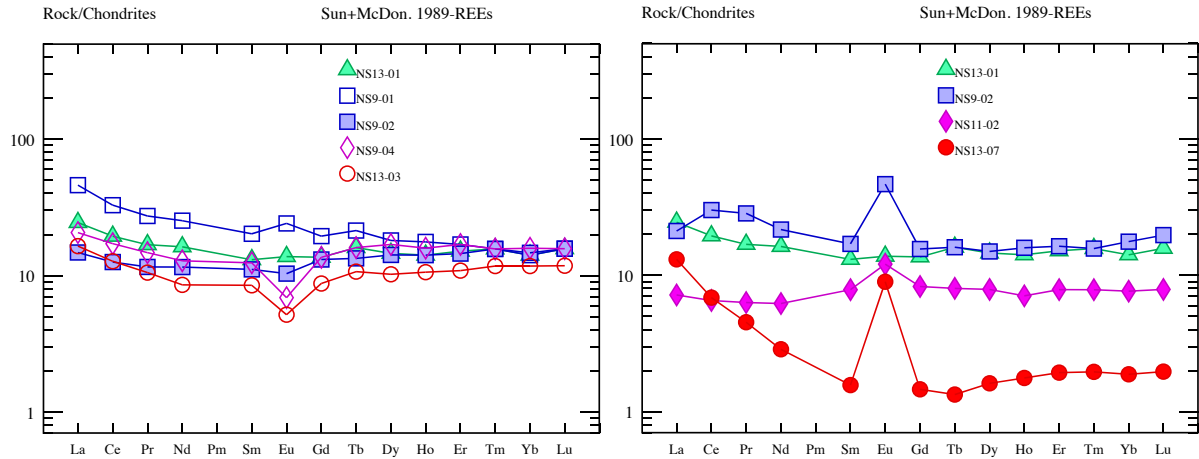


Figure 4.14. A) REE spider diagram of weakly to moderately altered feldspar-phyrlic (B6) basalts in the footwall to Zone I. Plot shows the effect of hydrothermal alteration of feldspars, creating a negative Eu anomaly with increasing alteration (9-01->13-01->9-02->9-04) as well as the effects of mass gain in sample 13-03. LREE are mobile, as shown in Figure 4.13, and create a 'fan' shape with increased alteration due to loss of LREE. B) Samples showing positive Eu anomalies. Sample 13-01 is least altered sample for comparison. Sample 9-17 is a hydrothermal sediment overlying the flank of Zone II. 11-23 and 11-24 are fragmental, tuffaceous, and mineralized rocks directly overlying Zone II. Normalized to chondrite values from Sun and McDonough (1989)

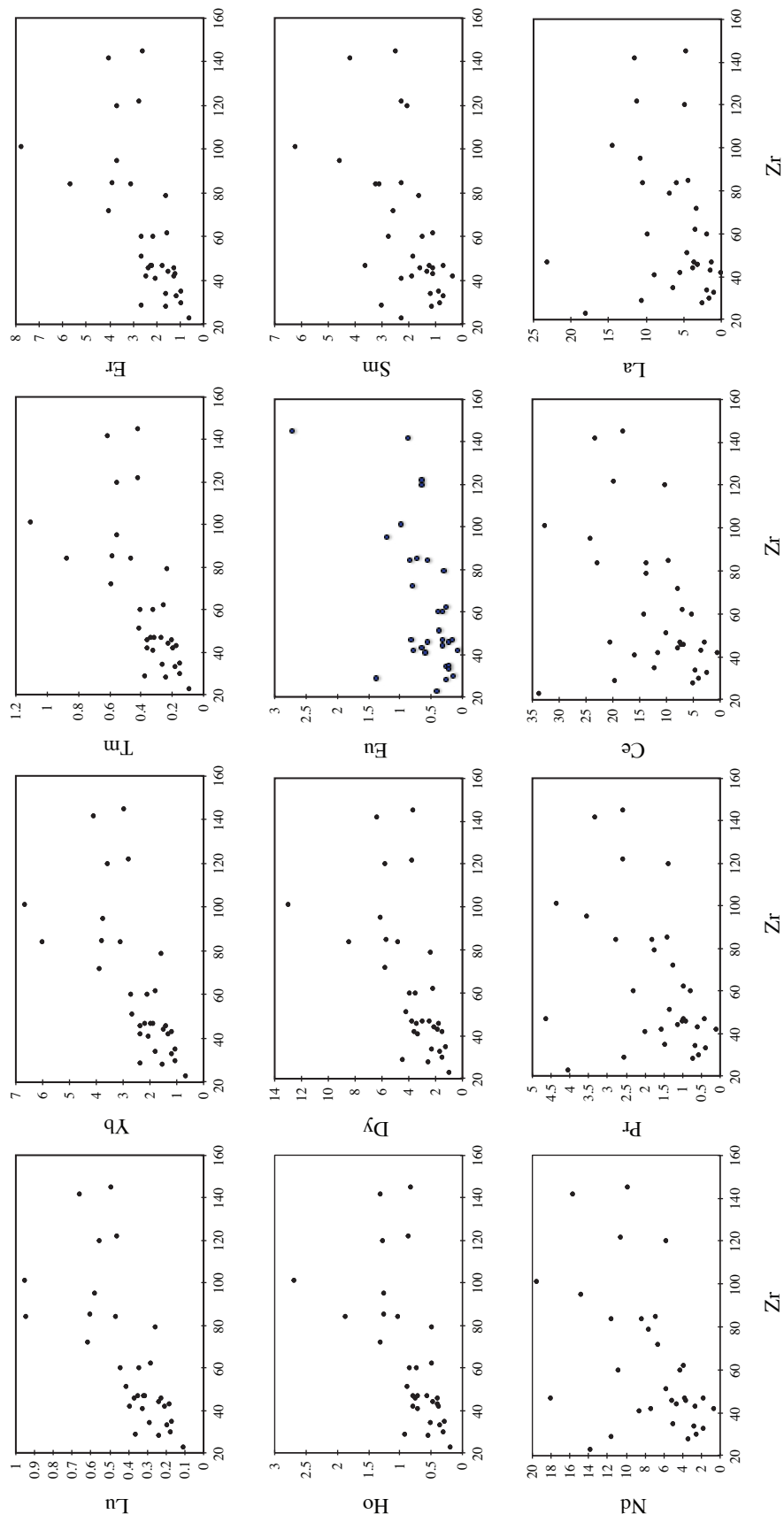


Figure 4.15. Plots of REE versus immobile Zr showing increasing scatter from heavy REE (Lu/Yb) to light REE (Ce/La), confirming increased mobility of the light REE.

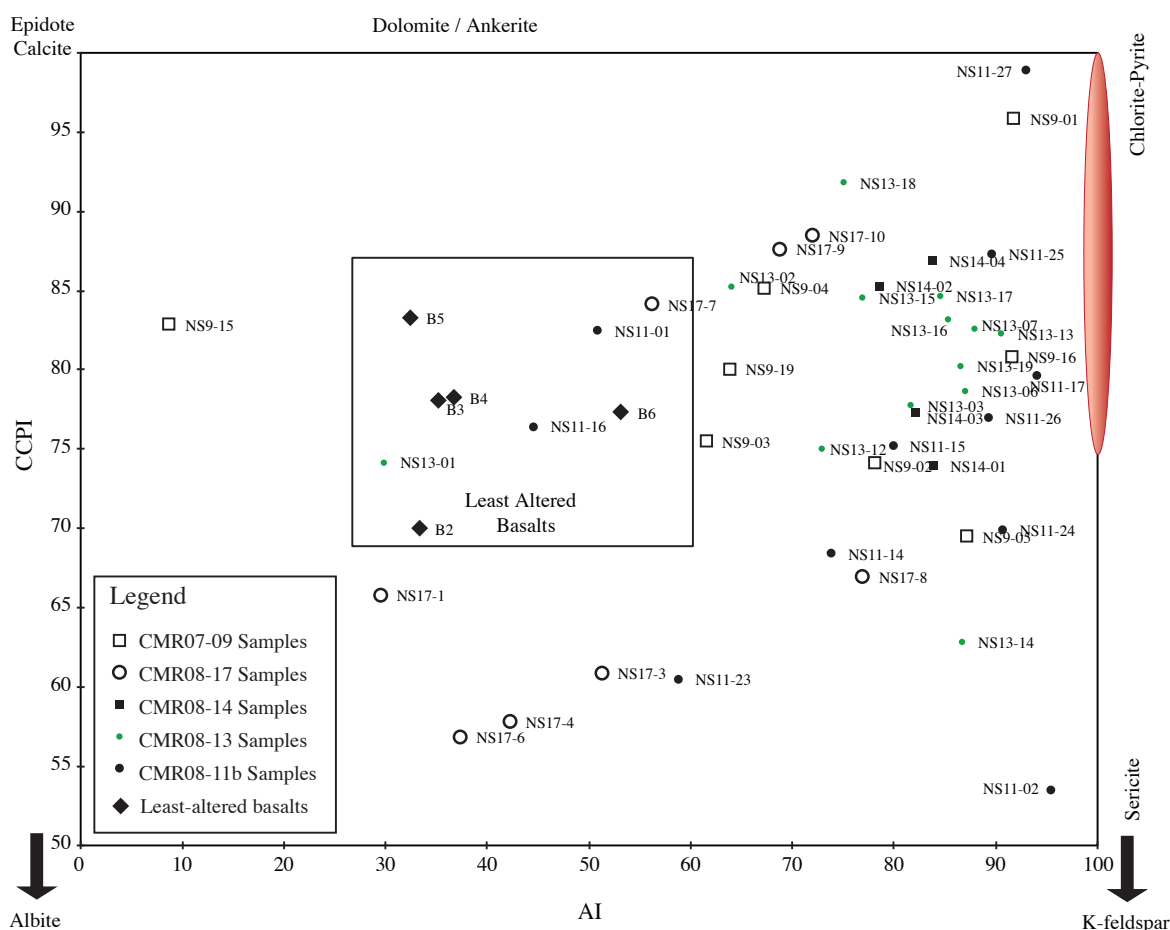


Figure 4.16. Alteration boxplot of Large et. al. (2001b) showing least altered basalts and altered rock samples.

Samples show progression from least altered to intensely sericite- and pyrite-altered in proximity to ore.

Samples that underlie the center of the ore lens, contain more chlorite and plot towards the upper right corner with increasing proximity to ore (e.g. NS17-09, NS17-10, NS14-04).

$$AI = \frac{100 (K_2O + MgO)}{(MgO + FeO + Na_2O + K_2O)} \quad CCPI = \frac{100 (MgO + FeO)}{(K_2O + MgO + Na_2O + CaO)}$$

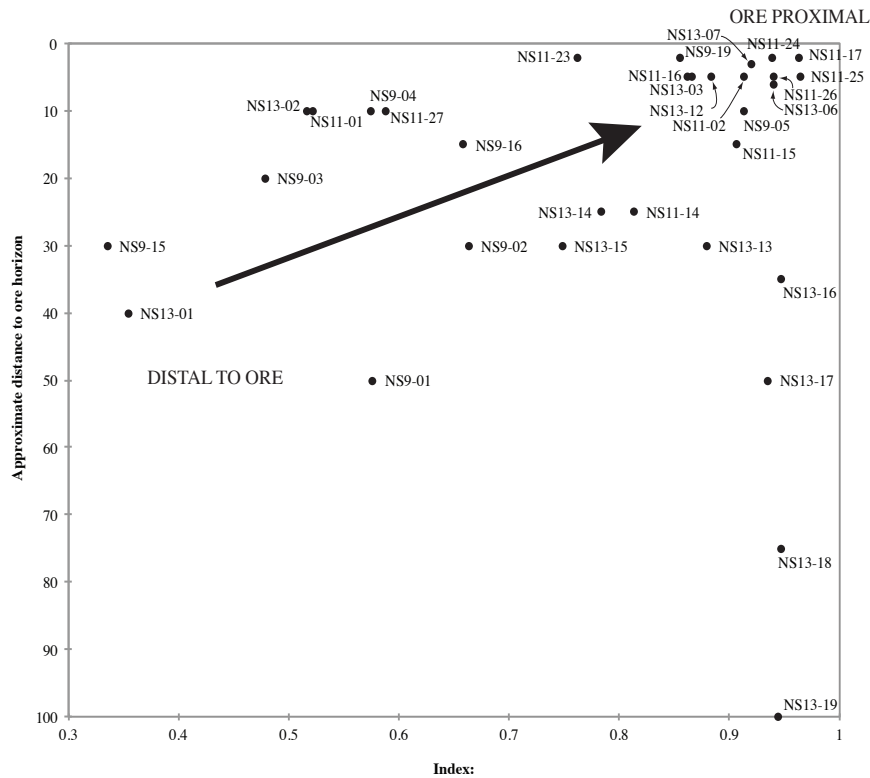


Figure 4.17. Empirical Glacier Creek Alteration Index (GIC AI) = Elements gained / [Elements gained + lost].

Samples with greater proximity to ore, and greater alteration intensity have higher index values. Distance from ore approximated from cross-section (Figure 2.9). Samples ideally plot from bottom left to top right with proximity to ore. Samples NS13-17, -18 and -19 have very high GIC AI values, but appear distal to ore, suggesting that they may be proximal to undiscovered ore. Compare with SWIR data in Figure 4.20.

GIC AI:

$$\text{GIC AI} = \frac{[\text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{SiO}_2 + \text{S} + \text{Ba}] + \text{Hg} + \text{Sb} + \text{As} + \text{Zn} + \text{Cu}}{([\text{Fe}_2\text{O}_3 + \text{K}_2\text{O} + \text{SiO}_2 + \text{S} + \text{Ba}] + \text{Hg} + \text{Sb} + \text{As} + \text{Zn} + \text{Cu}) + 5 * (\text{CaO} + \text{MgO} + \text{Na}_2\text{O} + \text{Sr})}$$

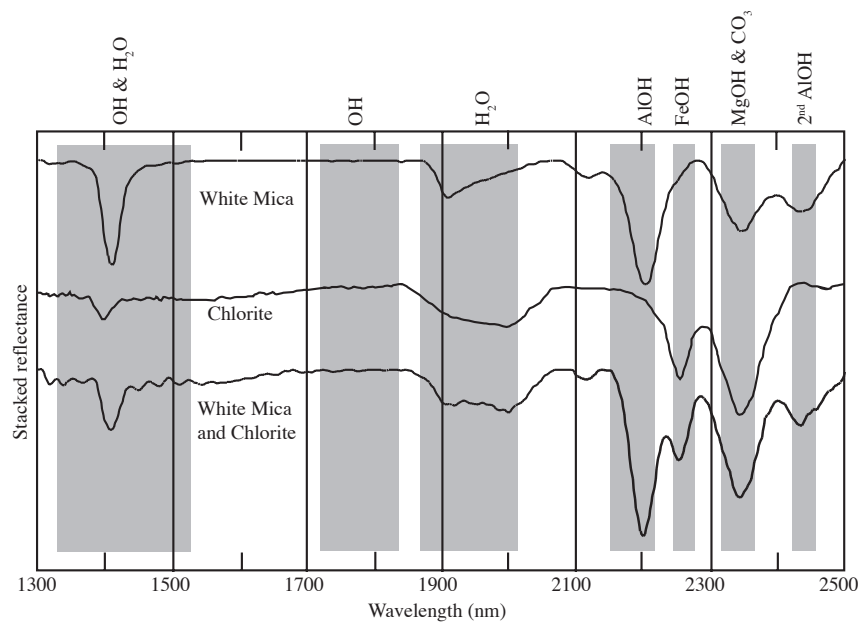


Figure 4.18. Idealized muscovite, chlorite and mixed SWIR spectra, with an applied Hull quotient correction to level out the curve. From Jones et al. (2005).

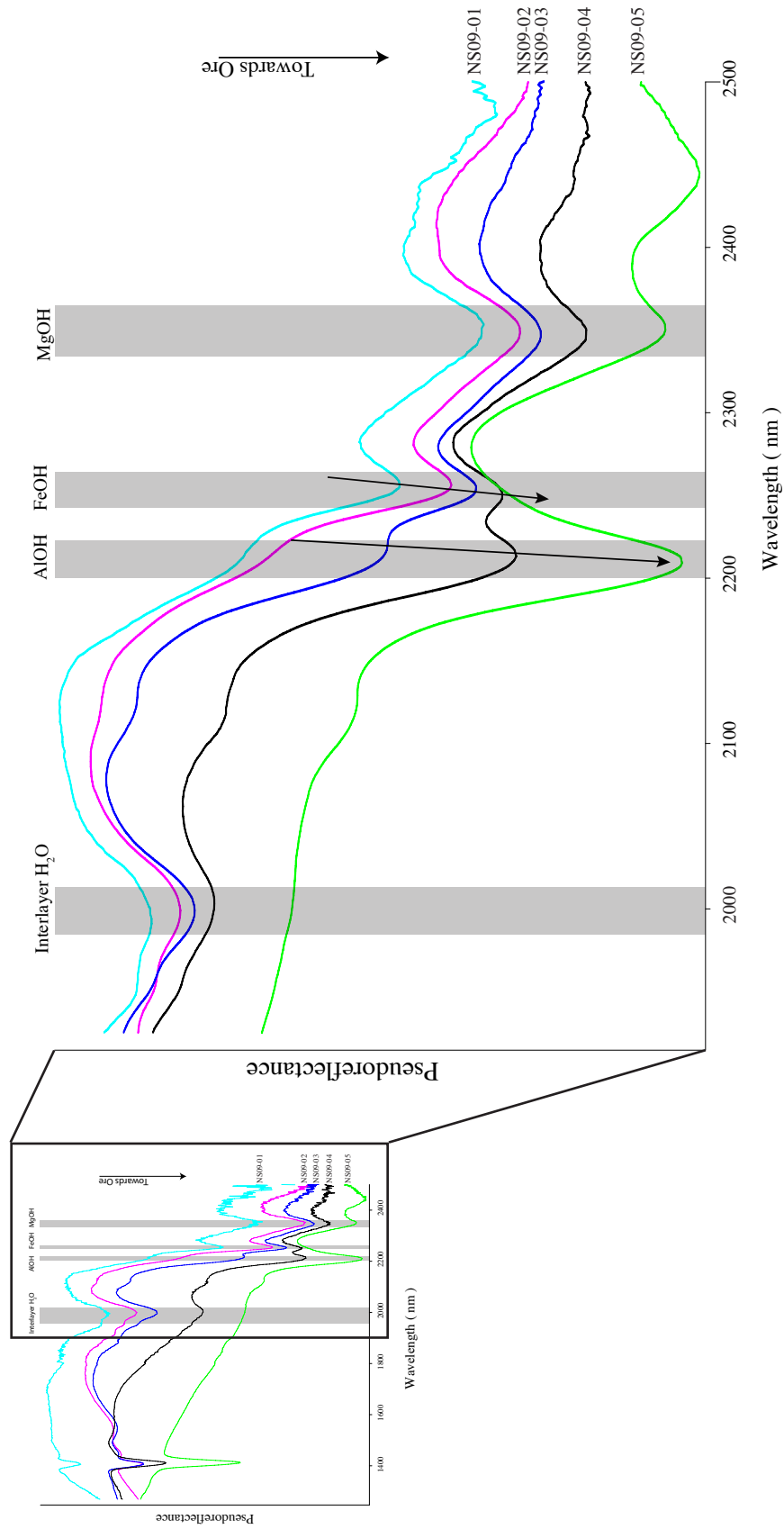
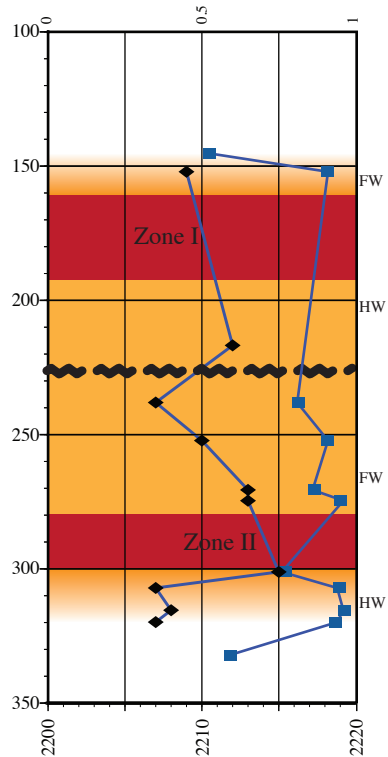
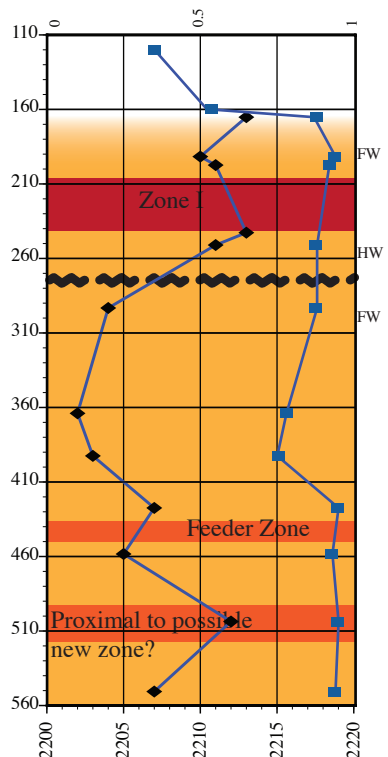


Figure 4.19. Example of change in SWIR spectra from samples below Zone I in drillhole CMR07-09. The distance to ore in the footwall decreases from NS09-01 to NS09-05. Spectra show a trend from Fe-chlorite dominated to muscovite-dominated samples. Note gradual appearance of AlOH absorption feature and decrease in FeOH feature with proximity to ore. Background chlorite is related to greenschist-facies metamorphism of mafic volcanic rocks and shows a trend from more Fe-chlorite to more Mg-chlorite towards ore. This is observed in the spectra as the FeOH feature decreases in wavelength with the addition of Mg to chlorite. Muscovite is distinguished from illite by a relatively flat interlayer H₂O feature. No Hull quotient correction applied.

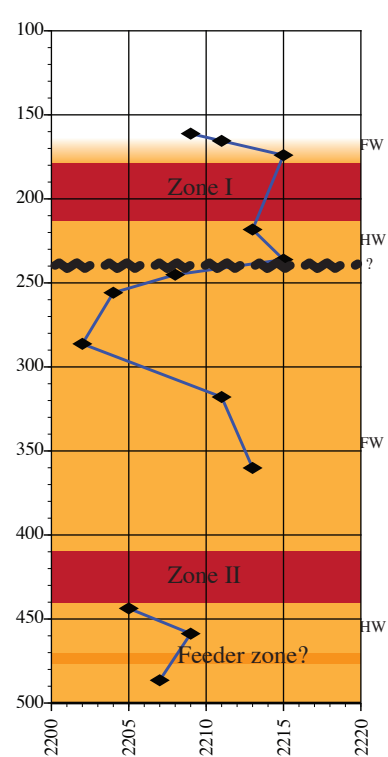
CMR08-11b



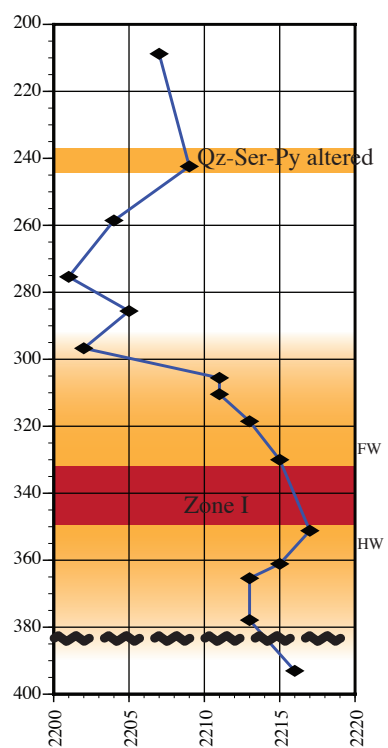
CMR08-13



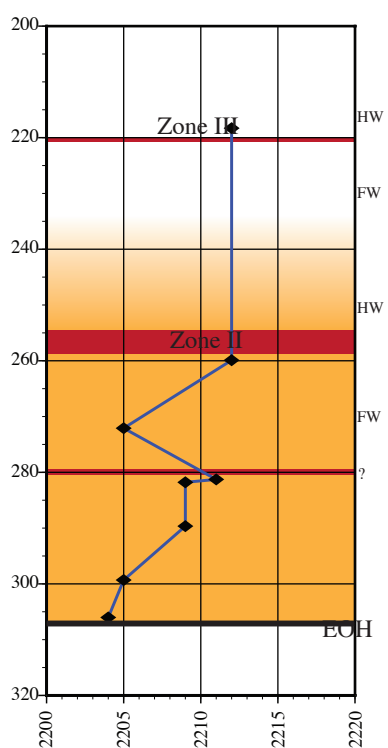
CMR08-14



CMR08-17



CMR08-18



CMR08-19

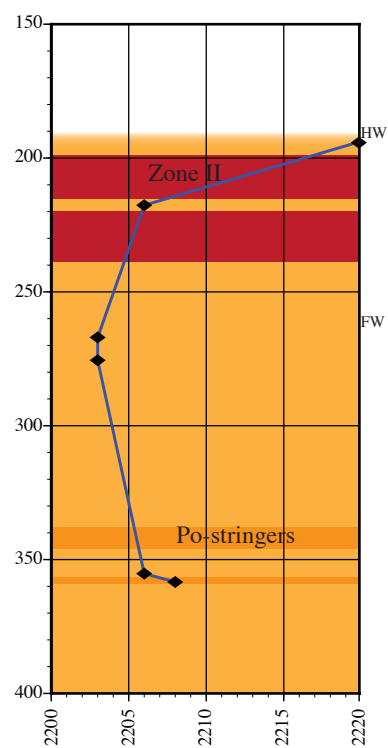




Figure 4.20. Simplified downhole plots of the position of the AIOH absorption features in the SWIR spectra.

Drillholes CMR08-11b and -13 also have downhole plots of the Glacier Creek Alteration Index (GIC AI; see Figure 4.17). A significant increase in depth (Figure 4.19) and wavelength of the AIOH absorption feature occurs towards mineralized zones, within ~30 m above and below. In general AIOH features above 2209 nm occur near massive sulfide, where well-defined AIOH features are present. Massive sulfide zones are highlighted in red and interpreted hydrothermal feeder zones are outlined in orange. Lighter tan represent dominantly muscovite-altered zones containing sufficient white mica (ie. >10%) to produce an AIOH absorption feature. The GIC AI generally mimics the AIOH pattern. CMR07-09 is not shown, as it does not contain a significant muscovite alteration zone. HW = hanging wall FW = footwall

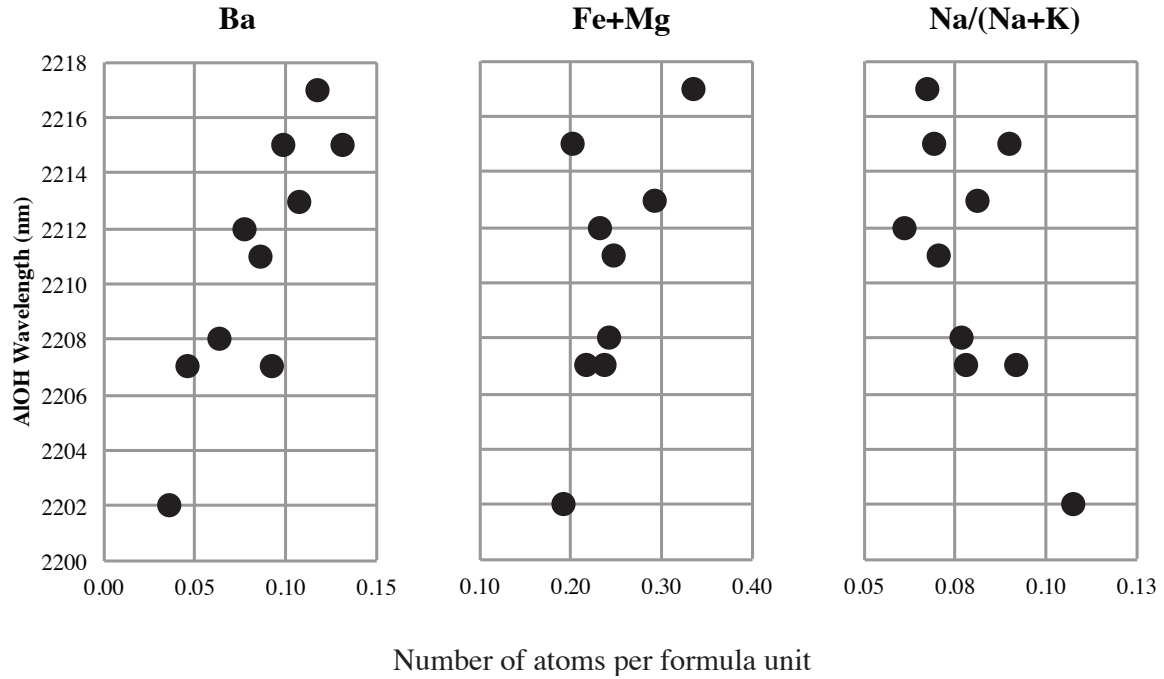


Figure 4.21. Number of atoms (per formula unit) of Ba, Na and Fe+Mg in muscovite versus the position of the AIOH absorption feature from SWIR. Ba and Mg+Fe increase with increasing wavelength of the AIOH feature whereas Na decreases. The more phengitic micas have higher Fe+Mg with AIOH features at higher wavelengths.

Chapter 5

SUMMARY AND DISCUSSION

The Glacier Creek deposit occurs in an oceanic back-arc or intra-arc, terrane-scale rift environment composed of Late Triassic rocks known as the Alexander Triassic Metallogenic Belt (ATBM). The ATBM shows a general change in depositional environment (south to north) from shallow to deep water stratigraphy and from felsic, calc-alkaline to mafic, tholeiitic magmatism, which is interpreted to have influenced the styles of mineralization along the belt. The host rock sequence for the Glacier Creek deposit comprises dominantly tholeiitic to transitional mafic volcanic and volcanoclastic rocks, with subordinate rhyolite and calcareous argillite and tuffaceous rocks. They broadly correlate with host rocks for the Windy Craggy and Greens Creek VMS deposits to the north and south, respectively.

The Glacier Creek deposit is one of 15 occurrences within the Palmer area on both sides of the border, although only a few have been studied in any detail. The deposit consists of 4 known tabular, Cu-Zn massive sulfide lenses, three of which appear to be stacked. Figure 5.1 illustrates a simplified reconstruction of the Glacier Creek deposit before and after deformation. The lowermost and largest of the stacked lenses (Zone I) overlies a thick, coherent feldspar-phyric basalt unit, while the upper lenses are hosted within strongly altered, dominantly volcanoclastic rocks of a similar composition. The fourth lens (RW zone) is hosted, in part by a coherent rhyolite unit overlying the feldspar-phyric basalt. The RW zone is split into two sections, an east and west zone, that have yet to be connected by drilling. Relatively unaltered, pillowed, aphyric and amygdaloidal basalts form the hanging wall to

the deposit, although minor feldspar-phyric basalt is also found. The feldspar-phyric basalt in the footwall is thought to be underlain by aphyric, amygdaloidal basalt that is chemically similar to the hanging-wall volcanic rocks. Numerous horizons of calcareous tuffaceous rock and argillite are intercalated within the hanging-wall basalts.

Calcareous, tuffaceous rocks occur immediately overlying Zones I and II. These tuffaceous rocks contain (Ba-K)-feldspar and are typically weakly mineralized. They have distinct geochemistry and extend laterally away from mineralization, marking a hiatus in volcanism that was coincident with mineralization. They are typically capped and locally underlain by cherts and calcareous argillites. These tuffaceous rocks likely represent hydrothermal sediments or “exhalites” of volcanic origin typical of massive sulfides in other VMS districts (Large, 1977). Together the mineralogy, morphology and metal zonation provide a better understanding of the structural context of the massive sulfide lenses which is illustrated schematically in Figure 5.2.

Petrographic and geochemical evidence indicate two distinct trace element suites within the ore at the Glacier Creek deposit, typical of many VMS deposits (e.g. Rosebery: Smith and Huston, 1992; Kidd Creek: Hannington et al., 1999). A strong correlation between Zn, Ba, Pb, As, Sb, Cd, Tl, F and Hg is evident in the barite-sphalerite (Zn-rich) ores. A Hg halo surrounds the ore lenses, with anomalously high (>1000 ppb) values extending 10s of meters into the hanging wall (Figure 5.2). Tl is abundant in altered rocks, and less so in the ores, forming a halo with Sb tens of meters around the ore lenses. F occurs in muscovites (up to 0.7 wt.%) surrounding the sulfide lenses and correlates strongly with Zn and

Sb, and moderately well with Hg and Ag. A second strong correlation exists between Cu, Fe, Au, Ag, As, in massive pyrite and pyrrhotite ores and locally within barite ores. Au and As appear to be correlated with the presence of minor arsenopyrite within Cu-rich massive pyrite ores. The Glacier Creek deposit contains very low Se, Te and Bi and therefore likely little or no magmatic component (cf. Hannington et al., 1995). By comparison with other deposits and with modern black smokers, the Zn-Ba-rich ores are interpreted to have formed at generally low temperatures (e.g., $\leq 250^{\circ}\text{C}$), whereas the Cu-rich ores with abundant pyrrhotite likely formed at much higher temperatures (e.g., $> 300^{\circ}\text{C}$).

Physical and chemical conditions of ore formation

At the Zone I massive sulfide lens, pyrrhotite underlies the main lens forming a small stringer zone and locally massive mineralization with chalcopyrite and Fe-rich sphalerite (Figure 5.2). Pyrrhotite, Fe-rich sphalerite and (Ba-K)-feldspar also overlie the main lens within the carbonate $\pm$ chlorite-rich ores. In contrast the main sulfide lens contains barite, pyrite, very low-Fe sphalerite, chalcopyrite and trace magnetite. In general, the observed mineralogical zonation can be interpreted in terms of a high temperature ($250\text{--}350^{\circ}\text{C}$), reduced hydrothermal fluid rising up through the volcanic pile and mixing with colder and typically (but not always) more oxidized seawater. Pyrrhotite and chalcopyrite were deposited at higher temperatures and/or lower $f\text{O}_2$, while pyrite, low-Fe sphalerite and barite formed at lower temperatures and/or higher $f\text{O}_2$. The transition from Fe-rich sphalerite in equilibrium with pyrrhotite in the stringer zone to low-Fe sphalerite with pyrite in the massive sulfide lens can be attributed mainly to the decrease in temperature (Figure 5.3). Figure 5.4 shows that the same fluid, cooling from $\sim 300^{\circ}\text{C}$ to $\sim 200^{\circ}\text{C}$ will precipitate pyrrhotite and chalco-

pyrite first, followed by pyrite and chalcopyrite, and then pyrite-sphalerite and barite. Magnetite may precipitate with barite, pyrite and sphalerite locally by an increase in fO_2 or pH (Figures 5.4 and 5.5). As the mound increased in size, the margins may have over-steepened and caused barite-sulfide material to slump down the sides, forming the local resedimented ores (i.e. 'barite sand'). Late Triassic seawater has a relatively light sulfur isotopic composition (Claypool et al., 1980) with an average $\delta^{34}S$ (CDT) of between $13.4 \pm 1.5\text{‰}$ (210Ma) and $14.7 \pm 1.8\text{‰}$ (215 Ma; Kampschult and Strauss, 2003). These values are similar to the average sulfate sulfur isotopic composition of barite from Zones I and II (12.68‰ ; Table 3.15), supporting the suggestions that the SO_4 in barite was derived from contemporaneous seawater. Average sulfide $\delta^{34}S$ values are up to 14.57‰ less than barite, which is similar to the $17.5 \pm 2.5\text{‰}$ difference observed in most VMS deposits (Huston, 1999).

In another model, the massive sulfides may have evolved over time from initially low-temperature 'white smokers', forming barite-pyrite-sphalerite on the seafloor ($\pm$ tetrahedrite, arsenopyrite and magnetite) to higher-temperature pyrrhotite-chalcopyrite ore. As the hydrothermal system developed, alteration of the footwall and capping of the hydrothermal system by the sulfide mound would have focused fluid flow and allowed temperature to increase. This would have promoted the deposition of pyrite-chalcopyrite at the base and core of the mound, and pyrrhotite and chalcopyrite as stringers below the mound.

The capping carbonate-rich zone contains pyrrhotite, Fe-rich sphalerite and dark green Fe-rich chlorite. For these minerals to have been deposited above the pyrite-barite-sphalerite assemblage, the temperatures must have increased or the local environment be-

came more reduced. That they occur with calcareous tuffs and black, calcareous argillites suggests that sedimentation was ongoing during deposition of these mineralized cap rocks. The black argillite and tuffaceous rocks locally contain chalcopyrite, pyrrhotite and dark red sphalerite (likely high-Fe), suggesting that hydrothermal fluid flow continued after burial of the deposit under strongly reduced conditions (Figure 5.3).

The occurrence of (Ba-K)-feldspar in the hanging-wall can be explained in two ways: either by the metamorphism and replacement of barite, or by the primary precipitation and later dehydration of cymrite during diagenesis or metamorphism. For cymrite to form, a reduced, SO_4 -deficient environment is required. Hyalophane occurs within tuffaceous cap-rocks overlying Zone I, where such an environment likely existed. These hyalophane grains are partially replaced by muscovite, reflecting a variable pH during hydrothermal activity after deposition. Variation in pH during ore formation also likely explains why barian muscovite is present within footwall altered rocks and (Ba-K)-feldspar is present at the ore horizon (Figure 5.5). Mixing at the seawater interface may have increased the pH of reduced, acidic hydrothermal fluids carrying Ba, forming barian-muscovite in the footwall and cymrite at the seafloor under anoxic, reduced conditions

Sulfides from Zone II, which is stratigraphically above Zone I, are isotopically lighter, possibly due to minor contributions from biogenically reduced sulfur in underlying stratigraphy. Pyrite and pyrrhotite from argillites overlying Zone I also have very low $\delta^{34}\text{S}$ values (Table 3.15), suggesting a strong input of biogenically reduced sulfur late in the history of the hydrothermal system. Sulfur reducing bacteria are anaerobes, surviving in anoxic

environments (Goodfellow et al., 2003). The presence of a thick package of black argillites with very low $\delta^{34}\text{S}$ values overlying Zone I suggests that continued extension and down-faulting of the local basin may have caused a significant influx of sediment, creating a local anoxic environment. Venting of a Ba-rich hydrothermal fluid into an anoxic basin in which SO_4 has been completely reduced (by anaerobic bacteria) would not produce barite (Goodfellow et al., 1985). The presence of stringer-style veins directly overlying Zone I confirm that hydrothermal activity continued after deposition of the main massive sulfide lens. It is likely, therefore, that hydrothermal activity continued during the influx of sediment, causing (Ba-K)-feldspar (cymrite) to form rather than barite in H_2S -rich pore fluids below the argillites. The effect of increased sedimentation during hydrothermal mineralization and the formation of (Ba-K)-feldspar is also documented at the Greens Creek deposit (Taylor et al., 2010).

Summary

- 1) Diffuse fluid flow first formed white smokers, depositing pyrite, sphalerite, galena, arsenopyrite, tetrahedrite and barite ($\pm$ magnetite) on and just below seafloor with coincident pervasive, widespread sericite $>$ quartz + pyrite alteration of the footwall.
- 2) Quartz-sericite alteration of the footwall caused a decrease in permeability, focusing hydrothermal fluids, and increasing the temperature below the new sulfide mound. Black smokers formed on top of the mound and lower-temperature white-smokers formed on the flanks, locally eroded into barite sand.
- 3) Pyrrhotite and Fe-rich sphalerite was deposited epigenetically in the stockwork below and at the base of the mound (Zone I) as temperatures increased. Outward of this stockwork, pyrite-sphalerite stringers formed and local increases in pH stabilized albite in the string-

ers.

- 4) Calcareous, mineralized tuffs and argillites covered the mound. Sulfate-reducing bacteria within sediments created a locally reduced environment and caused formation of pyrrhotite, high Fe-sphalerite, (Ba-K)-feldspar and locally chlorite within calcareous rocks overlying the massive sulfide mound.
- 5) Mafic volcanism resumed, burying massive sulfide lenses and hydrothermal activity in the area ceased.

Metal Sources

The rocks underlying the Glacier Creek deposit consist mainly of mafic and intermediate volcanics with minor rhyolite and intercalated, calcareous black shales and tuffaceous rocks. Large volumes of black shales and limestone underlie the volcanic pile below a poorly understood unconformity. All of these may have been sources for metals. However, the lack of galena within the barite-rich ores contrasts with many barite-rich deposits that derive their Pb from felsic or sedimentary sources (Large, 1977; Franklin et al., 2005). The rhyolite or sediments at Glacier Creek, therefore, were likely not a major metal source. The relatively simple Cu-Zn mineralogy suggests a mafic volcanic metal source, with Ba possibly derived from feldspar within basalts (e.g., Hannington et al., 1995). The B6 feldspar-phyric basalt, with up to 25% feldspar phenocrysts, is a likely candidate as a major source of Ba.

The Glacier Creek deposit has a relatively radiogenic Pb-isotope signature, with $^{206}\text{Pb}/^{204}\text{Pb}$ ranging between 18.816 and 18.839, $^{207}\text{Pb}/^{204}\text{Pb}$ between 15.180 and 15.184 and $^{208}\text{Pb}/^{204}\text{Pb}$ between 38.240 and 38.242 (Table 5.2; Godwin et al., 1988). These data are

similar to Pb isotopic data from other Palmer area occurrences (Table 5.2 and Figure 5.6), but distinct from the Windy Craggy and Greens Creek deposits. Many VMS deposits have Pb ratios that reflect mantle and upper-crust mixing, typically caused by the presence of oceanic volcanic and intercalated sedimentary rocks in the footwall (e.g., Newberry et al., 1997; Godwin et al., 1996; Peter and Scott, 1990; Mortensen et al., 2006; Ayuso et al., 2005). Palmer lead is slightly more radiogenic than the other Late Triassic VMS deposits of the Alexander terrane, and was likely derived from footwall mafic volcanic rocks and intercalated argillites and tuffaceous rocks, possibly with a large contribution from the B6 feldspar-phyric basalt.

Comparison to other VMS deposits

VMS mineralization in the ATMB ranges from near-arc, epigenetic deposits in the south to stratiform, rifted-basin deposits in the north, reflecting the transition from shallow-water, high-energy limestone-dominated stratigraphy and calc-alkaline, rhyolite dominated magmatism to deep marine, low-energy, shale-dominated stratigraphy and tholeiitic basalt-dominated magmatism (Taylor et al, 2008).

The mineralogy at Greens Creek consists of barite, sphalerite, galena, pyrite-pyrrhotite, variable chalcopyrite, and Sb-dominant sulfosalts such as tetrahedrite (Table 5.1). The ores are enriched in Fe, Zn, Cu, Pb, Au, Ag, As, Cd, Sb, Hg, Mn, ± Bi and Mo. Greens Creek massive sulfide formed at the contact between mafic and ultra-mafic volcanic rocks and hanging-wall argillites. The metals were in part, derived from the overlying argillites (Taylor et al., 2010). Felsic volcanic rocks are absent from the Greens Creek geology. North of Palmer, the mafic-dominated Windy Craggy deposit consists of a higher-tempera-

ture and/or more reduced assemblage of pyrrhotite ($\pm$ pyrite), with magnetite, anomalous Co (Peter and Scott, 1999; MacIntyre and Schroeter, 1985). Windy Craggy contains no barite or Sb-sulfosalts, two diagnostic features of Glacier Creek and Greens Creek. Three occurrences to the west of the Boundary occurrence at Palmer (Figure 2.6) are hosted within argillites and intercalated mafic volcanics and show similarities to Windy Craggy, approximately 40-60 km to the northwest, including high Cu-Co-Au-content, abundant chlorite alteration, and the presence of massive pyrrhotite. Felsic volcanic rocks are absent and the massive sulfides contain no Pb or Ba (Table 5.1). In the Goldrun area, northeast of Windy Craggy, the mineralization is very similar to that of Glacier Creek, with massive, layered, calcareous, baritic lenses containing significant Cu, Zn, Pb, Au and Ag with associated sericite-quartz-carbonate and local chlorite schists within mafic volcanics (Mihalynuk et al., 1993). These comparisons illustrate the important control of host rock lithology on the mineralogy and compositions of the deposits.

Glacier Creek is transitional in character. It has several similarities to the Greens Creek deposit, such as the presence of (Ba-K)-feldspars and barian muscovites, an argillite cover, mafic volcanic rocks in the footwall, relative absence of proximal-chlorite alteration, abundant quartz-sericite $\pm$ carbonate footwall alteration, and quartz, barite and carbonate gangue. Similarities with Windy Craggy include the abundance of pyrrhotite, local calcareous gangue, lack of well-formed pipe-like feeder zones, tabular lens shape, and similar 'exhalite' with identical REE patterns.

Exploration Significance

The pervasive, destructive nature of the quartz-muscovite-pyrite alteration at Glacier Creek has caused difficulties for past explorers. Companies exploring the Palmer property have relied on targeting exposed mineralization and geophysical anomalies using methods such as electromagnetics (EM) and induced polarization (IP). A detailed study of the litho-geochemical, trace element, infrared spectral and petrographic features of the alteration zones and ore-hosting lithologies has provided a number of other useful exploration guides. Figure 5.2 graphically summarizes many of the exploration vectors and geochemical halos, and provides an idealized model for massive sulfide lenses and alteration zones at Glacier Creek. The key exploration indicators are:

1) Chemostratigraphy: The feldspar-phyric (B6) basalt has a distinct immobile element ratio (Zr versus Al_2O_3) and appears to be the general footwall to mineralization at Glacier Creek.

2) Trace element vectors to ore: Ba/Sr ratios increase towards ore due to the increased Ba content of silicates and the loss of Sr, along with an overall increase of Zn, Hg, As and Au concentrations.

3) Volatile elements halos (Hg, Sb and Tl) surrounding ore lenses: Tl likely substitutes for K in white micas in the surrounding alteration (Large et al., 2001a), Hg occurs within sphalerite and increases towards ore with Zn, and Sb correlates very strongly with Hg, Zn and Cd.

4) Alteration facies and mass balance calculations: Alteration facies may be used to identify spatial relationships to ore, with the quartz-pyrite facies an indicator of ore-proximal hydrothermal conduits. Mass balance calculations provide quantitative data on alteration

intensity. Changes in REE patterns are also useful (e.g., positive Eu anomalies in unaltered feldspar-phyric basalt become negative with increased alteration intensity).

5) SWIR spectroscopy: AlOH absorption features from SWIR spectroscopy increase towards ore, coincident with an increase in Fe+Mg (phengite component) content of muscovite.

6) Alteration indices: A Glacier Creek alteration index (total elements gained/[gained +lost]) is a useful vector to ore.

7) Exhalative rocks at the ore horizon: These rocks have distinct, positive Eu anomalies and high Ba concentrations due to (Ba-K)-feldspars.

Summary and Conclusion

The Glacier Creek volcanogenic massive sulfide (VMS) deposit is hosted within Late Triassic, oceanic back-arc or intra-arc, rift-related, bimodal volcanic rocks (Hyd or Tats Group) of the allochthonous Alexander terrane known as the Alexander Triassic Metallogenic Belt (ATMB). The deposit presently consists of four tabular massive sulfide lenses with a resource of 4.75 Mt. at 1.84% Cu, 4.57% Zn, 0.15% Pb, 0.28 g/t Au and 29.07 g/t Ag. Three of the lenses are stacked and lie within the steep, overturned limb of a deposit-scale, south-verging anticline. The fourth lens is along the same horizon within the upright, shallowly dipping limb, and partially overlies a coherent rhyolite unit. A deposit-scale thrust fault offsets stratigraphy along the axial surface and between the stacked lenses.

The massive sulfide lenses are barite-rich and composed dominantly of massive barite-sphalerite-pyrite with massive and semimassive chalcopyrite-pyrite-quartz replacing

the base and center and local massive pyrrhotite above and below the lenses. The flanks and top of the lenses are carbonate-rich, either as interbedded carbonate and barite-sulfide, as resedimented massive barite-sulfide, or as mineralized massive carbonate rocks. Minor, diffuse 'stringer-style' sphalerite-pyrite (and locally chalcopyrite) mineralization occurs above and below the lenses and is evidence of continued hydrothermal activity after massive sulfide deposition. Small, local 'feeder zones' underlying lenses contain pyrrhotite and chalcopyrite stringer-style veins. There is a large range of sphalerite compositions, with low-Fe sphalerite dominant throughout the deposit and high-Fe sphalerite in pyrrhotite-rich zones. Silver is hosted in tetrahedrite and, to a lesser extent, in galena. Gold is hosted within tetrahedrite or arsenopyrite. Rare magnetite, molybdenite, native bismuth and tellurides are observed locally within massive sulfides. The massive sulfides locally contain anomalous Sb, Hg and Tl. Gangue minerals include barite, quartz, barian-muscovite, calcite, albite, highly subordinate chlorite and locally hyalophane and celsian. Overlying and locally underlying massive sulfide is a tuffaceous hydrothermal sediment with characteristic, anomalous REE patterns and locally abundant hyalophane.

The footwall to all four lenses and the rhyolite is a thick unit of coherent to volcanoclastic feldspar-phyric basalt containing extensive lateral alteration below the massive sulfide lenses. Four alteration facies are recognized: a prevalent muscovite > pyrite + quartz facies, a local, stratabound muscovite + quartz + pyrite > carbonate $\pm$ chlorite facies, a quartz > pyrite/pyrrhotite + muscovite facies associated with cross-cutting veins and stringers, and a more distal epidote > muscovite > quartz + pyrite/pyrrhotite facies that grades into the background greenschist facies metamorphic assemblage. Mass balance calculations for the

footwall indicate general gains of S, Fe, Si and K with coincident loss of Ca, Na and Mg, along with trace element gains of Tl, Sb, Hg, Ba, Zn, Cu, As and loss of Sr with increased alteration intensity. Muscovite compositional variations within the laterally extensive alteration zone are qualitatively measurable using short wavelength infrared (SWIR) spectroscopy. In general, as Na, K and Al contents of muscovite decrease and Fe+Mg and Ba contents increase towards ore, the wavelength of the AlOH absorption feature increases.

The transition from pyrrhotite, chalcopyrite, high-Fe sphalerite, barian muscovite and chlorite in the small footwall stringer zone to low-Fe sphalerite, pyrite and barite in the massive sulfide lens suggest that high-temperature ($\sim 300^{\circ}\text{C}$), reduced hydrothermal fluids in the footwall cooled while rising, and mixed with oxidized, SO_4 -rich seawater. Capping the sulfide mound is mineralized, carbonate-rich argillite and tuffaceous rocks containing pyrrhotite, Fe-rich sphalerite and (Ba-K)-feldspar, indicating a transition to cooler, low $f\text{O}_2$ - $f\text{S}_2$ conditions and a lack of SO_4 to form barite. The sudden increase in sedimentation of black muds likely records strongly reduced conditions. Low sulfur isotope values for sulfides within hanging-wall argillites (to -17 per mil) support a reduced environment of deposition.

Based on the integration of petrographic, mineral, chemical and isotopic data, this study proposes that the Glacier Creek massive sulfide deposit was formed by the exhalation of a high-temperature hydrothermal fluid into a first oxidized, then later reduced seawater environment. The deposit shows similar traits to those of numerous VMS deposits described within the literature, and shows transitional features between the Greens Creek and Windy Craggy deposits within the ATMB. Several exploration tools are proposed, and several

structural and stratigraphic problems have been solved based on these data and observations, which may aid in future discovery of ore within the region. The results described here serve to fill a gap in the understanding of the metallogeny of the Alexander Triassic Metallogenic Belt. In general, many aspects of this study have broad applications to the understanding of processes involved in the deposition of volcanogenic massive sulfide deposits.

Table 5.1 Comparison between Greens Creek, Windy Craggy and Glacier Creek VMS Deposits

	Glacier Creek	Greens Creek	Windy Craggy
Classification	Bimodal-mafic; 'Kuroko-type'	Mafic-siliciclastic; (± SEDEX and MVT-styles)	Mafic-siliciclastic; 'Besshi-type'
Age	<213 ± 5 Ma (U-Pb from FW Rhyolite)	~215 to 210.3 ± 0.3 Ma	Norian (~216-203 Ma)
Tonnage	4.75 Mt	24.2 Mt	297 Mt (possibly >500Mt)
Grade	1.84% Cu, 4.57% Zn, 0.15% Pb, 0.28 g/t Au, 29.1 g/t Ag	13.9% Zn, 5.1% Pb, 19.2 troy oz/ton Ag, 0.15 troy oz/ton Au	1.38% Cu, 0.07% Co, 0.2 g/t Au, 3.8 g/t Ag, locally 0.25% Zn
Host rocks	Tholeiitic feldspar-phyric basalt, minor rhyolite, tuffaceous rocks, argillites	Mafic- ultramafic rocks (volcanic and intrusive) foot-wall and hanging-wall argillite.	Argillites and mafic volcanic flows and dykes/sills
Metalliferous minerals	Pyrite, sphalerite, chalcopyrite, pyrrhotite, tetrahedrite, arsenopyrite, galena, magnetite, and rare molybdenite, bismuth and tellurides	Pyrite, sphalerite, galena, tetrahedrite, chalcopyrite, gold, electrum, Pb-Sb-As-sulfosals, pyrrargyrite. (+ >20 sulfides)	Pyrrhotite, pyrite, chalcopyrite, sphalerite, > marcasite, galena, digenite, arsenopyrite, Bi-telluride, cobaltite, cubanite, Au°, Ag°, electrum
Geochemical Signature	Ba, Zn, Cu, Pb, Ag, Au, (As, Sb, Cd, Hg, ± Mn, Tl, Co)	Ba, Zn, Pb, Cu, Ag, Au, As, Cd, Sb, Hg, Tl, Ni, Co, Cr, Mo	Cu, Co, Ag, Au, local Zn
Gangue minerals	Barite, quartz, calcite, bariann-muscovite, chlorite, (Ba-K)-feldspar, albite, siderite	Quartz, dolomite, barite, sericite, fuchsite, graphite cymrite	Siderite, calcite, ankerite, magnetite, quartz, chlorite, stilpnomelane and hisingerite (trace barite)
Alteration Minerals *	Quartz, (tr. chlorite), bariann-muscovite, carbonate, epidote, carbonate-chlorite	Quartz, bariann-sericite, carbonate, mariposite, (chlorite), serpentine, carbonate-chlorite	Chlorite, quartz, lesser epidote, calcite, local sericite

VMS classification based on Barrie and Hannington (1999). Where listed, minerals and metals are in order of decreasing abundance.

Data for Glacier Creek from this study and Green (2001); for Greens Creek from Taylor et al. (2010); for Windy Craggy from Peter and Scott (1999).

* in order of proximity to ore

Table 5.2 Lead Isotopic Data for Palmer Area Occurrences

Occurrence	$^{206}\text{Pb}/^{204}\text{Pb}$	$^{207}\text{Pb}/^{204}\text{Pb}$	$^{208}\text{Pb}/^{204}\text{Pb}$	Reference
Cap	18.761	15.542	38.101	Godwin et al., 1988
Glacier Creek	18.839	15.580	38.240	Godwin et al., 1988
Glacier Creek	18.816	15.584	38.243	Godwin et al., 1988
Glacier Creek	18.827	15.582	38.242	Godwin et al., 1988
Low Herbert	18.796	15.583	38.248	Godwin et al., 1988
Mt Henry Clay	18.924	15.589	38.281	Gacetta and Church, 1989
Mt Henry Clay	18.777	15.581	38.215	Godwin et al., 1988
Mt Henry Clay	18.788	15.580	38.234	Godwin et al., 1988
Mt Henry Clay	18.783	15.581	38.225	Godwin et al., 1988

See Figure 2.6 for occurrence locations. Low Herbert is ~2 km northwest of the Boundary occurrence.

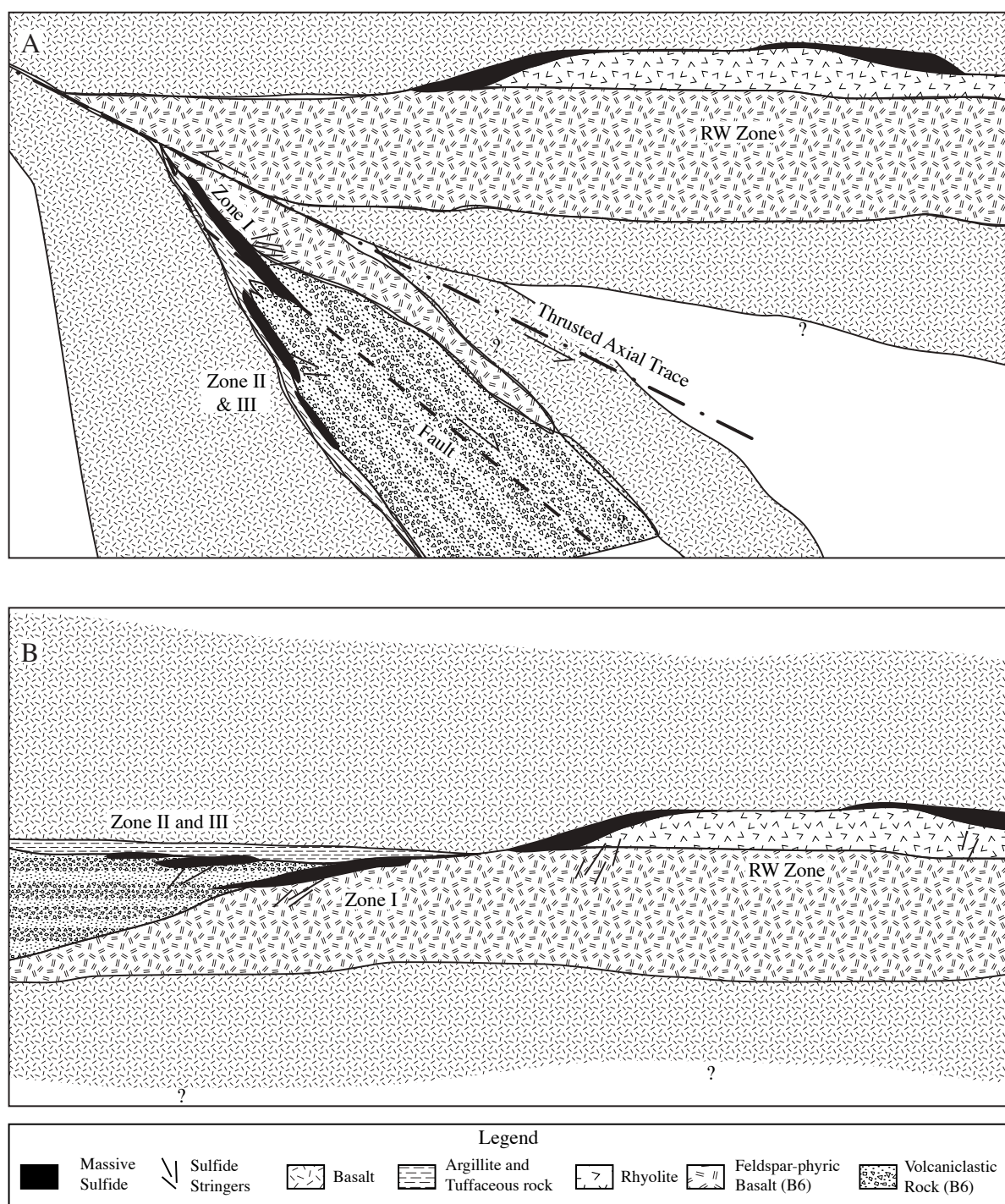


Figure 5.1. Idealized schematic of the Glacier Creek VMS deposit. The feldspar-phyric (B6) basalt is the general footwall to the ore-hosting horizon. A) Present-day schematic of Glacier Creek deposit. B) Reconstructed cross-section showing Glacier Creek before deformation.

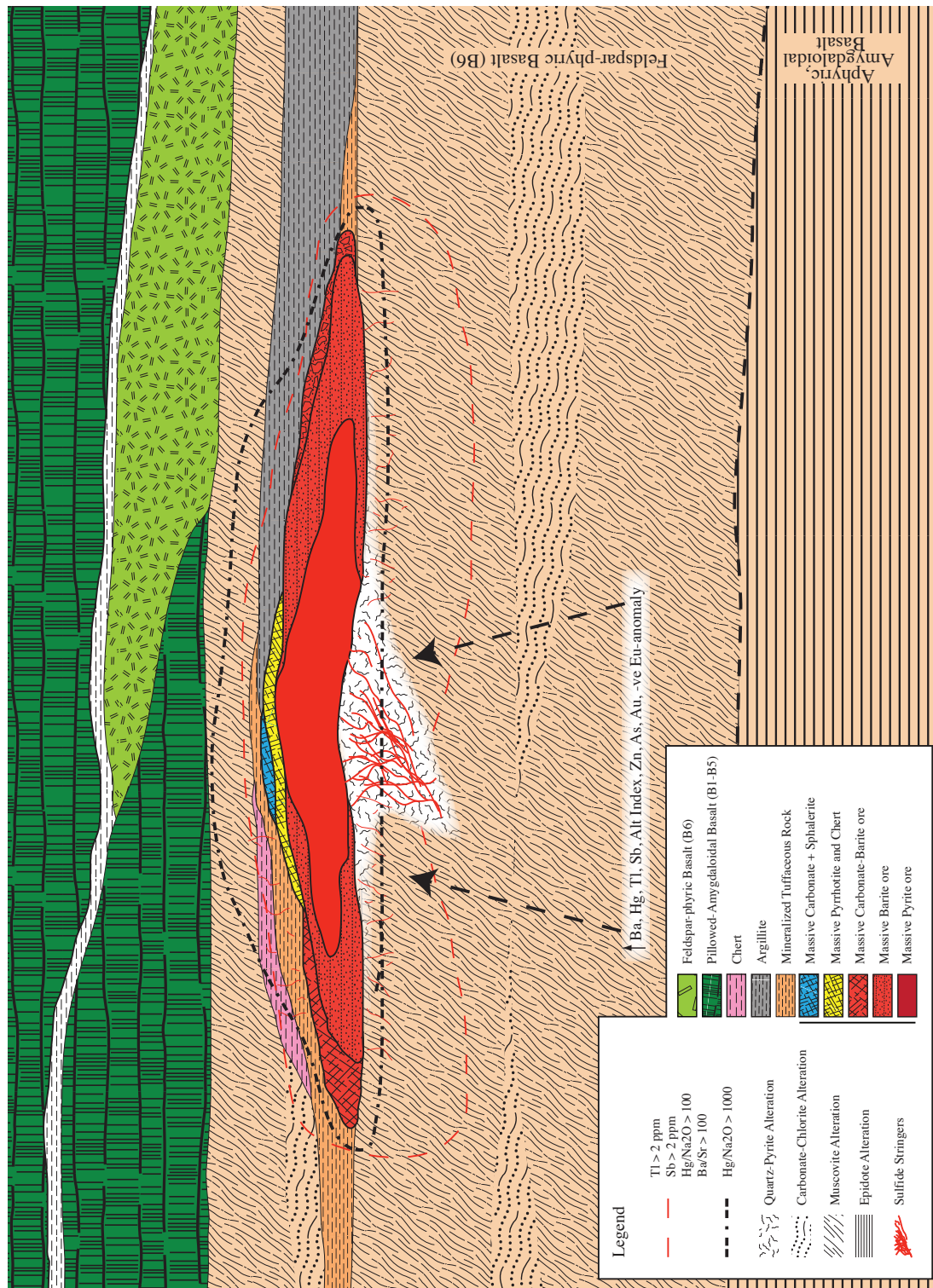


Figure 5.2. Exploration model and reconstructed schematic of an idealized massive sulfide lens from the 'southwall' at Glacier Creek.

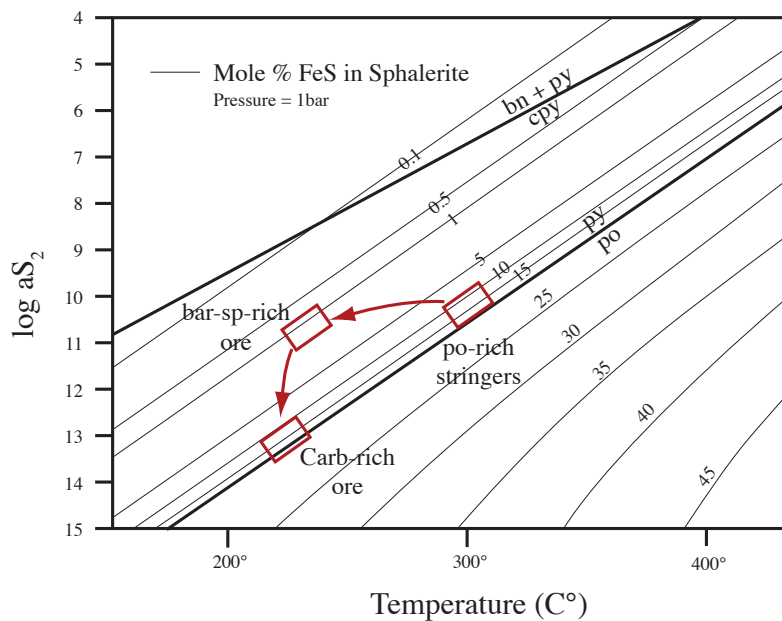


Figure 5.3. Mole% of FeS in sphalerite with respect to temperature and a_{S_2} (modified from Vaughan and Craig, 1997). Fe-rich sphalerite in the “high-temperature” stringer zone is in equilibrium with pyrrhotite $\pm$ pyrite. Fe-poor sphalerite in the “low-temperature” massive sulfide lens is in equilibrium with pyrite only. This trend in sphalerite compositions is consistent with the cooling of hydrothermal fluids as they rise to the seafloor. Fe-rich sphalerite in the “low-temperature” carbonate-rich ores at the top of the lens is in equilibrium with both pyrite and pyrrhotite.

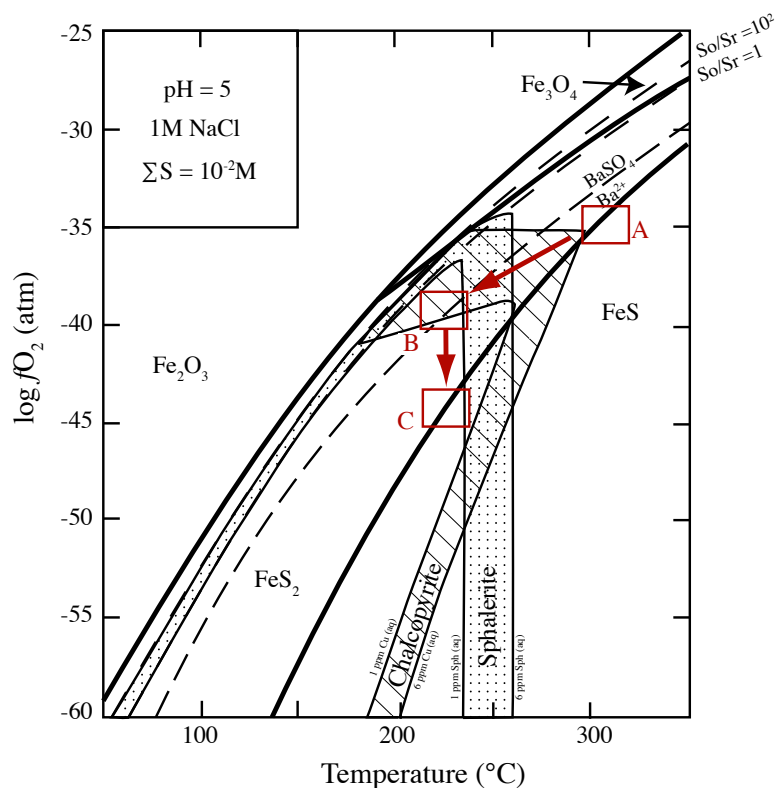


Figure 5.4. T- fO_2 diagram illustrating possible physical and chemical conditions of mineralization at Glacier Creek. Red arrow shows possible cooling path for Glacier Creek Zone I mineralization. A) Probable conditions of formation of “high-temperature” ore containing pyrrhotite + chalcopyrite $\pm$ pyrite. B) Probable conditions of formation of “low-temperature” ore containing pyrite + sphalerite + barite. C) Probably conditionals of formation of “low-temperature” ore containing pyrrhotite + Fe-rich sphalerite + (Ba-K)-feldspar. The solubilities of chalcopyrite and sphalerite show early deposition of chalcopyrite in the pyrrhotite $\pm$ pyrite ore and later deposition of sphalerite along the cooling path. Local magnetite (Fe_3O_4) may precipitate with pyrite, barite and sphalerite by local increases of fO_2 . Modified from Large (1977).

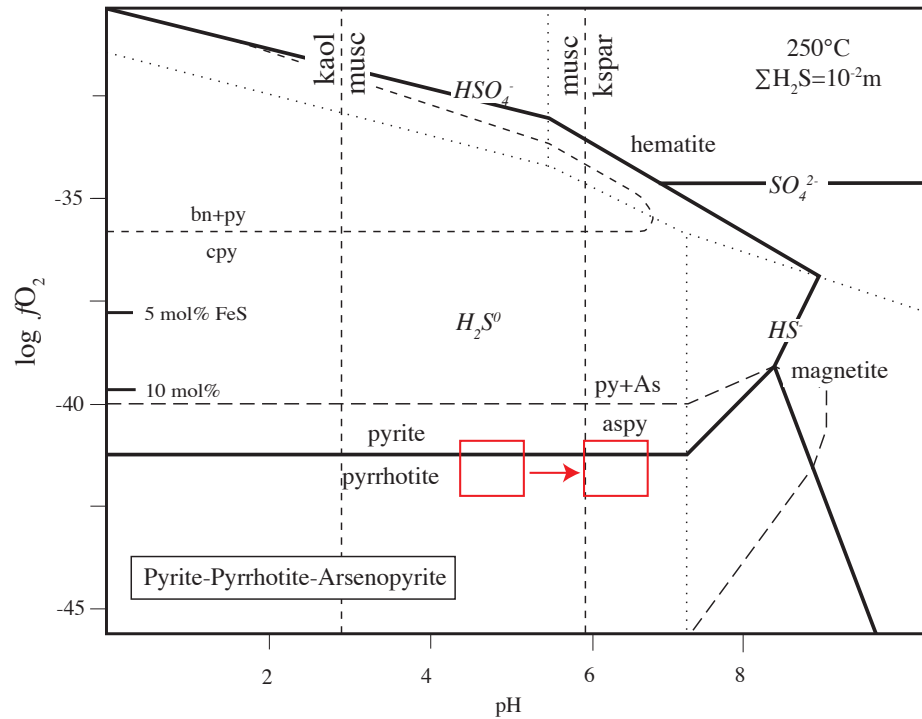


Figure 5.5. pH- fO_2 diagram illustrating the pH controls on muscovite and K-feldspar within the ore zone. Red arrow outlines path of reduced, acidic hydrothermal fluid increasing in pH upon mixing with seawater. The increase in pH resulted in the formation of (Ba-K)-feldspar. Modified from Hannington et al., 1999.

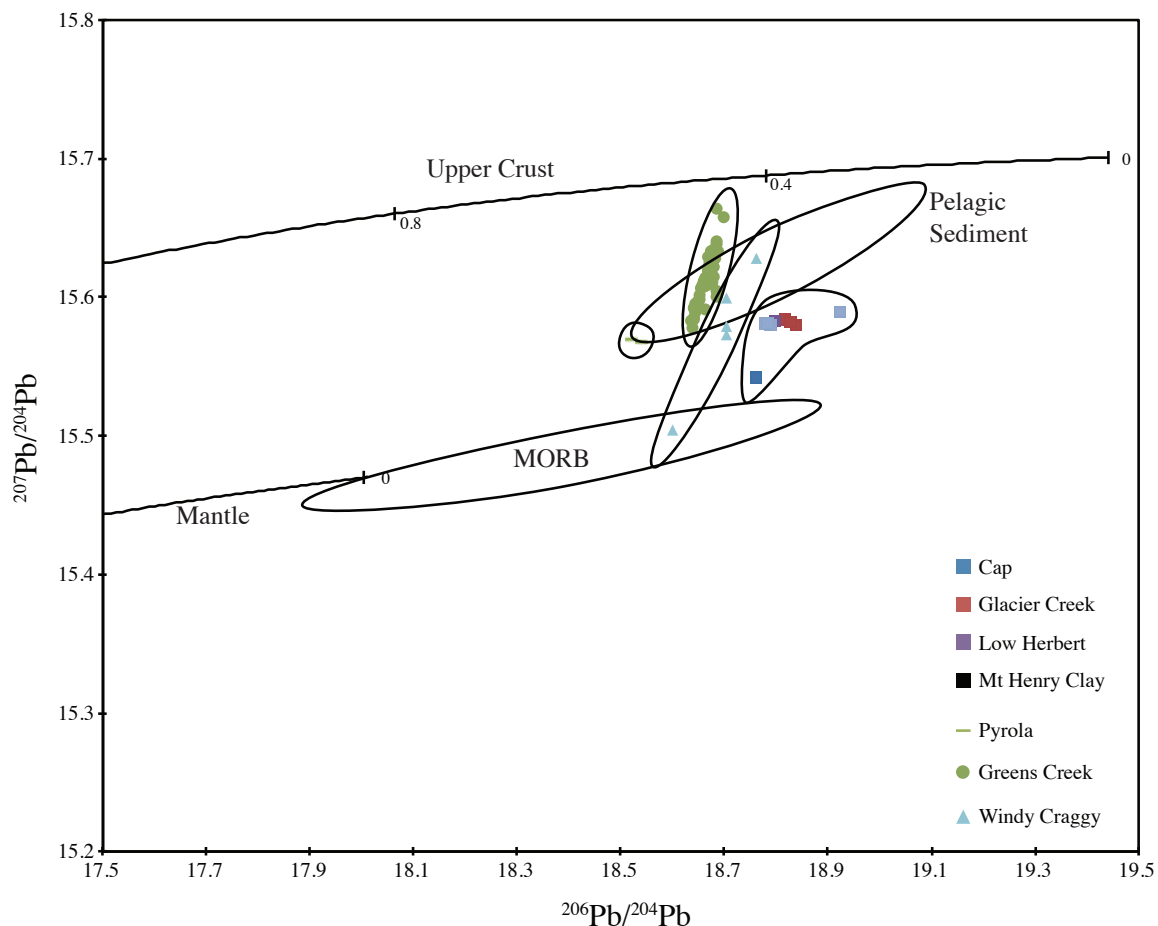


Figure 5.6. $^{207}\text{Pb}/^{204}\text{Pb}$ versus $^{206}\text{Pb}/^{204}\text{Pb}$ ratios for sulfides from massive sulfides in the Alexander Triassic Metallogenic Belt. Squares indicate samples from Palmer property area. Data plot between the mantle and orogenic growth curves and between modern MORB and pelagic sediment fields, suggesting a mixed metal source from oceanic and upper crustal sources. Low Herbert occurrence is ~2 km NW of the Boundary occurrence (Figure 2.6). Pyrola and Greens Creek are on Admiralty Island, ~14 km apart. See Figures 2.3 and 2.6 for locations. Mantle and upper crust growth curves are from Zartman and Doe (1981). MORB and pelagic sediment fields taken from Peter and Scott (1990). Windy Craggy data from Peter and Scott (1990); Cap, Glacier Creek, Low Herbert and Mt. Henry Clay data from Godwin et al. (1988); Greens Creek data from Taylor et al. (2010), van Nieuwenhuysen (1984) and Newberry and Brew (1997); Mt. Henry Clay data from Godwin et al. (1988) and Gacetta and Church (1989).

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APPENDIX A

Whole-rock Geochemistry

Table A.1. Whole rock geochemistry of low-sulfide rocks.

Analyte	Unit	D.L.	Method	NS9-01	NS9-02	NS9-03	NS9-04	NS9-05	NS9-12	NS9-13	NS9-14	NS9-15	NS9-16
SiO ₂	%	0.01	FUS-ICP	37.14	43.78	45.42	34.94	60.01	98.73	41.92	50.81	43.97	64.65
Al ₂ O ₃	%	0.01	FUS-ICP	16.9	21.07	21.21	17.28	14.39	0.21	2.96	4.5	20.06	4.13
Fe ₂ O ₃ (T)	%	0.01	FUS-ICP	22.82	14.21	11.24	21.06	10.22	1.67	3.82	3.1	12.92	4.81
MnO	%	0.001	FUS-ICP	0.408	0.261	0.174	0.16	0.009	0.011	0.332	0.232	0.088	0.137
MgO	%	0.01	FUS-ICP	8.65	4.34	7.29	6.18	0.76	0.02	1.3	1.2	5.96	0.1
CaO	%	0.01	FUS-ICP	0.84	0.34	1.54	0.48	0.63	0.03	26.5	20.75	0.18	9.75
Na ₂ O	%	0.01	FUS-ICP	0.05	2.1	4.18	3.26	0.17	0.03	0.07	0.1	0.72	0.64
K ₂ O	%	0.01	FUS-ICP	1.31	4.37	1.84	1.49	4.65	0.04	0.36	0.79	3.76	1.54
TiO ₂	%	0.001	FUS-ICP	0.565	0.864	1.531	0.834	0.99	0.005	0.172	0.291	1.535	0.716
P ₂ O ₅	%	0.01	FUS-ICP	0.2	0.14	0.3	0.15	0.14	< 0.01	0.13	0.15	0.07	0.06
LOI	%		FUS-ICP	9.31	7.2	4.81	12.2	6.93	0.18	13.44	14.08	8.58	1.64
Total	%	0.01	FUS-ICP	98.2	98.66	99.53	98.02	98.9	100.9	90.99	96	97.85	88.17
Au	ppb	1	INAA	< 1	< 1	< 1	< 1	< 1	< 1	79	< 1	< 1	< 1
Ag	ppm	0.5	MULT INAA / TD-ICP	< 0.5	< 0.5	< 0.5	< 0.5	0.8	< 0.5	7.6	< 0.5	0.9	8
As	ppm	1	INAA	< 1	13	< 1	17	81	< 1	21	< 1	45	27
Ba	ppm	1	FUS-ICP	692	1990	1374	832	1854	371	2857	1564	4945	599
Be	ppm	1	FUS-ICP	< 1	1	1	< 1	< 1	< 1	< 1	< 1	1	464
Bi	ppm	0.1	FUS-MS	0.3	2.1	0.3	2.3	4.6	< 0.1	0.5	< 0.1	0.3	5.5
Br	ppm	0.5	INAA	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.7	< 0.5	0.8	< 0.5	< 0.5
Cd	ppm	0.5	TD-ICP	1	0.9	0.5	1.6	5.4	< 0.5	19.8	0.8	0.6	2220
Co	ppm	0.1	INAA	87.9	48.5	19	81.2	44.1	2.3	4.9	4.5	55.7	20.5
Cr	ppm	0.5	INAA	178	230	162	208	170	145	47.3	79.7	29.3	40.9
Cs	ppm	0.1	FUS-MS	0.5	1.8	0.6	0.5	1.6	< 0.1	< 0.1	0.1	1	0.1
Cu	ppm	1	TD-ICP	1150	669	36	304	116	58	603	92	208	1660
Ga	ppm	1	FUS-MS	14	16	26	18	16	< 1	4	6	23	5
Ge	ppm	0.5	FUS-MS	1.1	0.6	1.1	< 0.5	< 0.5	2.6	0.6	1.4	1.9	1
Hf	ppm	0.1	FUS-MS	0.8	1.3	2.3	1.3	1.5	0.1	0.8	1.1	2.9	0.2
Hg	ppm	1	INAA	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	3
In	ppm	0.1	FUS-MS	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.7
Ir	ppb	1	INAA	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1	< 1
Mo	ppm	2	FUS-MS	< 2	< 2	< 2	< 2	< 2	4	< 2	< 2	5	40
Nb	ppm	0.2	FUS-MS	2.7	3.9	7.2	4.6	4.7	0.3	2.7	4.6	14.7	0.9
Ni	ppm	1	TD-ICP	84	55	37	97	55	6	21	30	33	45
Pb	ppm	5	TD-ICP	18	25	< 5	22	9	< 5	892	14	8	24
Rb	ppm	1	FUS-MS	21	66	27	31	72	< 1	6	9	52	6
S	%	0.001	TD-ICP	3.57	4.7	1.02	10.1	7.47	0.035	1.8	0.514	5.44	1.3
Sb	ppm	0.1	INAA	0.4	1	0.7	1.1	1	0.4	3.5	0.6	1.4	5.3
Sc	ppm	0.01	INAA	32	45.4	67.9	40	46.2	0.49	4.52	6.95	63.7	2.38
Se	ppm	0.5	INAA	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1.5	< 0.5	12.3
Sn	ppm	1	FUS-MS	< 1	< 1	1	< 1	2	< 1	< 1	< 1	1	1
Sr	ppm	2	FUS-ICP	36	76	137	117	24	3	253	128	74	247
Ta	ppm	0.01	FUS-MS	0.16	0.23	0.44	0.18	0.32	0.01	0.16	0.28	0.91	0.04
Th	ppm	0.05	FUS-MS	0.28	0.43	1.12	0.6	0.6	< 0.05	0.95	1.79	1.31	0.08
U	ppm	0.01	FUS-MS	2.03	1.09	2.89	2.53	1.5	0.49	1.41	2.87	4.45	1.97
V	ppm	5	FUS-ICP	207	281	604	305	371	< 5	85	90	456	< 5
W	ppm	1	INAA	5	5	< 1	< 1	< 1	10	5	< 1	< 1	< 1
Y	ppm	1	FUS-ICP	23	20	51	22	21	1	23	29	20	3583
Zn	ppm	1	MULT INAA / TD-ICP	908	314	427	742	1810	154	4670	120	228>	100000
Zr	ppm	1	FUS-MS	29	46	84	51	60	9	32	47	122	12
La	ppm	0.05	FUS-MS	10.9	3.48	6.15	4.89	2.19	3.12	19.3	23.4	11.5	3.1
Ce	ppm	0.05	FUS-MS	20.1	7.68	14.1	10.5	5.64	5.33	14.6	20.9	20.3	4.2
Pr	ppm	0.01	FUS-MS	2.6	1.07	1.87	1.4	0.83	0.54	4.03	4.69	2.65	0.43
Nd	ppm	0.05	FUS-MS	11.8	5.38	8.56	5.95	4.51	1.92	17.8	18.3	10.8	1.34
Sm	ppm	0.01	FUS-MS	3.09	1.67	3.32	1.91	1.57	0.23	3.29	3.71	2.36	0.24
Eu	ppm	0.005	FUS-MS	1.38	0.558	0.845	0.366	0.311	0.058	0.677	0.825	0.651	0.515
Gd	ppm	0.01	FUS-MS	3.95	2.65	5.63	2.81	2.42	0.2	3.47	3.81	2.58	0.3
Tb	ppm	0.01	FUS-MS	0.75	0.52	1.22	0.62	0.53	0.02	0.55	0.64	0.54	0.05
Dy	ppm	0.01	FUS-MS	4.59	3.57	8.61	4.31	3.68	0.14	3.46	3.89	3.95	0.41
Ho	ppm	0.01	FUS-MS	0.95	0.79	1.9	0.92	0.88	0.03	0.71	0.82	0.89	0.1
Er	ppm	0.01	FUS-MS	2.75	2.44	5.76	2.75	2.75	0.12	2.09	2.34	2.82	0.32
Tl	ppm	0.05	FUS-MS	0.35	1.92	1.52	1.83	6.28	0.11	0.63	0.85	4.46	0.91
Tm	ppm	0.005	FUS-MS	0.387	0.372	0.884	0.422	0.421	0.023	0.305	0.331	0.431	0.05
Yb	ppm	0.01	FUS-MS	2.44	2.45	6.1	2.72	2.78	0.21	1.91	2.05	2.85	0.32
Lu	ppm	0.002	FUS-MS	0.371	0.38	0.956	0.424	0.454	0.054	0.3	0.332	0.475	0.049
Mass	g		INAA	1.495	1.49	1.656	1.949	1.469	1.266	1.873	1.645	1.383	1.59
C-Total	%	0.01	IR	< 0.01	< 0.01	0.03	0.23	0.01	< 0.01	5.56	4.29	0.03	4.34
Total S	%	0.01	IR	3.74	4.58	1.03	10.9	7.11	0.05	1.87	0.85	5.59	1.36
CO ₂	%	0.01	COUL	< 0.01	< 0.01	0.14	0.89	0.06	0.05	20.1	15.8	0.11	16.8
F	%	0.01	FUS-ISE	0.02	0.02	0.03	0.02	0.04	< 0.01	0.04	0.01	0.03	< 0.01
Hg	ppb	5	FIMS	12	35	< 5	< 5	8	10	172	< 5	10	6070

Table A.1. Whole rock geochemistry of low-sulfide rocks (cont.)

Analyte	Unit	D.L.	Method	NS9-18	NS11-01	NS11-02	NS11-11	NS11-13	NS11-14	NS11-15	NS11-16	NS11-22	NS11-23
SiO ₂	%	0.01	FUS-ICP	80.82	44.7	57.07	42.08	57.78	54.15	65.31	64.66	48.16	68.95
Al ₂ O ₃	%	0.01	FUS-ICP	5.88	15.69	21.12	4.87	15.45	14.49	8.63	9.57	16.35	11.34
Fe ₂ O ₃ (T)	%	0.01	FUS-ICP	4.78	16.17	7.09	2.68	7.84	14.19	11.76	11.04	7.06	7.41
MnO	%	0.001	FUS-ICP	0.042	0.159	0.01	0.672	0.049	0.008	0.008	0.017	0.043	0.011
MgO	%	0.01	FUS-ICP	1.4	6.23	1.07	0.56	1.52	0.58	0.35	0.48	0.84	0.71
CaO	%	0.01	FUS-ICP	1.51	1.32	0.1	25.58	1.72	0.27	0.41	0.05	2.71	0.19
Na ₂ O	%	0.01	FUS-ICP	0.1	4.73	0.28	0.07	0.26	0.88	2.08	0.16	0.88	0.22
K ₂ O	%	0.01	FUS-ICP	1.44	0.03	6.82	1.21	4.06	3.98	1.65	2.78	4.28	3.27
TiO ₂	%	0.001	FUS-ICP	0.305	0.69	0.767	0.282	1.554	1.325	0.94	0.823	1.673	0.778
P ₂ O ₅	%	0.01	FUS-ICP	0.1	0.09	0.06	0.12	0.26	0.18	0.05	0.01	0.07	0.09
LOI	%		FUS-ICP	4.5	7.92	6.17	15.36	6.24	8.73	6.8	7.52	7.07	5.1
Total	%	0.01	FUS-ICP	100.9	97.72	100.5	93.5	96.74	98.77	97.99	97.1	89.13	98.07
Au	ppb	1	INAA	25	15	<1	<1	12	35	38	23	95	17
Ag	ppm	0.5	MULT INAA / TD-ICP	4.9	<0.5	<0.5	2.6	0.8	3.1	2	0.6	37	0.8
As	ppm	1	INAA	23	11	35	129	24	31	84	108	611	83
Ba	ppm	1	FUS-ICP	7300	39	3103	5947	15240	10460	13070	8878	20580	5064
Be	ppm	1	FUS-ICP	3	<1	1	<1	<1	<1	<1	<1	<1	<1
Bi	ppm	0.1	FUS-MS	0.2	4.2	1.8	<0.1	0.8	0.1	2.2	0.1	<0.1	<0.1
Br	ppm	0.5	INAA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cd	ppm	0.5	TD-ICP	24.6	0.6	<0.5	8.6	5.8	8.7	9.8	10.5	174	1
Co	ppm	0.1	INAA	5.4	65.6	43.9	5.1	48.1	49.1	37.1	32.8	19.8	23
Cr	ppm	0.5	INAA	176	93	89.3	72	71.3	78	61.6	96.8	83.3	126
Cs	ppm	0.1	FUS-MS	1.6	<0.1	2.2	0.2	1.3	1.4	0.6	1	1.7	1.6
Cu	ppm	1	TD-ICP	1260	149	25	52	26	712	788	306	2390	52
Ga	ppm	1	FUS-MS	15	12	19	5	14	17	12	14	20	15
Ge	ppm	0.5	FUS-MS	1.6	<0.5	<0.5	0.5	1	0.9	1.2	0.7	0.6	0.7
Hf	ppm	0.1	FUS-MS	1.5	0.8	1.1	1.2	3.5	2.2	1.4	2	3.3	0.9
Hg	ppm	1	INAA	<1	<1	<1	<1	<1	<1	<1	<1	8	<1
In	ppm	0.1	FUS-MS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	ppb	1	INAA	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Mo	ppm	2	FUS-MS	<2	<2	5	<2	3	5	16	4	6	7
Nb	ppm	0.2	FUS-MS	3.7	2.5	2.9	3.8	10.1	6.8	4.4	3.6	13	3.3
Ni	ppm	1	TD-ICP	33	67	51	40	55	52	20	32	22	29
Pb	ppm	5	TD-ICP	499	<5	16	584	25	420	<5	9	126	62
Rb	ppm	1	FUS-MS	27	<1	98	15	55	56	22	40	63	52
S	%	0.001	TD-ICP	0.696	6.3	5.27	0.557	5.12	10.7	9.41	9.54	7.72	5.53
Sb	ppm	0.1	INAA	6.7	0.4	1.6	3.2	3.6	4.1	3.7	3.5	286	3.4
Sc	ppm	0.01	INAA	8.69	47.5	39.1	7.41	41.8	41.2	25.5	27.6	39.8	26.5
Se	ppm	0.5	INAA	4.1	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sn	ppm	1	FUS-MS	2	2	<1	<1	1	1	<1	<1	3	<1
Sr	ppm	2	FUS-ICP	70	94	40	161	67	74	217	24	250	34
Ta	ppm	0.01	FUS-MS	0.29	0.13	0.2	0.26	0.73	0.43	0.32	0.26	0.87	0.24
Th	ppm	0.05	FUS-MS	1.99	0.45	0.22	1.4	1.78	1.29	0.75	0.36	2.14	0.52
U	ppm	0.01	FUS-MS	2.4	1.45	2.4	2.16	3.12	2.54	1.59	1.07	4.84	3.3
V	ppm	5	FUS-ICP	148	262	333	112	325	394	270	257	426	317
W	ppm	1	INAA	13	<1	<1	<1	21	13	11	9	<1	10
Y	ppm	1	FUS-ICP	22	14	9	26	30	34	14	14	26	12
Zn	ppm	1	MULT INAA / TD-ICP	2920	180	55	1640	1050	2150	2470	2650	40400	240
Zr	ppm	1	FUS-MS	60	34	42	49	142	95	62	79	145	43
La	ppm	0.05	FUS-MS	10.1	2.17	0.37	22.1	11.8	11	3.66	7.19	4.98	1.71
Ce	ppm	0.05	FUS-MS	14.5	4.9	0.85	16.3	23.6	24.5	7.31	14.1	18.4	3.96
Pr	ppm	0.01	FUS-MS	2.36	0.72	0.15	4.48	3.4	3.59	1.01	1.8	2.65	0.64
Nd	ppm	0.05	FUS-MS	11	2.99	0.85	19.3	15.9	15	4.07	7.78	10.1	2.91
Sm	ppm	0.01	FUS-MS	2.82	1.25	0.42	3.6	4.26	4.65	1.17	1.68	2.55	1.16
Eu	ppm	0.005	FUS-MS	0.383	0.255	0.069	0.777	0.882	1.21	0.264	0.299	2.72	0.653
Gd	ppm	0.01	FUS-MS	3.57	1.83	0.81	3.63	5.04	5.25	1.58	2	3.18	1.65
Tb	ppm	0.01	FUS-MS	0.66	0.37	0.21	0.6	1	0.97	0.34	0.4	0.58	0.32
Dy	ppm	0.01	FUS-MS	4.05	2.47	1.68	3.43	6.5	6.24	2.36	2.53	3.8	1.97
Ho	ppm	0.01	FUS-MS	0.77	0.54	0.41	0.75	1.35	1.28	0.52	0.53	0.86	0.42
Er	ppm	0.01	FUS-MS	2.24	1.71	1.32	2.26	4.11	3.78	1.66	1.7	2.7	1.27
Tl	ppm	0.05	FUS-MS	10	0.05	8.95	3.55	4.02	1.89	1.93	10.6	12.9	3.87
Tm	ppm	0.005	FUS-MS	0.333	0.273	0.209	0.338	0.627	0.57	0.271	0.249	0.432	0.19
Yb	ppm	0.01	FUS-MS	2.17	1.86	1.38	2.26	4.18	3.84	1.86	1.67	3.03	1.26
Lu	ppm	0.002	FUS-MS	0.354	0.299	0.217	0.363	0.669	0.592	0.294	0.268	0.504	0.195
Mass	g		INAA	1.472	1.343	1.424	1.599	1.497	1.485	1.414	1.574	1.453	1.294
C-Total	%	0.01	IR	0.83	0.23	<0.01	5.57	0.29	0.01	0.06	0.06	0.31	0.03
Total S	%	0.01	IR	0.87	6.65	4.9	1.14	5.43	10.7	9.21	9.42	7.83	5.35
CO ₂	%	0.01	COUL	3.23	0.89	0.02	19.9	1.12	0.05	0.21	0.2	1.28	0.06
F	%	0.01	FUS-ISE	0.01	0.03	0.05	0.02	0.03	<0.01	<0.01	0.02	0.05	<0.01
Hg	ppb	5	FIMS	63	<5	17	94	151	293	458	276	7560	443

Table A.1. Whole rock geochemistry of low-sulfide rocks (cont.)

Analyte	Unit	D.L.	Method	NS11-24	NS11-25	NS11-26	NS13-01	NS13-02	NS13-03	NS13-06	NS13-07	NS13-12	NS13-13
SiO ₂	%	0.01	FUS-ICP	61.22	63.01	31.31	41.64	43.38	48.05	60.44	37.77	56.74	62.39
Al ₂ O ₃	%	0.01	FUS-ICP	7.82	11.78	14.54	16.38	16.43	14.97	11.15	15.88	14.3	11.54
Fe ₂ O ₃ (T)	%	0.01	FUS-ICP	16.47	11.65	28.78	8.94	17.32	16.81	13.25	24.48	13.89	12.22
MnO	%	0.001	FUS-ICP	0.008	0.013	0.448	0.272	0.216	0.03	0.011	0.01	0.01	0.042
MgO	%	0.01	FUS-ICP	0.38	0.62	9.07	4.68	7.73	1.25	0.51	0.68	0.62	1.85
CaO	%	0.01	FUS-ICP	0.15	0.28	0.67	11.26	0.66	0.4	0.29	0.36	0.4	0.28
Na ₂ O	%	0.01	FUS-ICP	0.16	0.21	0.05	3.26	3.91	0.85	0.3	0.41	1.19	0.21
K ₂ O	%	0.01	FUS-ICP	2.29	3.46	0.35	1.48	0.41	4.32	3.43	4.9	3.64	2.82
TiO ₂	%	0.001	FUS-ICP	0.447	0.991	0.559	0.778	1.114	0.825	0.416	0.583	0.719	0.509
P ₂ O ₅	%	0.01	FUS-ICP	0.07	0.17	0.09	0.16	0.19	0.02	<0.01	<0.01	0.09	0.07
LOI	%		FUS-ICP	9.31	7.82	12.39	10.34	7.01	10.08	8.18	14	8.16	7.18
Total	%	0.01	FUS-ICP	98.33	100	98.25	99.21	98.37	97.61	97.98	99.09	99.73	99.09
Au	ppb	1	INAA	24	<1	14	<1	<1	<1	36	56	70	<1
Ag	ppm	0.5	MULT INAA / TD-ICP	0.6	<0.5	<0.5	<0.5	0.7	2	0.9	1.7	4.6	<0.5
As	ppm	1	INAA	175	93	51	<1	<1	45	24	78	47	121
Ba	ppm	1	FUS-ICP	2886	3858	850	573	157	2866	4833	6616	7638	3314
Be	ppm	1	FUS-ICP	<1	<1	<1	<1	<1	1	1	1	1	<1
Bi	ppm	0.1	FUS-MS	0.9	0.3	<0.1	0.2	0.7	3.2	12.6	45	0.3	1.2
Br	ppm	0.5	INAA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Cd	ppm	0.5	TD-ICP	0.8	0.9	2	0.6	1.8	8.6	3.1	3.9	1.5	1.9
Co	ppm	0.1	INAA	26.3	30.4	41.9	17.1	75.1	35.7	31.3	81.1	38.6	22.9
Cr	ppm	0.5	INAA	136	75.8	74.5	205	227	132	140	175	146	145
Cs	ppm	0.1	FUS-MS	1.2	1.9	0.3	1	1.3	1.5	1.3	1.8	1.1	1.1
Cu	ppm	1	TD-ICP	89	60	271	34	664	2490	912	736	2250	158
Ga	ppm	1	FUS-MS	9	13	15	12	16	17	13	16	15	13
Ge	ppm	0.5	FUS-MS	0.6	0.7	1.1	1.1	0.6	0.6	0.8	0.8	0.9	0.6
Hf	ppm	0.1	FUS-MS	0.6	2.7	1.1	1.2	1.8	1.1	0.5	0.8	1	0.7
Hg	ppm	1	INAA	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
In	ppm	0.1	FUS-MS	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ir	ppb	1	INAA	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Mo	ppm	2	FUS-MS	17	5	<2	<2	<2	4	7	46	12	2
Nb	ppm	0.2	FUS-MS	1.9	7.2	2.7	3.8	6.6	3.9	2	3.1	3.9	2.1
Ni	ppm	1	TD-ICP	28	27	46	29	80	67	37	68	47	39
Pb	ppm	5	TD-ICP	16	<5	14	<5	<5	9	<5	9	<5	27
Rb	ppm	1	FUS-MS	37	64	11	31	10	69	56	74	54	44
S	%	0.001	TD-ICP	13.2	8.93	10	0.58	4.92	12	10.4	18.8	9.99	8.4
Sb	ppm	0.1	INAA	4.3	2	1.8	<0.1	0.8	1.7	1.7	4.7	3.2	4.7
Sc	ppm	0.01	INAA	19.9	26.9	29.7	38.4	51.6	45.3	22.3	31.6	33.3	27.7
Se	ppm	0.5	INAA	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
Sn	ppm	1	FUS-MS	<1	<1	<1	<1	1	<1	1	2	<1	<1
Sr	ppm	2	FUS-ICP	23	39	30	295	102	69	36	46	93	29
Ta	ppm	0.01	FUS-MS	0.14	0.51	0.16	0.21	0.42	0.23	0.14	0.2	0.24	0.16
Th	ppm	0.05	FUS-MS	0.39	1.8	0.52	0.4	0.75	0.47	2.27	1.06	0.45	0.37
U	ppm	0.01	FUS-MS	1.14	2.66	0.67	0.38	1.87	2.06	2.65	3.37	2.75	0.83
V	ppm	5	FUS-ICP	161	224	195	214	353	281	194	244	250	221
W	ppm	1	INAA	9	8	<1	<1	<1	9	14	<1	12	9
Y	ppm	1	FUS-ICP	15	63	7	22	37	15	6	8	12	9
Zn	ppm	1	MULT INAA / TD-ICP	82	80	632	254	634	3870	407	666	244	284
Zr	ppm	1	FUS-MS	28	101	41	42	72	47	23	35	44	30
La	ppm	0.05	FUS-MS	2.74	14.8	9.16	5.75	3.5	3.86	18.4	6.74	3.97	1.9
Ce	ppm	0.05	FUS-MS	5.45	33.1	16.3	11.9	8.2	7.76	34.2	12.7	8.27	4.24
Pr	ppm	0.01	FUS-MS	0.77	4.42	2.05	1.63	1.29	1.01	4.09	1.53	1.17	0.63
Nd	ppm	0.05	FUS-MS	3.55	19.8	8.83	7.61	6.88	4	14	5.27	4.84	2.77
Sm	ppm	0.01	FUS-MS	1.2	6.32	2.34	1.96	2.64	1.29	2.34	0.94	1.41	0.92
Eu	ppm	0.005	FUS-MS	0.254	0.99	0.602	0.774	0.796	0.315	0.407	0.221	0.312	0.153
Gd	ppm	0.01	FUS-MS	2.04	9.37	2.98	2.76	4.23	1.76	1.52	0.98	1.61	1.35
Tb	ppm	0.01	FUS-MS	0.41	2.04	0.56	0.55	0.9	0.37	0.2	0.2	0.34	0.25
Dy	ppm	0.01	FUS-MS	2.66	13.1	3.5	3.7	5.95	2.62	1.12	1.35	2.28	1.64
Ho	ppm	0.01	FUS-MS	0.57	2.72	0.74	0.82	1.34	0.59	0.23	0.32	0.51	0.34
Er	ppm	0.01	FUS-MS	1.71	7.84	2.15	2.54	4.12	1.84	0.72	1.02	1.6	1.06
Tl	ppm	0.05	FUS-MS	2.92	7.65	1.36	0.78	0.59	2.08	4.16	7.65	1.31	0.92
Tm	ppm	0.005	FUS-MS	0.253	1.12	0.332	0.373	0.606	0.286	0.108	0.166	0.238	0.163
Yb	ppm	0.01	FUS-MS	1.63	6.72	2.11	2.44	3.94	1.97	0.75	1.14	1.58	1.11
Lu	ppm	0.002	FUS-MS	0.251	0.963	0.337	0.403	0.628	0.323	0.121	0.183	0.251	0.184
Mass	g		INAA	1.323	1.544	1.597	1.354	1.484	1.497	1.517	1.557	1.468	1.442
C-Total	%	0.01	IR	0.03	<0.01	0.04	2.25	0.04	0.11	0.01	0.01	0.02	0.05
Total S	%	0.01	IR	12.6	8.76	10.6	0.56	4.95	12.2	9.98	18.7	9.66	7.81
CO ₂	%	0.01	COUL	0.05	0.03	0.12	7.98	0.16	0.4	<0.01	0.03	0.13	0.22
F	%	0.01	FUS-ISE	<0.01	0.03	<0.01	0.01	0.05	<0.01	<0.01	<0.01	<0.01	<0.01
Hg	ppb	5	FIMS	199	20	66	<5	<5	39	53	265	59	56

Table A.1. Whole rock geochemistry of low-sulfide rocks (cont.)

Analyte	Unit	D.L.	Method	NS13-14	NS13-15	NS13-16	NS13-17	NS13-18	NS13-19
SiO ₂	%	0.01	FUS-ICP	50.98	41.37	59.34	54.36	49.85	61.15
Al ₂ O ₃	%	0.01	FUS-ICP	22.17	16.14	10.32	11.34	6.98	10.7
Fe ₂ O ₃ (T)	%	0.01	FUS-ICP	7.96	18.81	15.16	18.43	24.55	13.82
MnO	%	0.001	FUS-ICP	0.068	0.128	0.012	0.013	0.007	0.008
MgO	%	0.01	FUS-ICP	2.54	3.04	0.42	0.55	0.34	0.46
CaO	%	0.01	FUS-ICP	0.73	1.19	0.31	0.46	0.36	0.33
Na ₂ O	%	0.01	FUS-ICP	0.54	0.71	0.26	0.23	0.37	0.25
K ₂ O	%	0.01	FUS-ICP	5.67	3.28	2.88	3.21	1.85	3.26
TiO ₂	%	0.001	FUS-ICP	1.422	1.467	0.731	0.625	0.497	0.964
P ₂ O ₅	%	0.01	FUS-ICP	0.2	0.17	0.1	0.09	0.07	0.16
LOI	%		FUS-ICP	6.12	11.83	8.88	10.45	13.03	8.2
Total	%	0.01	FUS-ICP	98.41	98.14	98.4	99.76	97.9	99.31
Au	ppb	1	INAA	< 1	< 1	33	30	48	29
Ag	ppm	0.5	MULT INAA / TD-ICP	0.6	< 0.5	3.2	0.6	3	0.5
As	ppm	1	INAA	24	18	15	87	77	55
Ba	ppm	1	FUS-ICP	5554	3933	4141	2033	5184	1331
Be	ppm	1	FUS-ICP	< 1	< 1	< 1	< 1	< 1	< 1
Bi	ppm	0.1	FUS-MS	< 0.1	0.9	6.9	0.9	1.6	0.8
Br	ppm	0.5	INAA	< 0.5	< 0.5	< 0.5	< 0.5	1.6	< 0.5
Cd	ppm	0.5	TD-ICP	3.4	1.4	0.8	1.8	7.9	0.8
Co	ppm	0.1	INAA	71.6	27	53.2	39.8	33	43.8
Cr	ppm	0.5	INAA	245	175	114	101	132	59.6
Cs	ppm	0.1	FUS-MS	2.1	1.1	0.9	0.9	0.5	0.9
Cu	ppm	1	TD-ICP	160	170	1880	166	5870	43
Ga	ppm	1	FUS-MS	24	18	13	13	11	15
Ge	ppm	0.5	FUS-MS	0.6	1	0.5	0.6	0.6	0.5
Hf	ppm	0.1	FUS-MS	2.2	2.8	1	1	0.8	1.8
Hg	ppm	1	INAA	< 1	< 1	< 1	< 1	< 1	< 1
In	ppm	0.1	FUS-MS	0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1
Ir	ppb	1	INAA	< 1	< 1	< 1	< 1	< 1	< 1
Mo	ppm	2	FUS-MS	2	< 2	22	6	18	11
Nb	ppm	0.2	FUS-MS	6.1	9.5	3.6	3.6	2.5	6.5
Ni	ppm	1	TD-ICP	93	32	45	45	29	33
Pb	ppm	5	TD-ICP	15	8	196	< 5	7	15
Rb	ppm	1	FUS-MS	77	46	42	47	30	52
S	%	0.001	TD-ICP	3.75	10.4	11.9	14	19.1	10.3
Sb	ppm	0.1	INAA	2.8	2.6	2.1	3.8	3.2	3.1
Sc	ppm	0.01	INAA	70.2	57.7	33.3	34.4	20.9	33.2
Se	ppm	0.5	INAA	< 0.5	< 0.5	9.3	< 0.5	< 0.5	< 0.5
Sn	ppm	1	FUS-MS	1	1	< 1	< 1	< 1	< 1
Sr	ppm	2	FUS-ICP	91	77	37	40	38	42
Ta	ppm	0.01	FUS-MS	0.39	0.58	0.25	0.22	0.18	0.42
Th	ppm	0.05	FUS-MS	0.76	1.65	0.72	0.79	0.44	1.69
U	ppm	0.01	FUS-MS	2.12	1.14	1.14	1.07	1.71	1.53
V	ppm	5	FUS-ICP	607	465	371	249	215	338
W	ppm	1	INAA	< 1	< 1	10	< 1	< 1	13
Y	ppm	1	FUS-ICP	34	32	11	20	10	28
Zn	ppm	1	MULT INAA / TD-ICP	970	291	56	75	1640	43
Zr	ppm	1	FUS-MS	85	120	46	47	33	84
La	ppm	0.05	FUS-MS	4.73	5.17	3.34	1.55	1.26	10.7
Ce	ppm	0.05	FUS-MS	10.1	10.6	7.17	3.31	2.92	23.2
Pr	ppm	0.01	FUS-MS	1.45	1.43	0.96	0.47	0.44	2.83
Nd	ppm	0.05	FUS-MS	7.13	5.94	3.82	2.03	1.97	11.8
Sm	ppm	0.01	FUS-MS	2.36	2.13	1.17	0.8	0.79	3.16
Eu	ppm	0.005	FUS-MS	0.727	0.644	0.217	0.164	0.229	0.56
Gd	ppm	0.01	FUS-MS	3.77	3.78	1.48	1.64	1.18	3.94
Tb	ppm	0.01	FUS-MS	0.83	0.85	0.29	0.41	0.26	0.77
Dy	ppm	0.01	FUS-MS	5.82	5.93	1.95	3.1	1.79	4.95
Ho	ppm	0.01	FUS-MS	1.28	1.31	0.43	0.74	0.4	1.07
Er	ppm	0.01	FUS-MS	3.97	3.78	1.34	2.31	1.25	3.18
Tl	ppm	0.05	FUS-MS	2.97	1.17	0.61	1	1.6	0.37
Tm	ppm	0.005	FUS-MS	0.595	0.564	0.216	0.353	0.194	0.477
Yb	ppm	0.01	FUS-MS	3.87	3.66	1.47	2.27	1.28	3.18
Lu	ppm	0.002	FUS-MS	0.613	0.568	0.234	0.363	0.203	0.481
Mass	g		INAA	1.344	1.725	1.396	1.386	1.663	1.511
C-Total	%	0.01	IR	0.06	1.2	0.04	0.07	< 0.01	0.01
Total S	%	0.01	IR	3.96	10.9	11.4	13.9	19.5	10.2
CO ₂	%	0.01	COUL	0.33	1.26	0.13	0.26	0.13	< 0.01
F	%	0.01	FUS-ISE	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Hg	ppb	5	FIMS	39	13	23	22	1210	21

Table A.2. Whole rock geochemistry of sulfide-rich rocks

Analyte	Unit	D.L.	Method	NS9-06	NS9-07	NS9-08	NS9-09	NS9-10	NS9-11	NS9-17	NS11-03	NS11-04
CO ₂	%	0.01	COUL	0.03	< 0.01	< 0.01	< 0.01	< 0.01	0.02	13	9.34	0.03
Hg	ppb	5	FIMS	43	137	11600	723	869	13000	12300	63	11000
Cu	ppm	2	FUS-MS-Na ₂ O ₂	4340	102	17400	14600	38800	2450	330	17100	6680
Ni	ppm	10	FUS-MS-Na ₂ O ₂	10	40	< 10	< 10	< 10	< 10	< 10	30	< 10
Cr	ppm	30	FUS-MS-Na ₂ O ₂	110	270	60	< 30	< 30	< 30	40	200	< 30
Co	ppm	0.2	FUS-MS-Na ₂ O ₂	3.4	26.2	1.6	33.5	129	10	6.7	1.5	3.9
Se	ppm	0.8	FUS-MS-Na ₂ O ₂	8.3	6.5	9	11	8	14.5	19.2	16.5	23
Zn	ppm	30	FUS-MS-Na ₂ O ₂	590	250	91600	38100	19400	141000	137000	1570	229000
Pb	ppm	0.8	FUS-MS-Na ₂ O ₂	7.1	45.3	9060	188	278	14500	1020	9.6	16400
Ag	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	240	130	40	240	20	< 10	80
Cd	ppm	2	FUS-MS-Na ₂ O ₂	7	< 2	371	165	68	544	1420	27	1420
As	ppm	5	FUS-MS-Na ₂ O ₂	< 5	116	1200	363	485	451	< 5	< 5	707
Sn	ppm	0.5	FUS-MS-Na ₂ O ₂	0.7	< 0.5	1	< 0.5	< 0.5	6.6	< 0.5	0.8	< 0.5
Sb	ppm	2	FUS-MS-Na ₂ O ₂	< 2	8	850	104	39	514	20	< 2	192
Mo	ppm	1	FUS-MS-Na ₂ O ₂	20	36	8	14	47	42	< 1	120	13
B	ppm	10	FUS-MS-Na ₂ O ₂	50	60	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Li	ppm	3	FUS-MS-Na ₂ O ₂	4	6	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Be	ppm	3	FUS-MS-Na ₂ O ₂	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
V	ppm	5	FUS-MS-Na ₂ O ₂	384	407	142	50	21	45	< 5	38	< 5
Mn	ppm	3	FUS-MS-Na ₂ O ₂	79	75	47	8	18	38	3380	2320	79
Ga	ppm	0.2	FUS-MS-Na ₂ O ₂	22	19.3	10.7	4.4	0.8	8.9	1.2	1.4	10
Ge	ppm	0.7	FUS-MS-Na ₂ O ₂	7.5	4.6	3	3	6.8	< 0.7	1.6	7.9	< 0.7
Rb	ppm	0.4	FUS-MS-Na ₂ O ₂	93.7	96.9	3.1	< 0.4	< 0.4	0.9	0.4	1.6	< 0.4
Sr	ppm	3	FUS-MS-Na ₂ O ₂	35	47	3570	4620	1570	4820	587	112	3250
Y	ppm	0.1	FUS-MS-Na ₂ O ₂	8	6.2	3.1	0.7	3.8	0.8	5.5	2.9	1
Nb	ppm	2.4	FUS-MS-Na ₂ O ₂	3.1	4.1	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4
In	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	6.2	3.9	3.5	1.9	0.9	0.9	0.8
Te	ppm	6	FUS-MS-Na ₂ O ₂	< 6	< 6	< 6	< 6	< 6	< 6	8	< 6	< 6
Cs	ppm	0.1	FUS-MS-Na ₂ O ₂	1.6	1.6	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Ba	ppm	3	FUS-MS-Na ₂ O ₂	19100	14100	8420	8760	4300	54500	398	949	3390
La	ppm	0.4	FUS-MS-Na ₂ O ₂	< 0.4	2.6	19.4	17.5	2.4	3.7	2.3	4	1.9
Ce	ppm	0.8	FUS-MS-Na ₂ O ₂	< 0.8	4.3	27.4	24.6	4.3	2.2	2.8	5.1	2
Pr	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	0.4	3.7	2.5	0.5	0.1	0.4	0.6	0.2
Nd	ppm	0.4	FUS-MS-Na ₂ O ₂	< 0.4	2.1	12.5	7.4	2.2	< 0.4	1.7	2.2	0.9
Sm	ppm	0.1	FUS-MS-Na ₂ O ₂	0.3	0.4	2.9	1.1	0.6	0.3	0.6	0.6	0.2
Eu	ppm	0.1	FUS-MS-Na ₂ O ₂	0.2	0.2	1.3	0.5	< 0.1	< 0.1	0.3	2.4	0.2
Gd	ppm	0.1	FUS-MS-Na ₂ O ₂	0.5	0.6	1.3	0.7	0.5	0.4	0.6	0.5	0.2
Tb	ppm	0.1	FUS-MS-Na ₂ O ₂	0.1	0.1	0.1	< 0.1	0.1	< 0.1	0.1	< 0.1	< 0.1
Dy	ppm	0.3	FUS-MS-Na ₂ O ₂	1.2	1	0.7	< 0.3	0.7	< 0.3	0.7	0.5	< 0.3
Ho	ppm	0.2	FUS-MS-Na ₂ O ₂	0.3	0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
Er	ppm	0.1	FUS-MS-Na ₂ O ₂	1.2	0.8	0.4	< 0.1	0.5	< 0.1	0.4	0.3	< 0.1
Tm	ppm	0.1	FUS-MS-Na ₂ O ₂	0.2	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Yb	ppm	0.1	FUS-MS-Na ₂ O ₂	1.9	1.2	0.7	0.4	0.5	2.8	0.3	0.3	0.2
Hf	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Ta	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
W	ppm	0.7	FUS-MS-Na ₂ O ₂	2	4.6	3.1	3.6	2.1	< 0.7	3.7	2.4	< 0.7
Tl	ppm	0.1	FUS-MS-Na ₂ O ₂	48.1	66.3	21.7	9.7	8	11.3	0.8	0.2	2.7
Bi	ppm	2	FUS-MS-Na ₂ O ₂	< 2	< 2	6	30	14	39	129	< 2	13
Th	ppm	0.1	FUS-MS-Na ₂ O ₂	0.5	0.6	0.5	< 0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1
U	ppm	0.1	FUS-MS-Na ₂ O ₂	7.1	6.6	5.5	2.4	7.8	2.8	0.8	25.6	2.7
Al	%	0.01	FUS-Na ₂ O ₂	11.4	12	0.46	0.02	0.02	0.04	< 0.01	0.5	0.01
Ca	%	0.01	FUS-Na ₂ O ₂	0.31	0.38	0.14	< 0.01	< 0.01	0.1	11.5	7.81	0.07
Fe	%	0.05	FUS-Na ₂ O ₂	20.3	13.7	2.92	4.37	25	6.29	2.39	37.1	3.39
K	%	0.1	FUS-Na ₂ O ₂	4.8	5.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Mg	%	0.01	FUS-Na ₂ O ₂	0.54	0.57	0.03	< 0.01	< 0.01	0.02	0.24	0.51	0.05
P	%	0.005	FUS-Na ₂ O ₂	< 0.005	< 0.005	0.011	0.008	0.018	< 0.005	0.104	0.036	0.014
S	%	0.01	FUS-ICP	11.8	13.7	8.47	7.76	28.1	16	7.92	22.6	14.6
Si	%	0.01	FUS-Na ₂ O ₂	13.5	14.7	3.2	0.03	0.04	0.26	20.9	6.36	0.02
Ti	%	0.01	FUS-Na ₂ O ₂	0.52	0.57	0.03	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01

Table A.2. Whole rock geochemistry of sulfide-rich rocks (cont.)

Analyte	Unit	D.L.	Method	NS11-05	NS11-06	NS11-07	NS11-08	NS11-09	NS11-10	NS11-12	NS11-17	NS11-18
CO ₂	%	0.01	COUL	< 0.01	< 0.01	< 0.01	7.16	0.03	20.3	4.21	6.58	< 0.01
Hg	ppb	5	FIMS	11200	3790	4600	1340	4370	1570	11800	936	12300
Cu	ppm	2	FUS-MS-Na ₂ O ₂	4260	1060	107000	18300	3170	6470	940	76600	3300
Ni	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	20	< 10	< 10	10	< 10	10	< 10
Cr	ppm	30	FUS-MS-Na ₂ O ₂	< 30	70	< 30	40	90	< 30	80	80	130
Co	ppm	0.2	FUS-MS-Na ₂ O ₂	1.2	2.3	175	69.4	3.5	45.7	3.2	19.2	4.8
Se	ppm	0.8	FUS-MS-Na ₂ O ₂	8.1	10	10.5	10.9	17.9	21.9	4.7	10.5	15.7
Zn	ppm	30	FUS-MS-Na ₂ O ₂	67500	106000	40900	28100	113000	118000	29200	7530	133000
Pb	ppm	0.8	FUS-MS-Na ₂ O ₂	21200	127	922	333	1610	57	8320	12.8	943
Ag	ppm	10	FUS-MS-Na ₂ O ₂	120	30	130	80	50	40	30	90	80
Cd	ppm	2	FUS-MS-Na ₂ O ₂	357	357	132	107	482	1130	114	68	564
As	ppm	5	FUS-MS-Na ₂ O ₂	23	240	2780	399	1180	< 5	5	< 5	815
Sn	ppm	0.5	FUS-MS-Na ₂ O ₂	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	1	11.2
Sb	ppm	2	FUS-MS-Na ₂ O ₂	105	50	280	142	194	< 2	28	3	203
Mo	ppm	1	FUS-MS-Na ₂ O ₂	6	21	129	50	14	37	7	64	54
B	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Li	ppm	3	FUS-MS-Na ₂ O ₂	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
Be	ppm	3	FUS-MS-Na ₂ O ₂	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
V	ppm	5	FUS-MS-Na ₂ O ₂	< 5	< 5	16	< 5	< 5	< 5	17	< 5	< 5
Mn	ppm	3	FUS-MS-Na ₂ O ₂	18	68	54	32	93	5590	907	1930	89
Ga	ppm	0.2	FUS-MS-Na ₂ O ₂	2.9	4.4	2.1	2.5	3.5	2.1	4.7	1.4	12.3
Ge	ppm	0.7	FUS-MS-Na ₂ O ₂	< 0.7	< 0.7	10.1	8.1	3.3	1.7	< 0.7	3.3	4.8
Rb	ppm	0.4	FUS-MS-Na ₂ O ₂	< 0.4	< 0.4	< 0.4	0.7	< 0.4	2	4.4	0.6	< 0.4
Sr	ppm	3	FUS-MS-Na ₂ O ₂	4330	3660	75	257	2220	677	1050	151	2590
Y	ppm	0.1	FUS-MS-Na ₂ O ₂	0.3	< 0.1	6.5	0.2	0.4	4.9	5.5	2.6	0.6
Nb	ppm	2.4	FUS-MS-Na ₂ O ₂	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4
In	ppm	0.2	FUS-MS-Na ₂ O ₂	1.1	2.8	7.4	2.4	0.9	7	< 0.2	0.3	< 0.2
Te	ppm	6	FUS-MS-Na ₂ O ₂	< 6	< 6	< 6	< 6	< 6	< 6	< 6	< 6	< 6
Cs	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1
Ba	ppm	3	FUS-MS-Na ₂ O ₂	11600	6840	1940	2460	2400	1430	19200	7840	7170
La	ppm	0.4	FUS-MS-Na ₂ O ₂	6.3	1.9	7.9	0.5	2.9	14.8	5	1	26.3
Ce	ppm	0.8	FUS-MS-Na ₂ O ₂	6.9	< 0.8	15.2	1	3	17.1	5.7	1.7	60.3
Pr	ppm	0.1	FUS-MS-Na ₂ O ₂	0.6	< 0.1	1.7	< 0.1	0.2	1.6	0.7	0.2	6.7
Nd	ppm	0.4	FUS-MS-Na ₂ O ₂	1.4	< 0.4	8	< 0.4	0.5	6	4	1.1	28.5
Sm	ppm	0.1	FUS-MS-Na ₂ O ₂	0.2	< 0.1	1.4	< 0.1	0.1	1	0.8	0.3	3.1
Eu	ppm	0.1	FUS-MS-Na ₂ O ₂	0.3	< 0.1	0.3	< 0.1	0.2	0.8	0.6	0.3	0.4
Gd	ppm	0.1	FUS-MS-Na ₂ O ₂	0.2	< 0.1	1.1	< 0.1	0.1	0.8	0.9	0.3	1
Tb	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.1	0.2	< 0.1	< 0.1
Dy	ppm	0.3	FUS-MS-Na ₂ O ₂	< 0.3	< 0.3	1.3	< 0.3	< 0.3	0.9	0.9	0.4	< 0.3
Ho	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	0.3	< 0.2	< 0.2	< 0.2	0.2	< 0.2	< 0.2
Er	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	0.7	< 0.1	< 0.1	0.5	0.6	0.3	0.1
Tm	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
Yb	ppm	0.1	FUS-MS-Na ₂ O ₂	0.6	0.3	0.5	0.2	0.2	0.5	1.4	0.6	0.3
Hf	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Ta	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	0.4
W	ppm	0.7	FUS-MS-Na ₂ O ₂	< 0.7	< 0.7	8.7	1	< 0.7	20.9	3.7	4.2	220
Tl	ppm	0.1	FUS-MS-Na ₂ O ₂	4.9	4.4	31	15.6	2	0.2	3.2	1.2	1
Bi	ppm	2	FUS-MS-Na ₂ O ₂	< 2	3	51	35	6	6	< 2	< 2	4
Th	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1	0.3	0.3	1.4
U	ppm	0.1	FUS-MS-Na ₂ O ₂	1.3	0.7	14.3	2.7	1.1	1.8	1.4	3	5.6
Al	%	0.01	FUS-Na ₂ O ₂	< 0.01	0.05	0.03	0.06	< 0.01	0.25	0.89	0.4	0.01
Ca	%	0.01	FUS-Na ₂ O ₂	0.04	0.01	< 0.01	< 0.01	< 0.01	18.6	3.75	3.66	0.18
Fe	%	0.05	FUS-Na ₂ O ₂	1.7	6.97	39.9	43	21.8	17.5	3.58	16.7	2.72
K	%	0.1	FUS-Na ₂ O ₂	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1
Mg	%	0.01	FUS-Na ₂ O ₂	< 0.01	0.04	< 0.01	0.01	0.02	0.28	0.16	0.11	0.05
P	%	0.005	FUS-Na ₂ O ₂	< 0.005	< 0.005	0.054	0.011	< 0.005	< 0.005	< 0.005	0.039	< 0.005
S	%	0.01	FUS-ICP	6.88	13.5	44.5	47.2	29.2	16.9	6.24	11.3	9.47
Si	%	0.01	FUS-Na ₂ O ₂	0.04	0.22	0.18	0.35	0.13	1.38	25.3	21.7	8.28
Ti	%	0.01	FUS-Na ₂ O ₂	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.04	0.02	< 0.01

Table A.2. Whole rock geochemistry of sulfide-rich rocks (cont.)

Analyte	Unit	D.L.	Method	NS11-19	NS11-20	NS11-21	NS13-04	NS13-05	NS13-08	NS13-09	NS13-10	NS13-11
CO ₂	%	0.01	COUL	< 0.01	< 0.01	0.01	0.08	0.37	0.17	4.86	6.26	1.18
Hg	ppb	5	FIMS	12900	7170	3240	157	254	1290	1390	197	426
Cu	ppm	2	FUS-MS-Na ₂ O ₂	16800	4830	29200	38900	72300	15800	9270	7020	2500
Ni	ppm	10	FUS-MS-Na ₂ O ₂	40	< 10	< 10	< 10	20	30	10	20	40
Cr	ppm	30	FUS-MS-Na ₂ O ₂	90	90	250	100	50	110	70	150	200
Co	ppm	0.2	FUS-MS-Na ₂ O ₂	7.1	4.8	1.9	28	34.8	1.7	8	7.1	34.8
Se	ppm	0.8	FUS-MS-Na ₂ O ₂	22.5	23.2	9.1	14.9	20.5	11	32.8	14.9	24.1
Zn	ppm	30	FUS-MS-Na ₂ O ₂	113000	66500	7070	1360	3210	2010	22800	580	3090
Pb	ppm	0.8	FUS-MS-Na ₂ O ₂	5690	19600	3650	10.1	6.8	193	140	385	71.6
Ag	ppm	10	FUS-MS-Na ₂ O ₂	190	100	340	30	60	20	20	30	20
Cd	ppm	2	FUS-MS-Na ₂ O ₂	618	462	36	38	115	7	72	3	14
As	ppm	5	FUS-MS-Na ₂ O ₂	705	523	3390	< 5	< 5	< 5	< 5	< 5	< 5
Sn	ppm	0.5	FUS-MS-Na ₂ O ₂	< 0.5	< 0.5	< 0.5	3.2	23.6	< 0.5	1.4	2.1	< 0.5
Sb	ppm	2	FUS-MS-Na ₂ O ₂	517	157	132	< 2	< 2	4	< 2	29	16
Mo	ppm	1	FUS-MS-Na ₂ O ₂	62	19	10	51	57	41	27	30	65
B	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	30
Li	ppm	3	FUS-MS-Na ₂ O ₂	< 3	< 3	< 3	3	< 3	< 3	< 3	< 3	3
Be	ppm	3	FUS-MS-Na ₂ O ₂	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3	< 3
V	ppm	5	FUS-MS-Na ₂ O ₂	57	47	57	138	136	< 5	< 5	25	179
Mn	ppm	3	FUS-MS-Na ₂ O ₂	64	31	30	133	112	31	1890	1370	256
Ga	ppm	0.2	FUS-MS-Na ₂ O ₂	19.4	16.8	3.6	6.3	6.8	0.5	1.1	4.3	16
Ge	ppm	0.7	FUS-MS-Na ₂ O ₂	9.7	3.8	4.4	5.7	6	2.6	2.1	2.8	1.9
Rb	ppm	0.4	FUS-MS-Na ₂ O ₂	< 0.4	0.6	4	19.2	15.9	< 0.4	< 0.4	1.6	50.4
Sr	ppm	3	FUS-MS-Na ₂ O ₂	2220	3590	114	76	24	2450	1850	1800	103
Y	ppm	0.1	FUS-MS-Na ₂ O ₂	0.7	1.2	2.1	4.5	17	0.4	4.1	12.5	6.9
Nb	ppm	2.4	FUS-MS-Na ₂ O ₂	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4	< 2.4
In	ppm	0.2	FUS-MS-Na ₂ O ₂	2.4	< 0.2	< 0.2	0.6	6.2	0.9	0.7	0.2	< 0.2
Te	ppm	6	FUS-MS-Na ₂ O ₂	< 6	< 6	< 6	< 6	< 6	< 6	< 6	< 6	< 6
Cs	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	0.1	0.4	0.3	< 0.1	0.3	< 0.1	1.3
Ba	ppm	3	FUS-MS-Na ₂ O ₂	1980	10500	20200	1550	2510	2070	2110	2550	10900
La	ppm	0.4	FUS-MS-Na ₂ O ₂	87.5	7	5.2	25.3	7.2	4.1	3	14.1	3.6
Ce	ppm	0.8	FUS-MS-Na ₂ O ₂	251	7	6.5	129	14.9	6.5	4.9	30.1	6.5
Pr	ppm	0.1	FUS-MS-Na ₂ O ₂	25.2	0.7	0.9	15.1	2.1	0.8	0.7	4	0.8
Nd	ppm	0.4	FUS-MS-Na ₂ O ₂	139	2.6	3.2	95.9	8.8	3.1	3.4	17.2	3.1
Sm	ppm	0.1	FUS-MS-Na ₂ O ₂	13.6	0.4	0.5	14.4	2.1	0.5	0.8	4.6	0.8
Eu	ppm	0.1	FUS-MS-Na ₂ O ₂	1.5	0.2	< 0.1	1.6	0.6	< 0.1	0.2	2.1	0.2
Gd	ppm	0.1	FUS-MS-Na ₂ O ₂	3	0.2	0.4	3.4	2.1	0.3	0.8	4.2	0.8
Tb	ppm	0.1	FUS-MS-Na ₂ O ₂	0.1	< 0.1	< 0.1	0.2	0.4	< 0.1	0.1	0.7	0.2
Dy	ppm	0.3	FUS-MS-Na ₂ O ₂	0.3	< 0.3	0.3	1	2.7	< 0.3	0.6	3	1.1
Ho	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	< 0.2	< 0.2	0.6	< 0.2	< 0.2	0.5	0.3
Er	ppm	0.1	FUS-MS-Na ₂ O ₂	0.3	0.2	0.3	0.7	1.6	< 0.1	0.3	1.1	0.8
Tm	ppm	0.1	FUS-MS-Na ₂ O ₂	< 0.1	< 0.1	< 0.1	< 0.1	0.2	< 0.1	< 0.1	0.1	0.1
Yb	ppm	0.1	FUS-MS-Na ₂ O ₂	0.2	0.6	1	0.6	1.3	0.1	0.3	0.8	1.2
Hf	ppm	10	FUS-MS-Na ₂ O ₂	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10	< 10
Ta	ppm	0.2	FUS-MS-Na ₂ O ₂	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2	< 0.2
W	ppm	0.7	FUS-MS-Na ₂ O ₂	4.8	12.6	7.6	7.1	2.8	1.4	2.4	3.6	6
Tl	ppm	0.1	FUS-MS-Na ₂ O ₂	3.7	4.9	8.7	2.5	6.1	2.3	0.2	4.8	10
Bi	ppm	2	FUS-MS-Na ₂ O ₂	2	< 2	< 2	4	11	< 2	< 2	7	< 2
Th	ppm	0.1	FUS-MS-Na ₂ O ₂	5	0.2	0.5	4.3	< 0.1	< 0.1	< 0.1	0.8	0.3
U	ppm	0.1	FUS-MS-Na ₂ O ₂	2.1	5	3.6	1.1	5.3	2	0.5	33.6	11.9
Al	%	0.01	FUS-Na ₂ O ₂	0.09	0.11	0.65	2.56	1.92	0.17	0.07	1.07	5.97
Ca	%	0.01	FUS-Na ₂ O ₂	< 0.01	< 0.01	0.03	0.16	0.17	0.07	4.91	5.14	0.74
Fe	%	0.05	FUS-Na ₂ O ₂	16.1	3.89	2.71	18.5	35.1	23	23.8	24.1	17.8
K	%	0.1	FUS-Na ₂ O ₂	< 0.1	< 0.1	0.2	0.8	0.7	< 0.1	< 0.1	< 0.1	2.1
Mg	%	0.01	FUS-Na ₂ O ₂	0.02	0.02	0.03	0.46	0.08	0.11	0.11	1.16	0.55
P	%	0.005	FUS-Na ₂ O ₂	0.012	< 0.005	0.014	0.034	0.038	0.015	0.008	0.089	< 0.005
S	%	0.01	FUS-ICP	22.8	8.36	3.63	11.9	23.3	25.1	27	25.4	17.7
Si	%	0.01	FUS-Na ₂ O ₂	0.5	3.5	37.4	25	12.8	0.47	0.09	1.28	18.2
Ti	%	0.01	FUS-Na ₂ O ₂	< 0.01	0.01	0.04	0.14	0.09	< 0.01	< 0.01	< 0.01	0.27

Table A.3. Definition of methods used.

Method	Definition	Comments
FUS-ICP FUS-MS	Fusion inductively coupled plasma emission spectrometry with mass spectrometry add-on	For whole-rock analysis of sulfide-poor samples. Mass spectrometry add-on for Nb, Ti, Sn and REEs at low levels.
INAA	Instrumental neutron activation analysis	For Au, Ag, Br, Co, Cr, Hg, Ir, Sb, Sc, Se and W in sulfide-poor rocks
TD-ICP	Total Digestion followed by inductively coupled plasma	Uses hydrochloric, nitric, perchloric and hydrofluoric acids to dissolve sample. Unreliable for several minerals.
IR	Infrared	For S data for low-sulfide rocks and for C to distinguish carbonate carbon from graphitic carbon (in argillites).
COUL	Coulometry	For CO ₂
FUS-ISE	Fusion specific ion electrode	For low detection of Fluorine in low-sulfur rocks
FIMS	Cold Vapour-Flow Mercury System	For ppb analysis of Hg
FUS-MS-Na ₂ O ₂ and FUS-Na ₂ O ₂	Sodium peroxide fusion followed by inductively coupled plasma optical emission spectrometry (OES) OR mass spectrometry (MS)	For ultra-low trace in sulfide-rich ores. All metals are soluble.

APPENDIX B

Petrographic Descriptions

(See attached DVD)

TS ID: 9-01
DDH: **CMR07-09, 99.5m**
Sample: **NS9-01**

Lithology: **Feldspar-phyric basalt**
Alteration: **Mod perv chl, mod sel. ser, weak sel. qtz**

Hand Sample Observations:

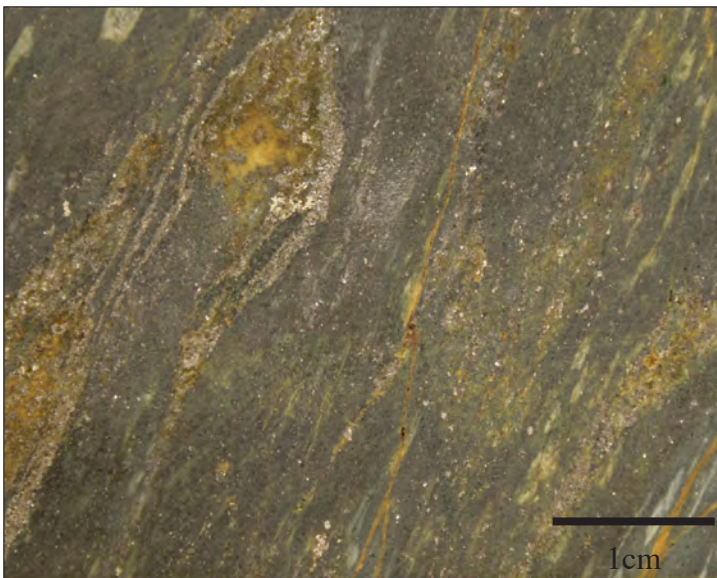
Dark green, altered feldspar-phyric mafic volcanic. Feldspars are deformed and elongate parallel a moderate foliation. Pyrite is disseminated throughout, and concentrated in diffuse, foliation-parallel stringers. Local boudins of quartz (<1cm) are associated with pyrite stringers. Vfg disseminated magnetite is visible under hand lens. The sample is weakly pervasively magnetic. Thin veinlets of sericite(?) cut sub-parallel foliation.

Thin Section Observations:

Feldspars are lenticular and flattened, in a chlorite-rich matrix. Feldspars are now mostly muscovite, with lesser chlorite. Diffuse stringers of granular quartz-chl-sulfide cut sample. Sample is weakly crenulated. Po is oxidized, and partially to fully replaced by Mt?.

Mineralogy:

-Chlorite	70%
-Muscovite	15%
-Quartz	15%
-Pyrrhotite	5%
-Sphalerite	trace
-Chalcopyrite	trace
-Pyrite	trace
-Ilmenite(?)	trace
-Magnetite?	



TS ID: 9-02
DDH: **CMR07-09, 114.9m**
Sample: **NS9-02**

Lithology: **Altered feldspar-phyric basalt**
Alteration: Mod perv ser-chl, sel. weak quartz

Hand Sample Observations:

Medium green altered feldspar-phyric mafic volcanic. Feldspars have been altered to chlorite, locally incompletely and feldspar cores can be seen with chlorite rims. Local domain-style selective quartz-sericite alteration as patches within chlorite alteration. Chlorite is pervasive, and also selective as replacement of feldspars. Hairline chlorite veinlets, and stringer-style pyrite veinlets cut sub-parallel foliation. Pyrite veinlets have a very thin sericite(?) selvage.

Thin Section Observations:

Feldspars altered to chlorite and quartz, flattened and lenticular - OR altered to muscovite. Not sure what controls this. Local patches of needly-feldspar (less altered zones?). Sulfides are locally disseminated, and concentrated within thick quartz-chlorite stringers, mostly as sub-euhedral pyrite aggregates and grains. Some sections of groundmass are more quartz-sericite altered, versus chlorite. Much of groundmass is too fine-grained to properly identify. Local stringer of sphalerite. Disseminated leucoxene locally.

Mineralogy:

-Chlorite	40%	
-Quartz	15%	
-Muscovite	35%	
-Plagioclase	5%	(needles)
-Pyrite	5%	
-Sphalerite	trace	
-Ilmenite	trace	



TS ID: 9-03

DDH: **CMR07-09, 128.9m**

Sample: NS9-03

Lithology: **massive mafic volcanic**

Alteration: **weak sel. quartz-chl-carb, weak perv. musc**

Hand Sample Observations:

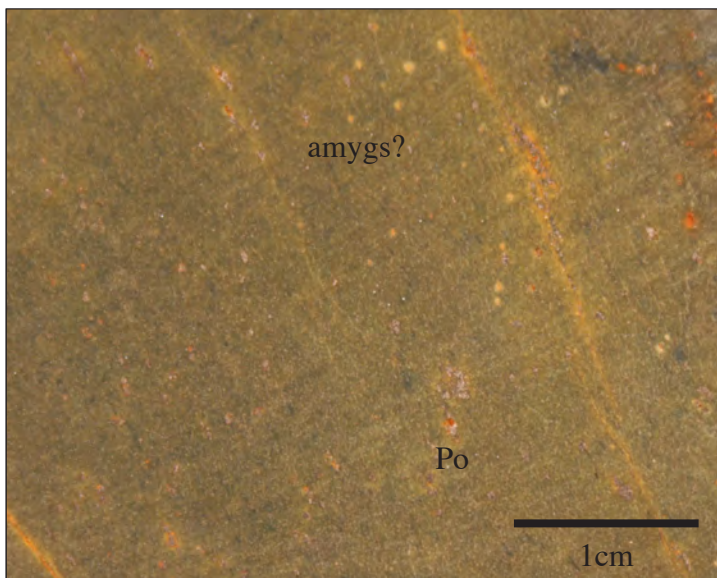
Massive, coherent mafic volcanic. Subtly ser and chl altered. Very minor disseminated pyrrhotite. Local trace white speckles may be small feldspars(?), although they are not evenly distributed. Perhaps amygds? No carb alt. Pervasively weakly magnetic. Hairline Po veinlets cut parallel a very weak foliation. Resembles less cherty 9-19 (244.6m) and 9-15 (211.5m).

Thin Section Observations:

Groundmass is full of feldspar needles, very weakly oriented. Large phenos may be amygds? filled with chlorite-sulfide-carbonate-quartz. Dark groundmass is chl with minor muscovite. Dominant sulfide is Po, with trace Cpy associated with it. Po occurs along veins and within amygds, but also appears to be disseminated weakly. Leucoxene is disseminated throughout groundmass, as anhedral rounded grains. No qtz in groundmass, only in amygds and veins.

Mineralogy:

-Chlorite	50%
-Plagioclase	40%
-Muscovite	5%
-Quartz	1%
-Pyrrhotite	2%
-Chalcopyrite	rare trace
-Leucoxene	3%
-Carb	



TS ID: 9-04
DDH: **CMR07-09, 139.0m**
Sample: NS9-04

Lithology: **altered volcanic breccia (mafic?)**
Alteration: **chlorite**

Hand Sample Observations:

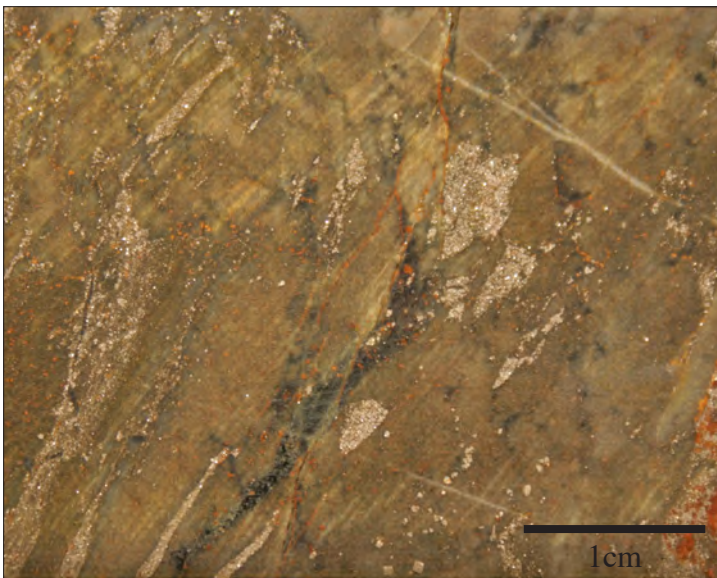
Clast-supported breccia. Alteration is pervasive, although zoned working its way into clasts. 1-5 mm discontinuous pyrite stringers cut parallel a weak foliation. Clasts are elongate and aligned parallel weak foliation. Some stringers appear to be brecciated? and are present as angular to rounded clasts elongate parallel foliation. Within drill core this may be a local thing? But also could represent the bottom autobrecciated part of a flow?

Thin Section Observations:

Sample is mainly of chlorite, fan-shaped and randomly oriented. Variable grain size, with much coarser chl within sulfide veins. Veinlets are from <0.1mm to 1cm across, and brecciate host rock. Sulfide is mostly sub-euhedral pyrite cubes, concentrated within chl-sulfide veins. Med grey min also with Pyrite - Leucoxene Magnetite? Little to no alteration. Possible albite?

Mineralogy:

-Chlorite	60%
-Plagioclase	30%
-Pyrite	10%
-Leucoxene	trace



TS ID: 9-05
DDH: **CMR07-09, 141.6m**
Sample: **NS9-05**

Lithology: **Altered volcanic**
Alteration: **strong perv quartz, ser, pyrite.**

Hand Sample Observations:

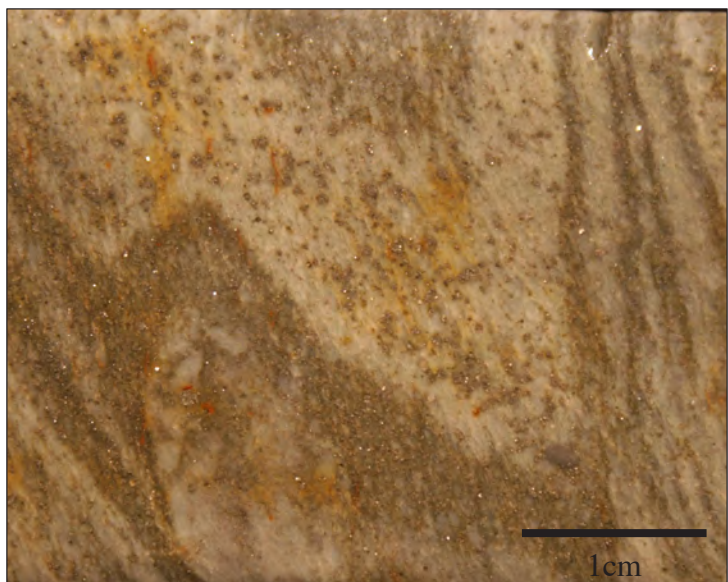
May have been a volcanic fragmental of sorts. Folding defined by more sulfide rich bands and more qz-ser rich bands (or zoned clasts?). Disseminated angular qz-clasts (<1mm) within sulfide bands, and disseminated pyrite (<1mm) in qz-ser bands. Bands are not sharply defined, and have soft outlines.

Thin Section Observations:

Sample is moderately foliated. Sample consists of rounded aggregates of quartz within a fg muscovite matrix. Likely a tectonic fabric, separating phyllosilicates from quartz, and boudinaging qtz to form rounded 'grains'

Mineralogy:

-Quartz	40%
-Muscovite	45%
-Pyrite	15%
-Leucoxene	1%



TS ID: **9-06**
DDH: **CMR07-09, 149.4m**
Sample: **NS9-06**

Lithology: **Pyrrhotite-chalcopyrite stringers**
Alteration: **intense sericite, subtle quartz**

Hand Sample Observations:

Thin muscovite and sulfide stringers elongate parallel moderate foliation. About equal parts sulfide-sericite. Minor Py as disseminated subhedral fg crystals. Weak-moderately magnetic (Po). 1-2 cm bands of variable Po-Ser.

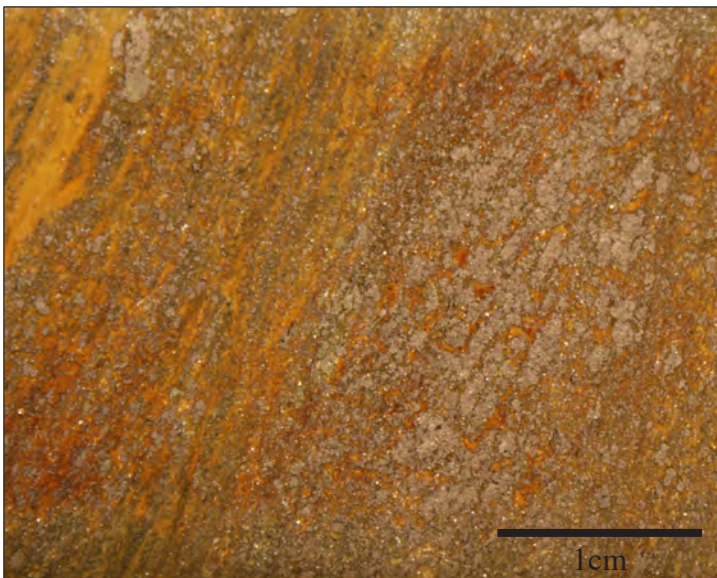
Thin Section Observations:

Sample is mostly iron oxidized muscovite, of varying grain size and orientation. Although most muscovite needles are moderately aligned parallel a foliation, locally there are aggregates of larger, possibly metamorphic? or later muscovites growing in random orientation. Anhedral quartz locally forms boudins. Iron oxide causes everything to have a brownish orange, grungy appearance. Larger muscovites and quartz form around larger Po aggregates/crystals.

Pyrrhotites have a thin white outline of pyrite (Bird's eye) and also exhibit different shades of cream-colour internally. Minor Cpy and lesser Sph typically within Po grains, or on their own associated with Po. Several very large euhedral Pyrite crystals locally, with abundant Cpy around them.

Mineralogy:

-Muscovite	50%
-Quartz	5%
-Pyrrhotite	40%
-Pyrite	2%
-Chalcopyrite	3%
-Sphalerite	trace



TS ID: **09-07**
DDH: **CMR09-07, 150.6m**
Sample: **NS9-07**

Lithology: **Altered volcanic**
Alteration: **intense sericite**

Hand Sample Observations:

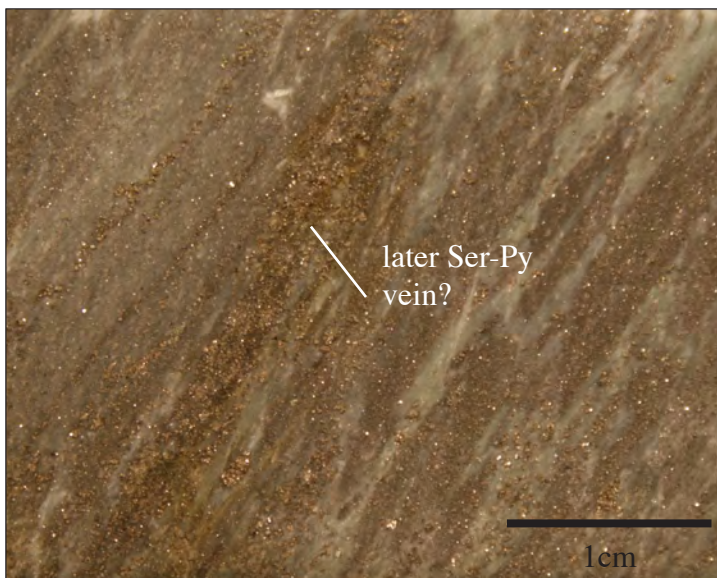
Intensely altered breccia. May be hydrothermal or pseudobreccia, not necessarily primary volcanic breccia. Clasts are mostly fg disseminated pyrite and sericite.

Thin Section Observations:

Clasts of sericite and disseminated pyrite, cut by foliated sericite stringers. This breccia is later(?) cut by a thicker coarser sericite-pyrite stringer (see photo). Sericite is crenulated weakly.

Mineralogy:

-Sericite 80%
-Pyrite 20%



TS ID: **9-08**
DDH: **CMR07-09, 153.8m**
Sample: **NS9-08**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Moderately foliated, banded to massive barite and sulfide. Sulfide is fg, disseminated honey brown sphalerite, chalcopyrite as fg blebs elongate and following foliation, and trace vfg disseminated galena.

Thin Section Observations:

Mostly coarse, equigranular barite and sulfide, cut by continuous stringers of muscovite, quartz, chalcopyrite and sphalerite, with lesser tetrahedrite and galena. Minor rounded, subhedral pyrites disseminated throughout - low pyrite content compared to other barite samples. Within stringers, sphalerite and cpy locally exhibit a 'spray paint' look, as cpy replaces sph?. Hairline muscovite veinlets throughout sample weave between grains. Local fg pods of quartz proximal to muscovite veinlets.

Geochemistry:

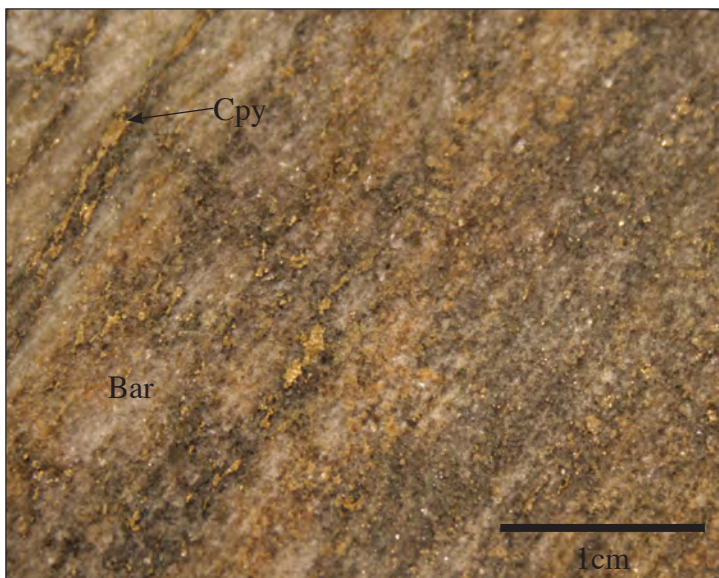
High Au and Ag. Very high Pb, As and Sb due to high galena, tetrahedrite and arsenopyrite content. Au and Ag likely correlate with As and/or Sb.

Mineralogy:

-Barite	60%
-Muscovite	trace
-Quartz	1%
-Sphalerite	20%
-Chalcopyrite	7%
-Pyrite	7%
-Galena	2%
-tetrahedrite	3%
-Arsenopyrite	trace

Grain Size:

fg
micro-vfg
vfg
fg-mg
fg
vfg-fg
vfg-fg
fg
micro



TS ID: 9-09
DDH: CMR07-09, 155.4m
Sample: NS9-09

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Layered massive fg barite with bands of py-sph and bands of cpy-sph (<1 cm thick each).

Thin Section Observations:

Sulfide bands through barite gangue. Barite has been annealed, and recrystallized, to form large polygonal-shaped crystals, with 120° triple junctions. Two main sulfide bands within sample separated by barite with lesser sulfide. One large band is mostly euhedral to subhedral, friable and fractured pyrite grains, surrounded by sphalerite and tetrahedrite, with lesser cpy, and trace galena and arsenopyrite around Py grains. Locally pyrite grains appear to be weakly recrystallized framboids. Tetrahedrite is common with sphalerite, but oddly, only on one side of the band - the side closer to the cpy band. Sph displays chalcopyrite disease. Aspy is subhedral to euhedral, same as Py. Galena is rare, and sub-microscopic, typically within tetrahedrite as inclusions.

The other band is mainly cpy replacing sph with cusped 'dustings' of Sph left, and minor subhedral to anhedral, strongly friable and fractured py grains disseminated throughout. Trace Arsenopyrite disseminated throughout Cpy as large, corroded euhedral crystals.

Between bands, resembles average barite ore - with barite interspersed with pyrite and sphalerite grains that have been locally replaced by chalcopyrite. Within cpy-band, barite has strange vfg mottled texture - was it not recrystallized here? Rare trace of covellite oxidation on fractures through Cpy and Sph.

Geochemistry:

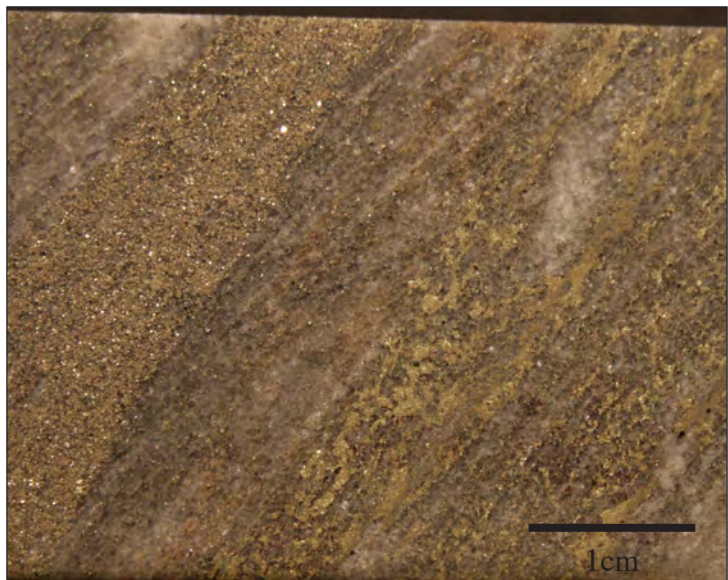
Relatively high Au and Ag (from tetra?). Moderate Sb and As. Low Hg for the barite ores.

Mineralogy:

-Barite	60%
-Muscovite	rare trace
-Sphalerite	7%
-Chalcopyrite	5%
-Pyrite	7%
-Tetrahedrite	1%
-Arsenopyrite	trace
-Galena	rare trace

Grain Size:

fg-mg
micro-vfg
vfg-fg
vfg-fg
vfg
vfg
micro-vfg
micro



TS ID: **9-10**

DDH: **CMR07-09, 160.6m**

Sample: none (too close to 9-11?)

Lithology: **Massive Pyrite Ore / Barite Ore**

Alteration:

Hand Sample Observations:

Massive barite, pyrite, sphalerite and Cpy, fg, weakly layered, and granular.

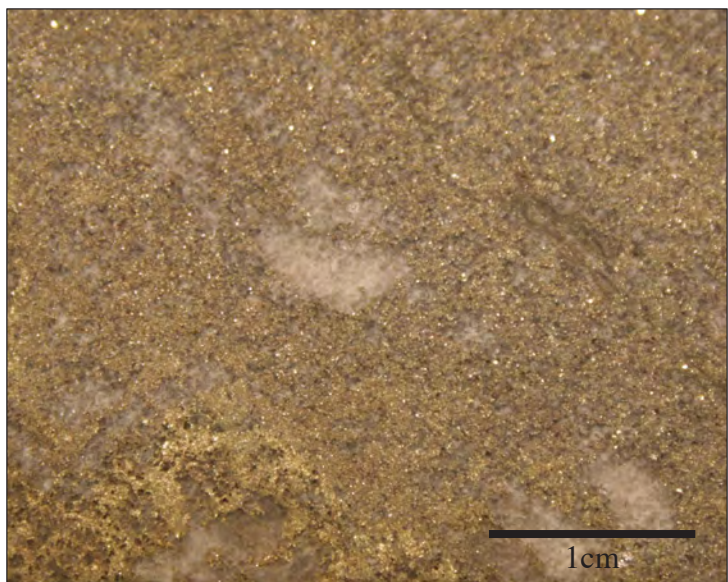
Thin Section Observations:

Mostly all Barite and sulfide. Local pods of just barite. Locally minor quartz, as later quartz cuts barite? And minor sericite as veinlets with sulfide. Evidence of continued hydrothermal activity?

Pyrite is dominant as subhedral aggregates. Cpy and Sph after Py, filling fractures and pore-spaces. Sph has pale yellow-white IRs. Lighter grey mineral is Galena. Lesser amounts, and with Cpy-Sph. Chalcopyrite disease in Sphalerite.

Mineralogy:

-Barite	30%
-Quartz	10%
-Muscovite	5%
-Pyrite	30%
-Chalcopyrite	10%
-Sphalerite	15%
-Galena?	trace
-Tetrahedrite	trace



TS ID: **9-11**
DDH: **CMR07-09, 161.2m**
Sample: **NS9-11**

Lithology: **Massive Pyrite Ore / Barite Ore**
Alteration:

Hand Sample Observations:

Massive barite pyrite, sphalerite and chalcopyrite.

Thin Section Observations:

Sample is mainly subhedral to anhedral, rounded, friable and fractured pyrites, surrounded by sphalerite and chalcopyrite. Minor subhedral, fractured and replaced, arsenopyrites throughout. Chalcopyrite appears to be replacing sphalerite. Sphalerite locally replaces pyrites forming atoll structures. Rare trace of covellite oxidation on fractures through Cpy and Sph. Sub-micro inclusions of galena within sphalerite locally. No cobaltite observed.

Geochemistry:

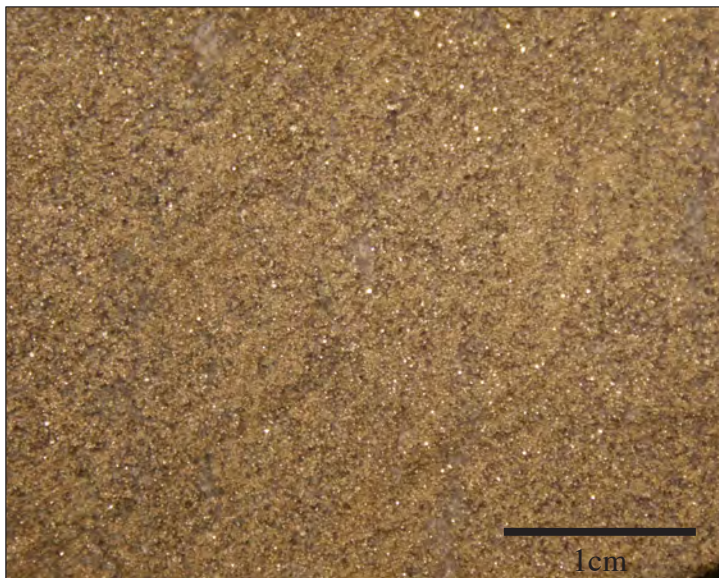
High As, from arsenopyrite, and low Sb. No tetrahedrite. Moderate Au, but no tetra, so Au possibly in Cpy or Arsenopyrite. Very low Cd, and low Hg. High Co - no cobaltite. Co within arsenopyrite?

Mineralogy:

-Barite	40%
-Muscovite	rare trace
-Pyrite	45%
-Chalcopyrite	10%
-Sphalerite	5%
-Arsenopyrite	trace
-Galena	rare trace
-Covellite	rare trace

Grain Size:

vfg-fg
vfg
vfg-fg
vfg
vfg
micro
micro
crypto



TS ID: 9-12
DDH: **CMR07-09, 167.5m**
Sample: **NS9-12**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Equigranular barite and sulfide (sphalerite/pyrite). Sphalerite is light brown. Pyrite is vfg and disseminated.

Thin Section Observations:

Mostly barite gangue. Sphalerite all looks ragged and vuggy. Eaten away? Barite has very grungy, altered-looking rims. Trace quartz as rounded grains disseminated throughout. Pyrites have clean rims, and form subhedral-euhedral, disseminated grains. Chalcopyrite disease in Sphalerite. Pale ylw-brown IRs in sphalerite. Local minor tetrahedrite (or possibly tennantite?).

Geochemistry:

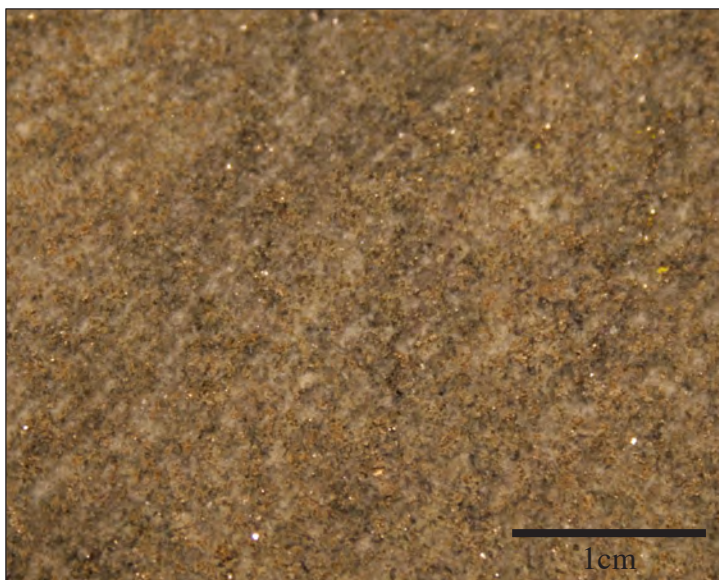
Very high Au and Ag. Possibly associated with Tetrahedrite? and Cpy? High Sb (from tenn?). Relatively high Cd (from Sph). Very high Hg (also from sphalerite?). Relatively high Sn.

Mineralogy:

-Barite	60%
-Quartz	trace
-Sphalerite	25%
-Pyrite	15%
-Galena	2%
-Chalcopyrite	<1%
-Tetrahedrite	1%

Grain Size:

vfg-fg
vfg
vfg-fg
vfg-fg
vfg
vfg
vfg



TS ID: **9-13**
DDH: **CMR07-09, 173.6m**
Sample: **NS9-13**

Lithology: Quartz? Chert?
Alteration: intense pervasive quartz?

Hand Sample Observations:

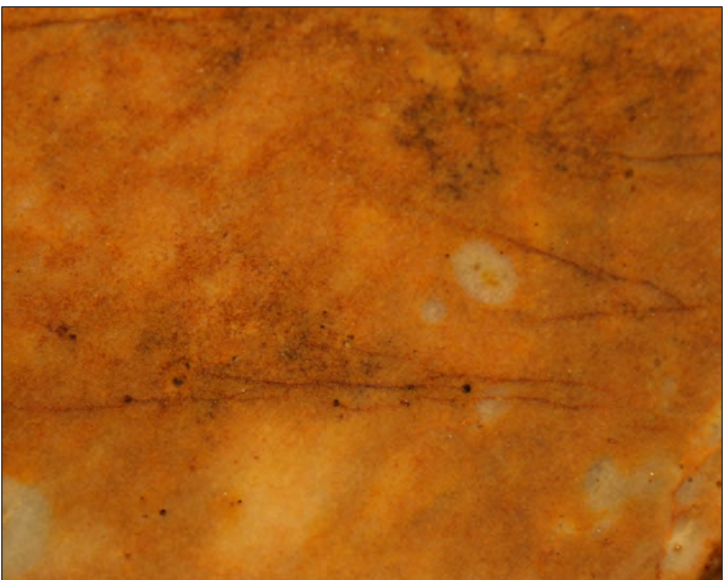
Rusty chert? - Amorphous massive quartz with local round 1-10mm white quartz nodules (amygs?). Some nodules are hollow - have been weathered out.

Thin Section Observations:

Mostly all equant quartz crystals, as a mosaic. Orange oxidation between quartz crystals gives rock rusty colour. White round vugs (see photo) contain sulfides - Py and Cpy. Pyrites are framboidal? Cpy is euhedral. Sericite/muscovite also present in vugs and thin fractures cutting quartz. Ser replacing quartz? locally along fractures? Sericite also disseminated throughout, replacing(?) quartz.

Mineralogy:

-Quartz	99.0%
-Sericite/Muscovite	0.5%
-Pyrite	Trace
-Chalcopyrite	Trace



TS ID: **9-14**
DDH: **CMR07-09, 189.1m**
Sample: **NS9-14**

Lithology: Argillite
Alteration:

Hand Sample Observations:

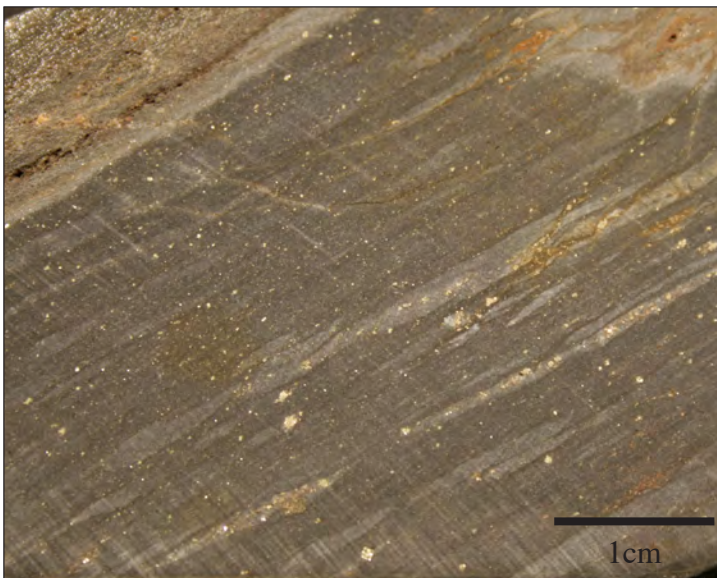
Strongly calcareous, dark grey-black, 'layered' argillite. Thin, 1-5 mm, discontinuous, boudinaged lighter grey layers pinch and swell amongst the darker layers. Disseminated fg pyrite euhedral throughout. Very subtly magnetic (from minor Po?).

Thin Section Observations:

Mostly Calcite, with lesser muscovite, cut by qtz-sulfide veins. Disseminated Py throughout, with greater accumulations along coarser horizons. Trace Cpy and Sph with Py, again mostly in these coarse sulfide-rich horizons (see pic). Sphalerite has dark red internal reflections - high Fe? Very weak foliation oblique to layering. Possible very weak C-S fabric? (photo)

Mineralogy:

-Carbonate	90%
-Quartz	5%
-Muscovite	trace
-Pyrite	5%
-Chalcopyrite	Trace
-Sphalerite	Trace



TS ID: **9-15**

DDH: **CMR07-09, 211.5m**

Sample: **NS9-15**

Lithology: **Tuffaceous rock/Chert**

Alteration: **strong quartz??**

Hand Sample Observations:

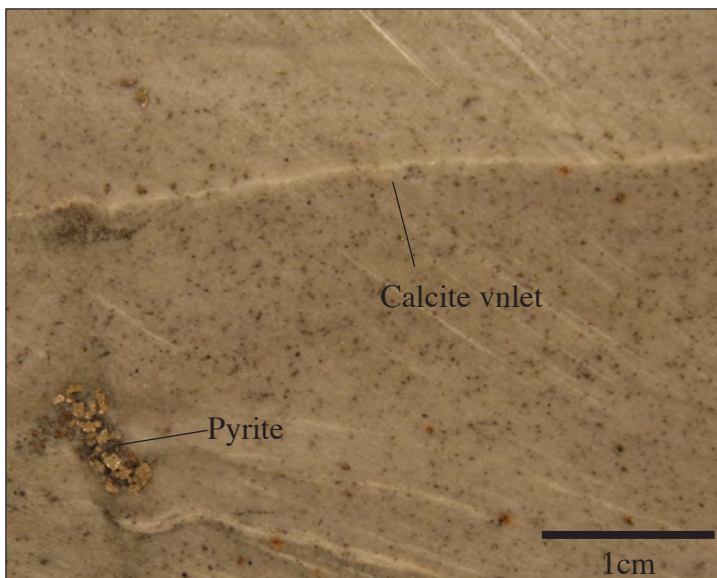
Light grey-white, massive siltstone(?). Looks like felsic seds - and in drill core, is a gradual change from dark grey argillite to this felsic siltstone. Could be cherty argillite?. Vfg disseminated pyrrhotite ($\pm$ pyrite?) throughout, and rock is weakly pervasively magnetic. Pervasive calcite may be primary? Rock is hard, so likely high amount of quartz. No visible layering. Strongly resembles a chertier, more silicified version of 9-3 (128.9m) and 9-19 (244.6m).

Thin Section Observations:

Obvious strong crenulation across entire section. Mostly Calcite and Quartz, with trace muscovite. Disseminated Po and trace Sph and Cpy. Sulfide forming in between Qz/Calcite grains. Locally large Py grains (see hand sample pic), much bigger than Po. Pyrites contain inclusions of Cpy. Cpy also as local tiny blebs between gangue xtals. Po is locally bladed. Thin white calcite veinlets cut (see pic)

Mineralogy:

-Calcite	50%
-Quartz	46%
-Muscovite	1%
-Pyrrhotite	2%
-Sphalerite	Trace
-Chalcopyrite	Trace
-Pyrite	Trace



Thin Section ID: 09-16
DDH: **CMR07-09, 221.5m**
Sample: **NS09-16**

Lithology: **altered volcanic rock?**
Alteration: **strong sericite, chlorite...?**

Hand Sample Observations:

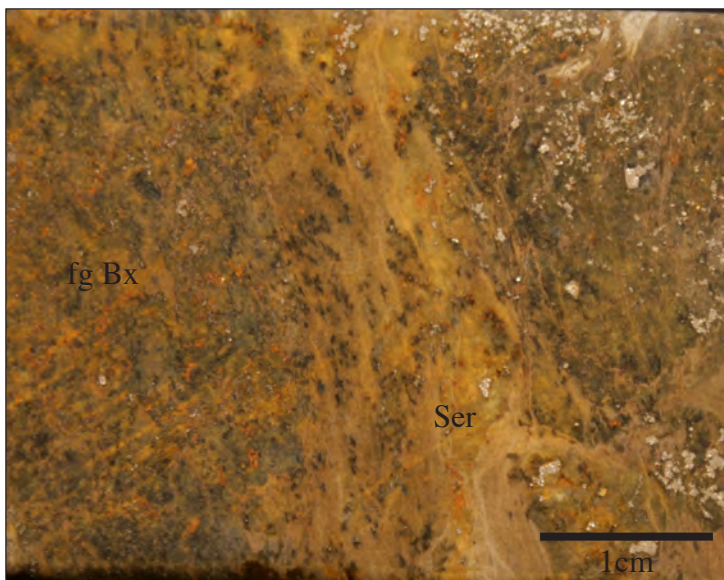
Breccia of sorts? Fine grained fragmental texture? overprinted by variable alteration, mostly sericite and chlorite. Grungy green mineral, similar to the fault zone uphole. Locally disseminated, and aggregate pyrite, fg-mg. Sericite stringer/conduit cuts through middle of sample.

Thin Section Observations:

Sample may be strongly chlorite altered? Variably muscovite and chlorite(?) groundmass, fine grained, cut by what appear to be very fine tension gashes? and veins of quartz and sulfide.

Mineralogy:

-Chlorite	40%
-Muscovite	50%
-Quartz	5%
-Pyrite	5%



TS ID: 9-17
DDH: CMR07-09, 240.5m
Sample: NS09-17

Lithology: **Oxidized leached layered Chert/Tuff**
Alteration: **intense carbonate, quartz + sericite?**

Hand Sample Observations:

Strongly oxidized and leached, layered chert-carbonate + sulfide rock. Locally fine laminations of chert, and distinct layers of carbonate (and those without). Sulfide is/was disseminated throughout as fg-mg. Now pitted and porous. Locally some euhedral pyrite remains within thicker (<1cm) cherty layers. Strongly resembles 9-18 (243.2m) but oxidized.

Thin Section Observations:

Mostly coarse calcite and quartz (recrystallized). Quartz is all small equant grains making an interconnected mosaic, looks like large grains that have been recrystallized (?) into mosaics. Calcite forms very large degraded crystals that include the quartz. Minor muscovite needles intergranular to quartz. Grungy brown alteration around quartz grains, as seen in 9-13. Trace chl fans around sphalerites. Sphalerite has dark red to honey brown IR. Sph is often replacing Py and Po, along fractures and around edges. Py typically is euhedral to subhedral cubes. Po is anhedral blebs. Cpy may also be replaced by sph locally??

Mineralogy:

-Quartz	45%
-Carbonate	50%
-Sphalerite	3%
-Pyrite	trace
-Pyrrhotite	trace
-Chalcopyrite	trace
-Muscovite	trace
-Chlorite	trace



TS ID: **9-18**
DDH: **CMR07-09, 243.2m**
Sample: NS09-18

Lithology: **Chert-Carbonate Tuff + Sph-Py Stringers?**
Alteration: **Intense Quartz-Carbonate**

Hand Sample Observations:

Interlayered/laminated chert-sulfide and carbonate. Sulfide is mainly dark brown sphalerite. Small 5 mm quartz vein cuts oblique to layering through sample. Layers are often discontinuous and broken.

Thin Section Observations:

Mostly quartz and carbonate, possibly interlayered? Abundant sphalerite as stringers with dark red IR. No muscovite here. Trace pyrite, but most of it is being replaced by sphalerite. Many inclusions within sphalerites, including pyrite, galena and chalcopyrite. Sphalerites also exhibit cpy-disease, and interestingly another mineral with a similar phenomenon - possibly bismuthenite? or hematite? Trace galena as tiny grains disseminated.

May be stringers and veins through chert, or else may be interlayered exhalative quartz, carbonate and sphalerite.

Geochemistry:

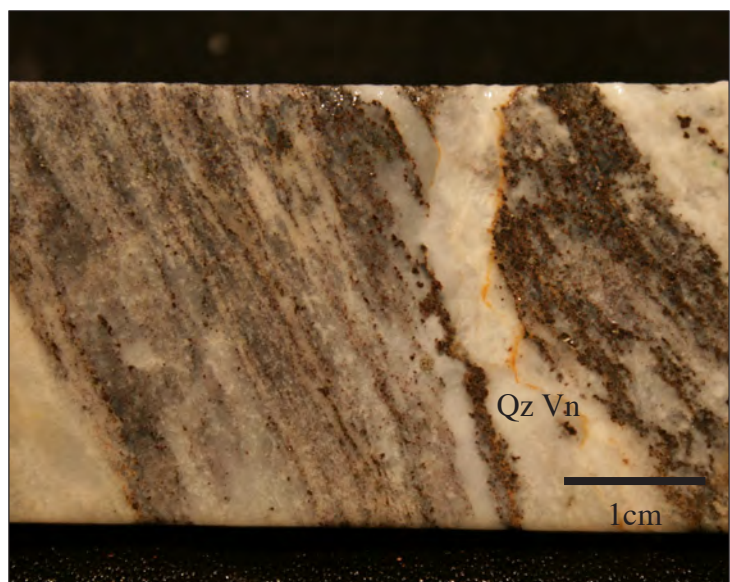
Very high Bi (129 ppm), but very little pyrite for it to exist in. Mystery mineral may be bismuthenite? Bi indicates high Temp or magmatic component, yet this is an exhalite?

Mineralogy:

-Quartz	40%
-Carbonate	40%
-Sphalerite	20%
-Pyrite	trace
-Galena	trace

Grain Size:

vfg
vfg-fg
micro-fg
micro-fg
micro



TS ID: **9-19**
DDH: **CMR07-09, 244.6m**
Sample: **NS9-19**

Lithology: Tuffaceous rock
Alteration: moderately pervasive quartz, weak ser.

Hand Sample Observations:

Greenish-grey, aphanitic, massive coherent volcanic (mafic?), pervasively moderately quartz altered. Disseminated fg pyrite throughout (<1%). Numerous hairline fractures. Weak pervasive sericite alteration. No carb, no mag. Resembles both 9-3 (128.9m) and 9-15 (211.5m). - maybe it's a chert? or Sed?

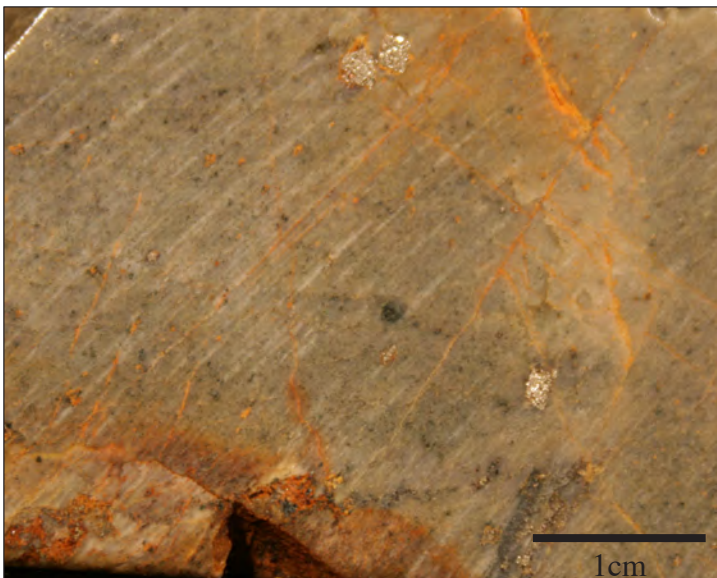
Thin Section Observations:

Massive volcanic, altered to quartz, chlorite and sericite. What appear to have been amygdules(?) are now coarse qtz-chl-pyite. Chl phenos throughout as well. Trace Py, Sphalerite and rare Chalcopyrite as dissminations and filling amygs??

May be Tuff? Similar geochem to Tuff at 211.5m? Except much more Carb there, and more Si here.

Mineralogy:

-Quartz	70%
-Sericite	15%
-Chlorite	20%
-Pyrite	2%
-Sphalerite	trace
-Chalcopyrite	trace



TS ID: 11-01

DDH: CMR08-11b, 145.2m

Sample: NS11-01

Lithology: **Altered, massive mafic volcanic**

Alteration: **Weak perv Chl, sel. chl-carb-quartz**

Hand Sample Observations:

Dark green, massive, aphanitic, altered coherent mafic volcanic cut by several thin pyrite stringers. Alteration is subtle and pervasive, likely replacing primary mafics and feldspars. A weak, pervasive foliation is present throughout sample. Pyrite stringers that cut parallel to sub-parallel to foliation are relatively straight, and sharply defined. Veinlets that cut at high angles to foliation are undulating, irregular, and exhibit numerous off-shoots branching parallel to foliation, suggesting that either foliation was present at time of vein growth, or, more likely, alteration and veinlet formation occurred during deformation, or while the rocks were under stress. (replacement of Px and Plag by Chl and Ser while under stress would likely create a foliation no? - dynamic recrystallization).

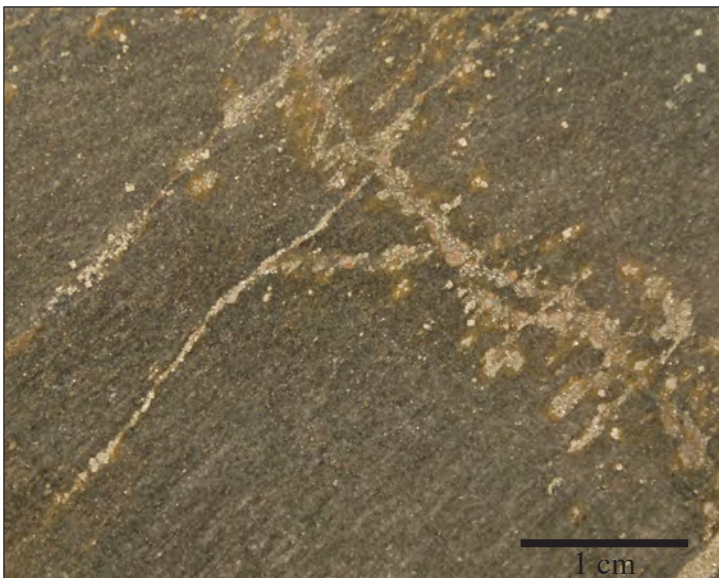
Sample contains both disseminated and stringer-style pyrite. Disseminated pyrite is typically euhedral, and vfg-fg. Pyrite stringers are vfg to msf, and have a Ca-Carb (+/- Fe-Carb) gangue.

Thin Section Observations:

Rock is needle-shaped plagioclase, and lesser chlorite phenos in a vfg chloritic groundmass. Cut by chl-sulfide-carbonate-quartz veins. No muscovite/sericite. Plag needles are twinned. Sub-euhedral pyrite aggregates locally altering to Pyrrhotite as colloform replacement. Trace Cpy and Sph with Py locally. Grey skeletal mineral associated with Py, often with Py inclusions.

Mineralogy:

-Chlorite	50%
-Plagioclase	43%
-Pyrite	7%
-Chalcopyrite	trace
-Sphalerite	trace
-ilmenite(?)	<0.5%



TS ID: 11-02
DDH: **CMR08-11b, 152.1m**
Sample: NS11-02

Lithology: altered Feldsphyric mafic volcanic
Alteration: Strong perv. sericite, mod sel. quartz

Hand Sample Observations:

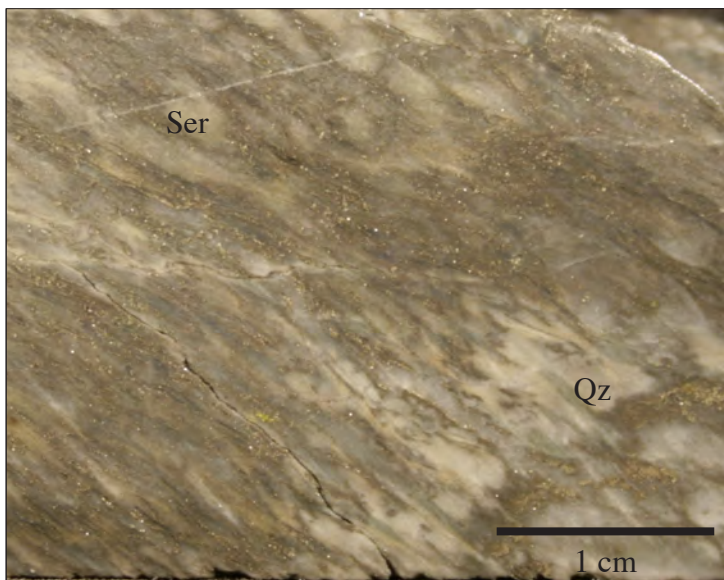
Dark grey, moderately foliated, strongly altered, feldspar-phyr-ic, coherent mafic volcanic. Feldspars are anhedral, lenticular, mostly altered to sericite and/or quartz locally, and elongate parallel foliation. Groundmass is largely vfg Pyrite.

Thin Section Observations:

Sample is heavily cut by quartz veins, which have been tightly folded, broken and transposed structurally. Sample is sheared. Sample is mainly muscovite with minor quartz, cut by quartz-sulfide veins. Pyrite locally as very elongate tabular crystals. Disseminated leucoxene throughout, elongate and skeletal grains.

Mineralogy:

-Muscovite	70%
-Quartz	20%
-Pyrite	10%
-Sphalerite	rare trace
-ilmenite(?)	trace



TS ID: **11-03**
DDH: **CMR08-11b, 160.9m**
Sample: **NS11-03**

Lithology: **Massive Pyrrhotite Ore**
Alteration:

Hand Sample Observations:

Rock is primarily massive pyrrhotite with large euhedral calcite and quartz crystals. Large (<1.5 cm), pink, rhombohedral calcite crystals and hexagonal quartz crystals (<5 mm) both float in a pyrrhotite ground-mass, and contain inclusions of pyrrhotite and chalcopryite. The calcite crystals appear to be more closely associated with chalcopryite within and immediately surrounding calcite. Quartz and calcite also occur as fracture fill through pyrrhotite.

Thin Section Observations:

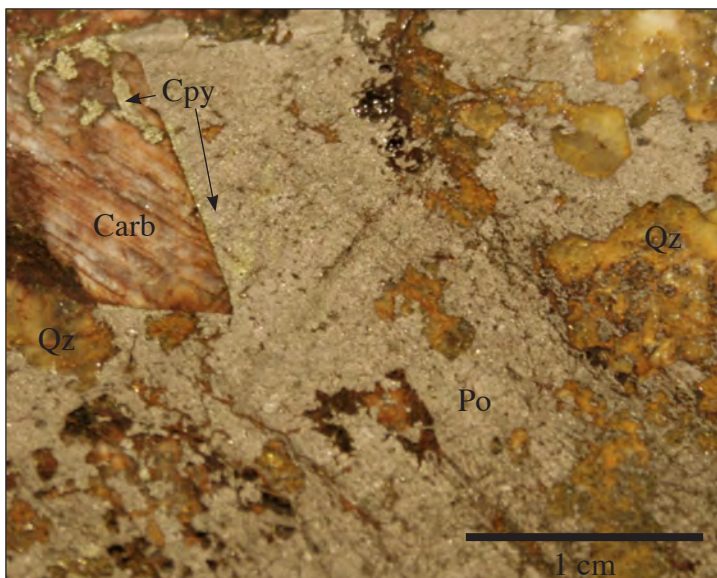
Section is mostly Po, with very large anhedral quartz crystals, euhedral calcite crystals and pods/fans of muscovite. Muscovite also fills fractures through Po. Locally abundant Cpy within or around Po, especially around carbonate crystals. Locally, Po is being replaced along fractures and edges by pyrite, as bird's eye texture. Sphalerite forms locally within Po, and has deep-red IRs. Muscovite growing around edges of quartz, and within fractures - replacing quartz? Small, booklets of clear chlorite as inclusions within quartz, and along with muscovite. Trace elongate, needle-like hematite and molybdenite with muscovites locally.

Mineralogy:

-Quartz	20%
-Carbonate	10%
-Muscovite	5%
-Chlorite?	5%
-Pyrrhotite	50%
-Chalcopryite	5%
-Sphalerite	1%
-Pyrite	1%

Grain Size:

fg-cg
cg-vcg
vfg
vfg
massive
massive
mg
micro



TS ID: **11-04**
DDH: CMR08-11b, 165.6m
Sample: **NS11-04**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Equigranular, disseminated honey-brown sphalerite (40%), galena (3%) and chalcopyrite (1%) within a barite matrix. No pronounced foliation.

Thin Section Observations:

Mostly barite and pale honey brown sphalerite. Sphalerite and barite strongly recrystallized, polygonal mosaic. A few local up to 2 mm pods(?) of vfg muscovite-barite are possibly clasts? Or altered plagioclase?. Rare intergranular muscovite throughout barite gangue. Barite edges are all 'fuzzy' - possibly altered?

Sphalerite exhibits chalcopyrite-disease. Py is granular, rounded, subhedral, disseminated, and well-dispersed. Some pyrites fractured, and Cpy and Sph, Gal, Tetra and aspy within pyrite cracks, and surrounding pyrites. Trace arsenopyrite observed, euhedral, adjacent pyrites. Arsenopyrite does not exhibit good anisotropy. Sph has 'torn' looking edges with barite, but pyrite does not - has smooth edges. Tetrahedrite often have thin rims replaced mostly by chalcopyrite, and also galena, arsenopyrite, and sphalerite. Galena also locally replacing Tetrahedrite. Pyrite atoll structures observed.

Geochemistry:

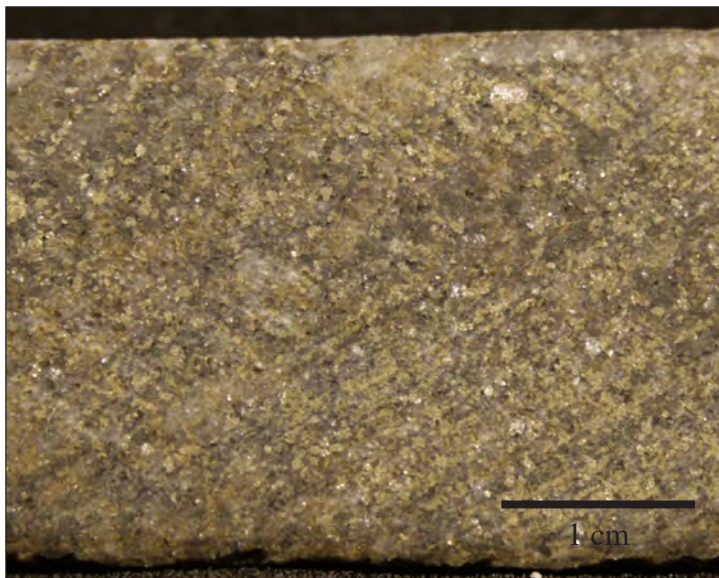
Relatively high As and Sb, explained by arsenopyrite and tetrahedrite. Very high Au, Cd and Hg.

Mineralogy:

-Barite	45%
-Sphalerite	40%
-Pyrite	10%
-Chalcopyrite	2%
-Galena	3%
-Tetrahedrite	trace
-Arsenopyrite	trace

Grain Size:

mg
mg
fg
vfg
vfg
vfg
vfg



TS ID: **11-05**
DDH: **CMR08-11b, 170.6m**
Sample: **NS11-05**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Compositionally banded, disseminated, honey-brown sphalerite, pyrite, galena and chalcopyrite within massive barite. Bands alternate sulfide-rich and sulfide-poor. Layering may be transposed?

Thin Section Observations:

Barite grains are very weakly elongate parallel the foliation. Pyrites are subhedral, rounded, disseminated grains and aggregates. Locally small round Sph inclusions in Py. Sphalerite grains are ragged-looking, whereas pyrite edges are clean and smooth. Galena is locally intergranular to barite, fills triple junctions.

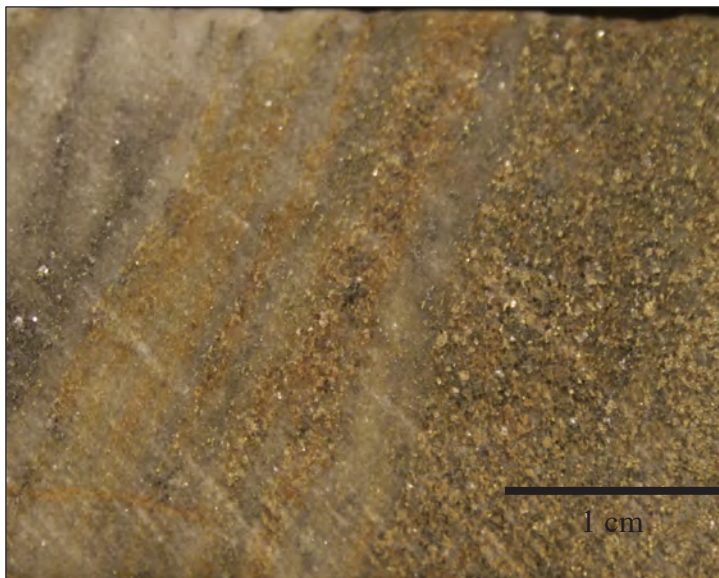
Sulfide bands vary in composition - one band is Py-Sph dominated, another of galena dominated and another of galena-cpy dominated, observed and between the two, get a mix of both, Py-Sph-Gal-Cpy. Galena and chalcopyrite are possibly replacing sphalerite? They occur around edges of large sphalerite grains. Locally get elongate stringers of galena and sphalerite. Magnetite present as euhedral crystal with sphalerite, galena and chalcopyrite. Locally rims around sphalerite are magnetite?? Possible Pyrrhotite replacing magnetite locally - although too fine-grained to be sure.

Mineralogy:

-Barite	70%
-Sphalerite	20%
-Pyrite	5%
-Chalcopyrite	1%
-Galena	3%
-Magnetite	trace

Grain Size:

vfg-fg
fg
vfg-fg
microcrystalline-fg
microcrystalline-fg
microcrystalline



TS ID: **11-06**
DDH: **CMR08-11b, 174.7m**
Sample: **NS11-06**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Foliated massive barite with fg disseminated honey-brown sphalerite, pyrite and trace chalcopyrite. Strands of sulfide follow foliation preferentially.

Thin Section Observations:

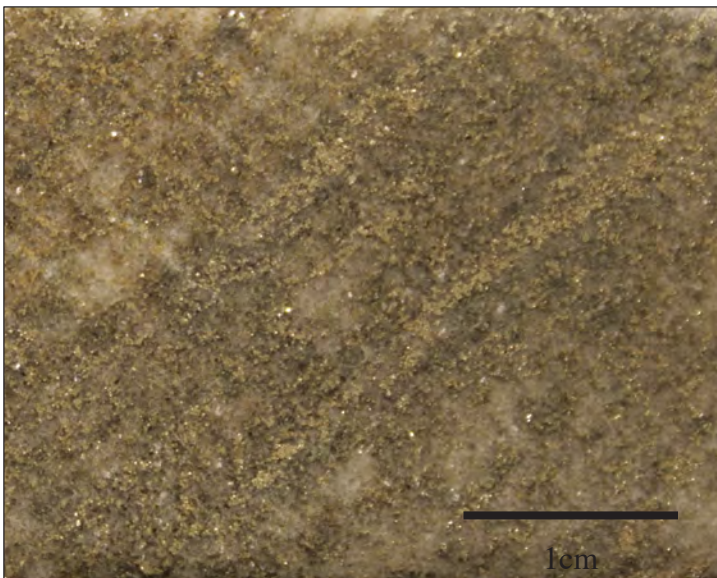
Mostly recrystallize, polygonal barite with sphalerite, pyrite, chalcopyrite. Pyrites are rounded to angular, euhedral to anhedral aggregates. Sphalerite is coarse, pale yellow IRs. Cpy disease in Sph. Very similar to 11-4 and 11-5. Barite has fuzzy rims. Local round blobs of tetrahedrite (pale greenish), being replaced by chalcopyrite typically. Trace magnetite, typically euhedral (cubes and triangles) disseminated. Trace arsenopyrite, also typically euhedral as bladed crystals and as cubes.

Mineralogy:

-Barite	65%
-Sphalerite	20%
-Pyrite	15%
-Chalcopyrite	<1%
-Tetrahedrite	trace
-Arsenopyrite	trace
-Magnetite	trace

Grain Size:

fg
fg
vfg-fg
vfg
vfg-fg
micro-vfg
micro



TS ID: **11-07**
DDH: **CMR08-11b, 177.3m**
Sample: **NS11-07**

Lithology: **Massive Pyrite Ore**
Alteration:

Hand Sample Observations:

Massive pyrite and chalcopyrite. Gangue is quartz. A weak foliation is defined by wisps of chalcopyrite and gangue.

Thin Section Observations:

Relatively no gangue - just minor barite with rare muscovite. Mainly subhedral to anhedral, rounded, heavily fractured and friable pyrite grains in a chalcopyrite and sphalerite matrix, and local traces of tetrahedrite and arsenopyrite. Cpy vs Sph dominated bands. Tetrahedrite and sphalerite seem to be closely associated. Weak foliation defined by banding. Rare trace of galena as tiny inclusions within sphalerite. Sph has clear IRs?

Geochemistry:

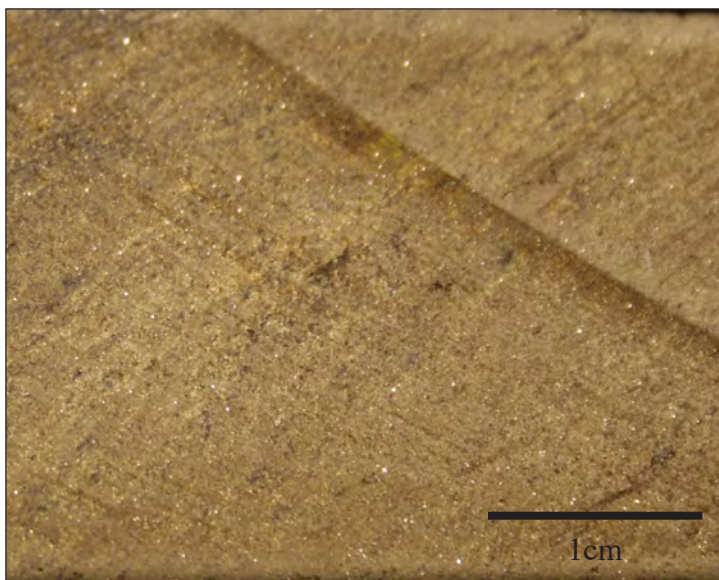
Very high Au, Ag, Sb and As. Relatively high Bi, same as other massive pyrite ores. High Co. No cobaltite found. High Mo, but no molybdenite found.

Mineralogy:

-Barite	3%
-Muscovite	trace
-Pyrite	40%
-Chalcopyrite	40%
-Sphalerite	15%
-Tetrahedrite	<1%
-Arsenopyrite	1%
-Galena	rare trace

Grain Size:

vfg
micro
micro-vfg
massive
vfg-fg
vfg
micro-fg
micro



TS ID: **11-08**
DDH: **CMR08-11b, 182.2m**
Sample: **NS11-08**

Lithology: **Massive Pyrite Ore**
Alteration:

Hand Sample Observations:

Massive, fg pyrite. Weak foliation .

Thin Section Observations:

Sample is mostly sub-anhedral, but locally euhedral pyrite grains, within cpy-sph-asp matrix. Minor barite identified as gangue. Barite is anhedral grains, filling spaces between sulfides. Sample is very porous, and much of gangue is likely gone, now filled with epoxy. Maybe have been Fe-Carb - judging from geochem. Chalcopyrite and sphalerite fill spaces between Pyrite grains, and as round inclusions within Pyrite. Pyrites are round, anhedral, friable and fractured grains, packed fairly tightly. Possible covellite along fractures in pyrite, and chalcopyrite. Locally sphalerite shows green IRs? There is approximately 5% empty space within section. Locally arsenopyrite replaces pyrite? Rare trace tetrahedrite with sphalerite and chalcopyrite - replaced by cpy?

Geochemistry:

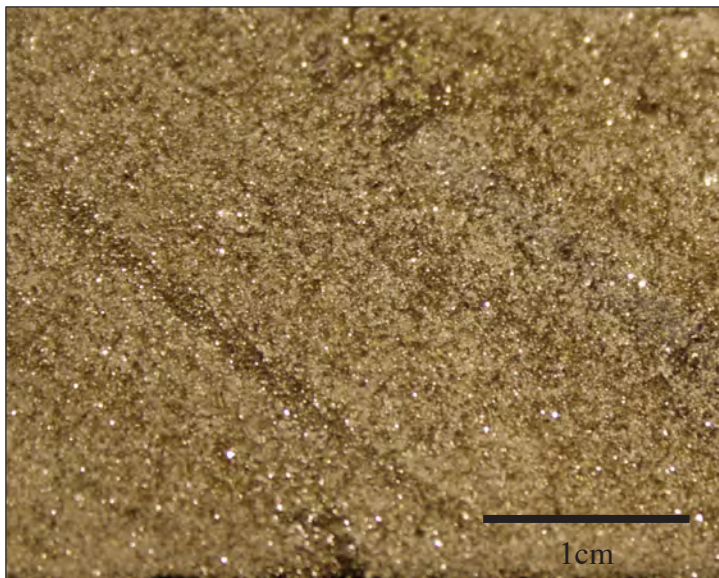
Sample contains high CO₂, but no Ca, Mn, or Mg. Could be from Fe-carbonate, however, much of gangue is gone. Moderate As and Sb, from arsenopyrite and tetrahedrite. Relatively high Bi, same as other massive pyrite ores.

Mineralogy:

-Barite	5%
-Muscovite	trace
-Pyrite	80%
-Sphalerite	10%
-Chalcopyrite	5%
-Arsenopyrite	<1%
-Tetrahedrite	trace
-Covellite	trace

Grain Size:

vfg
micro
micro-vfg
vfg
micro-vfg
vfg
micro-vfg
crypto?



TS ID: **11-09**
DDH: **CMR08-11b, 185.9m**
Sample: **NS11-09**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Weakly foliated, fg, equigranular, disseminated pyrite and pale brown sphalerite with barite. Sample is banded with varying ratios of barite/pyrite/sphalerite.

Thin Section Observations:

Mostly barite. Sphalerite exhibits Cpy-disease. Pyrites are rounded, subhedral to anhedral. No quartz. Arsenopyrite is common in trace amounts, as partial euhedral crystals adjacent pyrites, and locally overgrowing them. Pyrites exhibit atoll structures with sphalerite replacing/intergrowing. Cpy, gal, tetra and aspy appear later than py and sph. Locally cpy, tetra, galena and aspy exhibit a strange intergrown texture (pic).

Geochemistry:

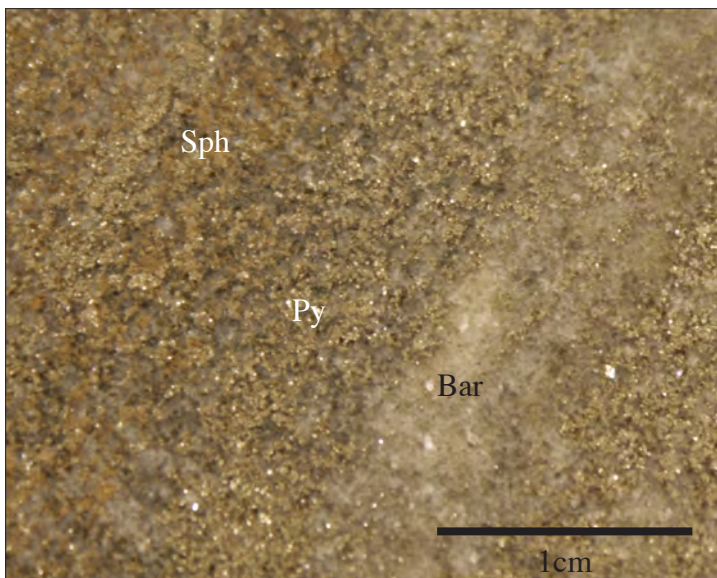
Very high As, represented by arsenopyrite. No significant gold or silver though.

Mineralogy:

-Barite	65%
-Pyrite	20%
-Sphalerite	10%
-Galena	trace
-Chalcopyrite	trace
-Tetrahedrite	trace
-Arsenopyrite	trace

Grain Size:

fg
vfg-fg
vfg-mg (massive)
micro
micro
micro-fg
micro



TS ID: 11-10
DDH: **CMR08-11b, 187.5m**
Sample: NS10-11

Lithology: Massive Pyrrhotite Ore
Alteration:

Hand Sample Observations:

Massive pyrrhotite, carbonate and quartz. Recrystallized. Trace chalcopyrite throughout.

Thin Section Observations:

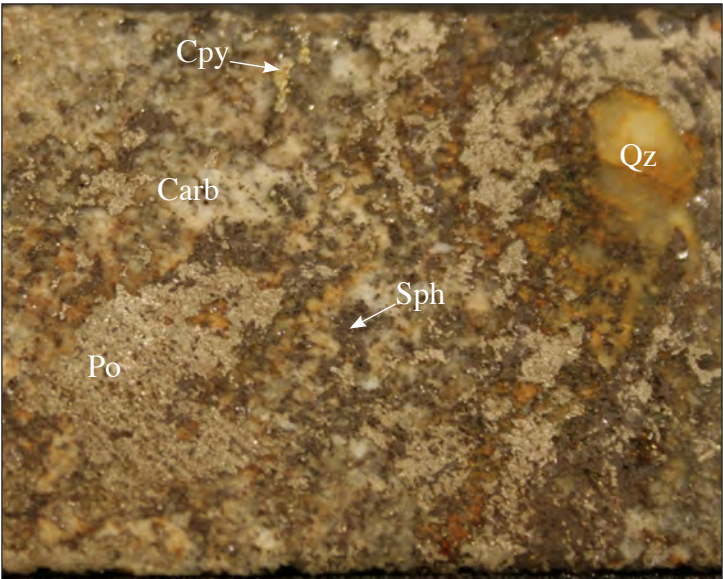
Mostly pyrrhotite and carbonate, with quartz and sphalerite. Very coarse grained. Muscovite crystal aggregates/fans disseminated throughout. Pyrite as birds eye replacement texture around pyrrhotite.

Mineralogy:

-Quartz	10%
-Carbonate	50%
-Muscovite	2%
-Pyrrhotite	20%
-Pyrite	1%
-Sphalerite	20%
-Chalcopyrite	1%

Grain Size:

fg-vcg
fg-mg
vfg
massive
micro
fg
vfg



TS ID: **11-11**
DDH: **CMR08-11b, 198.3m**

Lithology: **Argillite**
Alteration:

Hand Sample Observations:

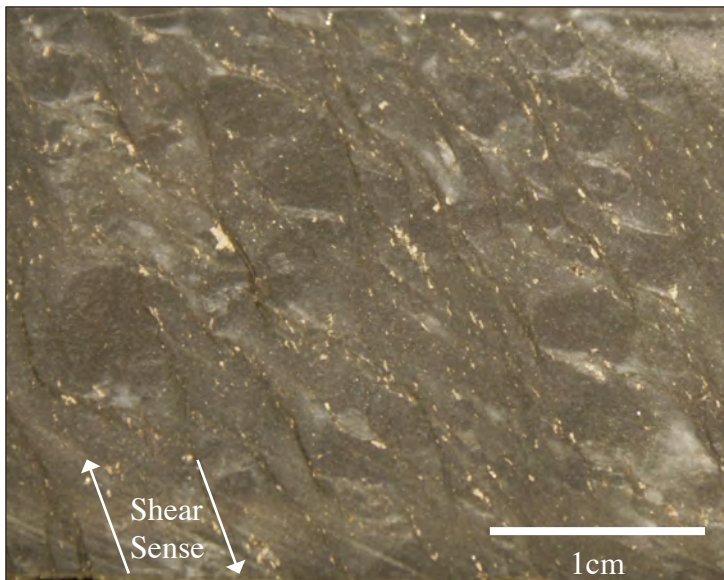
Calcite-rich, dark grey argillite. Minor (1%) disseminated Po. Sigma-style dextral shear sense indicators indicated by dark grey augens (<5 mm) with light grey tails. Foliation-parallel dissolution fabric (stylolites) outline shear planes, and locally resemble C-S fabric.

Thin Section Observations:

Mostly very fine calcite, with quartz, and numerous stylolites that contain trace muscovite(?). Disseminated Pyrrhotite throughout. Po is bladed, and trace Cpy observed within/at the edge of few grains. Sphalerite also observed at the edge of, and within Po grains - likely replacing Po in places.

Mineralogy:

-Calcite	70%
-Quartz	25%
-Pyrrhotite	5%
-Sphalerite	trace
-Pyrite	trace
-Chalcopyrite	trace



TS ID: **11-12**
DDH: **CMR08-11b, 207.0m**
Sample: **NS11-12**

Lithology: **Chert (with Py-Sph Stringers)**
Alteration: **mod sel. carbonate-albite**

Hand Sample Observations:

Completely silicified (or primary chert?) clast supported breccia, with calcite and sulfide matrix. Sulfide is fg honey-brown sphalerite and fg pyrite. Quartz is grey to white and amorphous.

Thin Section Observations:

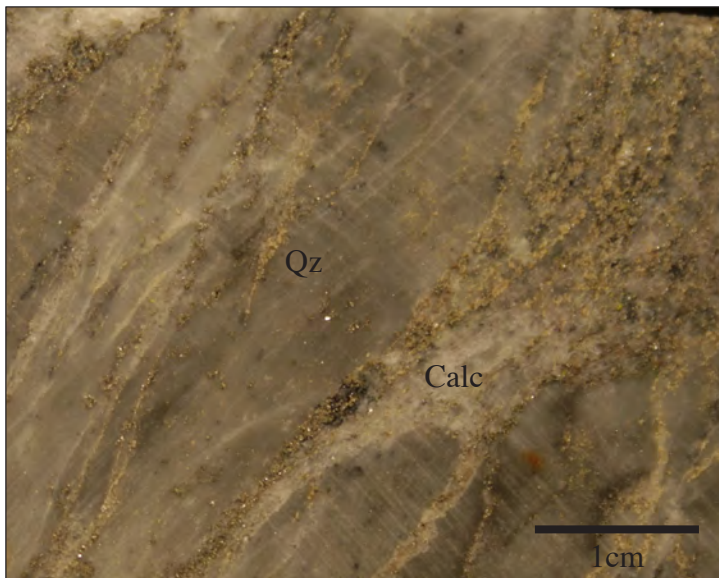
Mostly quartz, lesser calcite vfg sediment, cut by coarse quartz-plagioclase-calcite-muscovite-sulfide veinlets/stringers. Chert is vfg equant quartz crystals with trace amounts of intergranular muscovite. Abundant Py and Sphalerite in stringers. Sph has pale yellow IR. Py is euhedral to subhedral, and cubic. Cpy is fairly abundant, always forming grains with either Py or Sph. Galena is rare, only locally forming grains with Sphalerite.

Minor muscovite (sericite) associated with the veinlets/stringers. Minor calcite within the vfg quartz/chert, but most of it is within the stringers as coarse calcite. Abundant coarse plagioclase also within stringers, along with quartz, exhibiting distinct albite twinning.

Mineralogy:

-Quartz	65%
-Calcite	15%
-Albite	10%
-Muscovite	trace
-Pyrite	5%
-Sphalerite	5%
-Chalcopyrite	<1%
-Galena?	trace

:



TS ID: 11-13

DDH: CMR08-11b, 216.8m

Sample: none (no material remained)

Lithology:

Quartz-Chlorite breccia (Scoria breccia?)

Alteration:

strong quartz, chlorite, calcite

Hand Sample Observations:

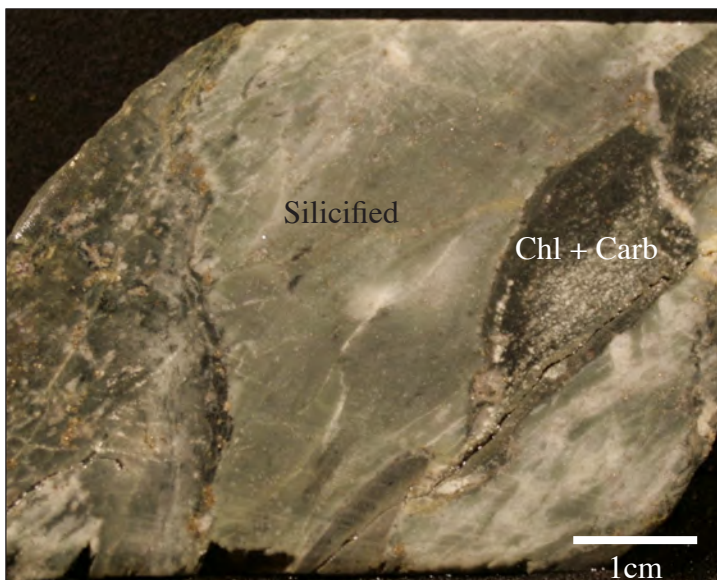
Appears to have large strongly chlorite altered clasts within a strongly silicified matrix(?). Clasts are cm-scale, as is matrix. Clasts contain abundant small calcite-filled amygdules, whereas lighter green silicified matrix is massive and aphanitic, although patchy pervasive calcite is present. Clast margins are sharply outlined, typically with a dark chlorite rind. Both clasts and matrix exhibit vfg disseminated pyrite. Could be scoria breccia?

Thin Section Observations:

Mostly quartz-chlorite matrix, cut by thin chlorite veinlets, and chlorite-carbonate (calcite) veins. Locally a section with muscovite(sericite) with the chlorite. Fg to cg euhedral, disseminated pyrites. Trace Cpy and Sph locally - rare.

Mineralogy:

-Chlorite	30%
-Quartz	40%
-Muscovite	2%
-Calcite	10%
-Pyrite	1%
-Sphalerite	trace
-Chalcopyrite	rare trace



TS ID: 11-14
DDH: **CMR08-11b, 238.0m**
Sample: NS11-14

Lithology: Volcaniclastic (large clasts?)
Alteration: strong Qz-Ser-Py with weak Carb, doml/select

Hand Sample Observations:

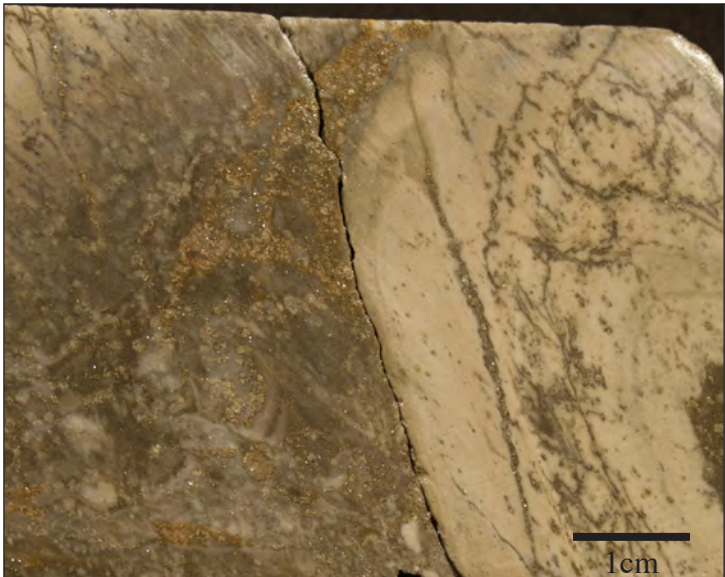
Altered volcaniclastic - breccia? Possibly large clasts or preferentially altered? Clasts are more quartz?

Thin Section Observations:

Quartz amyg(?) within a qtz-sericite matrix. Amygs also contain carbonate (calcite?), pyrite, muscovite, and the fan-shaped mineral. But mostly quartz. Also veins cutting matrix of the same assemblage.

Mineralogy:

-Quartz	10%
-Muscovite	70%
-Carbonate	5%
-Chlorite	<1%
-Pyrite	5%
-Sphalerite	1%
-Galena??	rare



TS ID: 11-15
DDH: **CMR08-11b, 252.2m**
Sample: NS11-15

Lithology: **Altered, volcanoclastic (breccia)**
Alteration: **strong sericite, quartz, pyrite**

Hand Sample Observations:

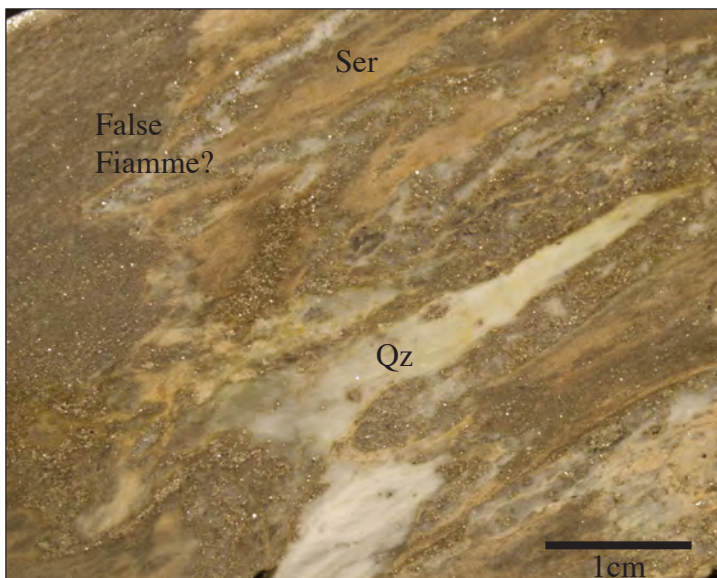
Strongly altered volcanic breccia. Clasts are wispy, and elongate parallel a strong foliation, and resemble fiamme (although may be false pyroclastic texture). Clasts appear polyolithic, however it is likely that this is a result of variable, patchy domain-style selective alteration. Part of the sample is more homogeneous, and may be part of a very large volcanic clast or fragment. This clast, and the matrix to the strongly quartz-sericite altered wispy clasts contains ~10% vfg disseminated pyrite.

Thin Section Observations:

Quartz augens in sericite matrix. Sericite is crenulated. Alternating quartz stringers and sericite stringers? Some sericite zones are pale green and pleochroic in PPL, although high birefringence. Most Py and Sph with the coarser Qtz stringers. Sulfide is vfg speckled throughout, to cg anhedral aggregates. Rare covellite, seems to be replacing Cpy.

Mineralogy:

-Quartz	40%	
-Muscovite	40%	
-Pyrite	20%	
-Sphalerite	1%	
-Chalcopyrite	rare trace	
-Covellite?	rare trace	(vfg bright blue)
-Mystery opaque	rare trace	



TS ID: 11-16
DDH: **CMR08-11b, 270.6m**
Sample: NS11-16

Lithology: **Altered volcanoclastic**
Alteration: **strong quartz, sericite, carbonate**

Hand Sample Observations:

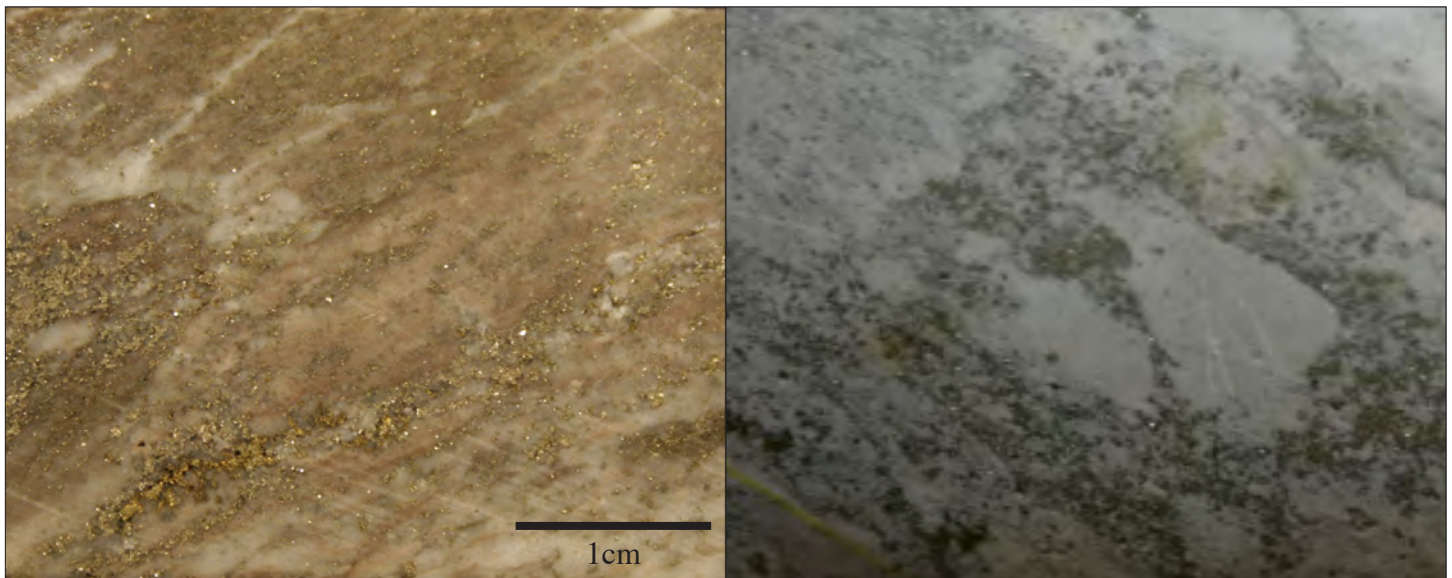
Very strongly quartz-sericite-pyrite altered rock. Possibly a coherent, or locally brecciated volcanic that has been pervasively and domain-type selectively altered. Small rounded fragments(?) may be preferential alteration along perlitic fractures, or perhaps just grain boundaries (feldspars/pyroxenes). Part of sample (back-side, see photo) exhibits definite breccia texture, with selectively white quartz altered clasts. May be in-situ selectively altered hyaloclastite within a more coherent volcanic?

Thin Section Observations:

Strange texture in carbonates - vuggy? Quartz veins cutting sample. Quartz grains within carbonate matrix - shows resedimented quality.

Mineralogy:

-Quartz	60%
-Muscovite	10%
-Carbonate	5%
-Albite	trace
-Pyrite	20%
-Sphalerite	3%
-Chalcopyrite	trace



TS ID: 11-17
DDH: **CMR08-11b, 274.6m**
Sample: **NS11-17**

Lithology: Altered Volcaniclastic, tuffaceous(?) rock
Alteration: **intense quartz, strong sericite**

Hand Sample Observations:

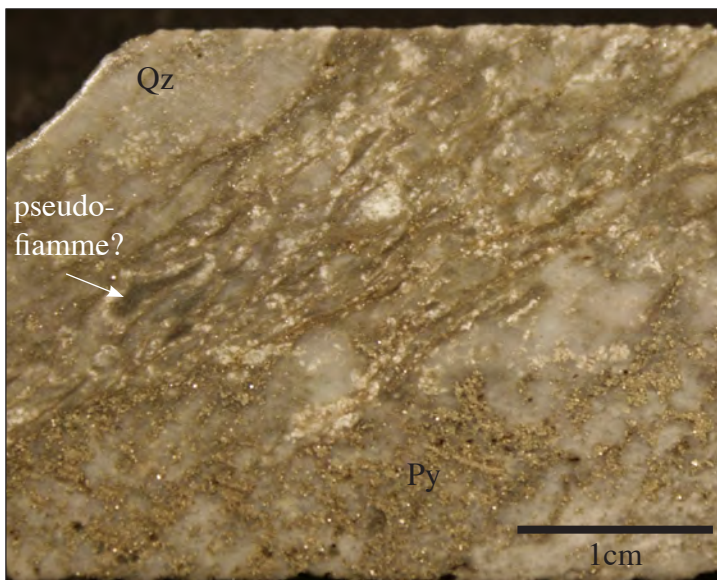
Intensely altered volcanic breccia. Maybe be scoria or pumice fragments. Fragments are strongly quartz and sericite altered. Matrix is mostly sulfide and sericite. Dark wispy chlorite fiamme (or pseudo-fiamme?) are aligned parallel a dominant, weak-moderate foliation. White speckles throughout clasts and matrix may be sulfide? Need thin section. Trace dark red sphalerite is present locally.

Thin Section Observations:

Local sphalerite crystals within quartz veins. Also very fine grained Sph spattered with pyrite. Quartz and sericite veinlets cut throughout. Trace carb locally, looks like little overprint. May be in part tuffaceous?

Mineralogy:

-Quartz	70%
-Muscovite	20%
-Carbonate	trace
-Pyrite	10%
-Sphalerite	<1%



TS ID: **11-18**
DDH: **CMR08-11b, 279.5m**
Sample: **NS11-18**

Lithology: Chert/Tuffaceous rock. Mineralized.
Alteration: strong carb

Hand Sample Observations:

Sample is from zone of massive sulfide and chert fragments. Uphole is layered chert, into massive sulfide with cm-scale rounded chert fragments/clasts floating. Sulfide is mainly disseminated Po(5%) and Cpy (15%), and minor fg magnetite(?). Gangue is mainly Carbonate (calcite).

Chert is grey, amorphous, not carbonate altered, and slightly layered (although likely not primary). Minor thin sulfide veinlets cut through chert.

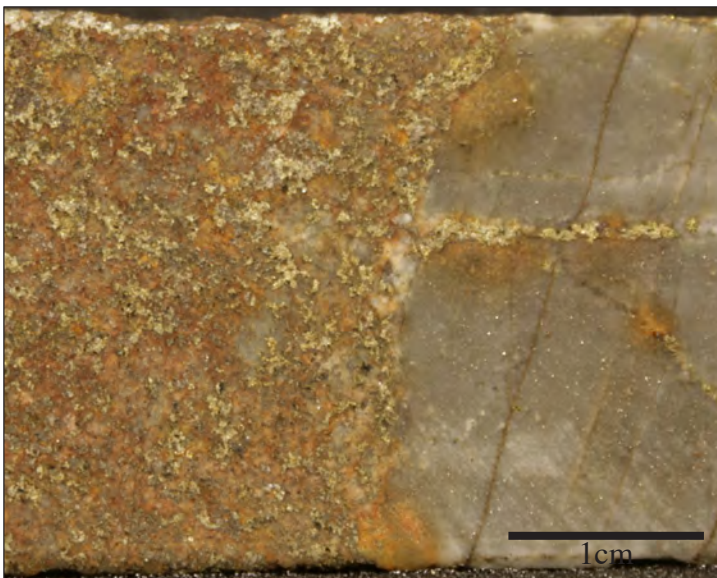
Thin Section Observations:

May be a thick stringer of qz-carb-sulfide cutting through or replacing chert? On either side of section are zones of vfg equant quartz - or chert (one of which may be a chert enclave in the stringer). Qtz and carb in sulfide zone is much coarser than in chert zone. Qtz in stringer is coarse aggregates, with coarse carbonate associated. Minor chlorite fans, and fanned needles within quartz, both within chert and stringer section (just finer grained in the cherts).

Fine grained bits of Cpy and Po throughout the calcite grains, and minor amounts in fractures through the quartz aggregates. Much of Pyrrhotite is replaced by radiating Pyrite crystals.

Mineralogy:

-Quartz	35%
-Calcite	30%
-Chlorite	1%
-Chalcopyrite	20%
-Pyrrhotite	10%
-Pyrite	5%
-Sphalerite	2%



TS ID: 11-19
DDH: CMR08-11b, 281.9m
Sample: NS11-19

Lithology: Barite-Quartz? Ore (resedimented?)
Alteration:

Hand Sample Observations:

Honey-brown coloured fg disseminated sphalerite and chalcopyrite along with minor sericite within massive barite. Weak banded look parallel a moderate foliation, with thin grungy brown and black bands (of sulfide).

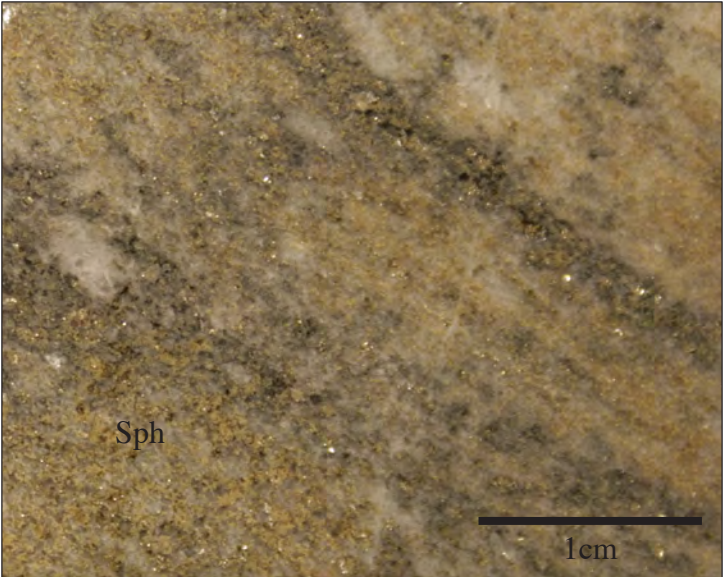
Thin Section Observations:

Barite and quartz, intergrown. Possibly resedimented, with evidence of quartz-sulfide clasts (pics). Sample has been strongly recrystallized/annealed. Pyrite as rounded, subhedral grains and aggregates. Py often looks like only weakly recrystallized framboids - could be protected within a clast?. Appears as though sulfides surrounded by quartz gangue are less recrystallized - perhaps quartz buffered the recrystallization? Cpy-Aspy-tetra after Pyrite, growing around and within fracs through pyrite. Cpy after Sphalerite, growing around edges, and as Cpy-disease within Sph. Galena after Cpy(?), growing around Cpy. Aspy as partial euhedra overgrowing py and sph?

Geochemistry:

Anomalously high W and Sn. No sign of wolframite or scheelite. No scheelite observed under short-wave UV.

Mineralogy:		Grain Size:	
-Barite	40%	fg	Seen in SEM
-Quartz	30%	fg	
-Sphalerite	20%	vfg-fg	
-Pyrite	5%	micro-fg	
-Chalcopyrite	5%	vfg-massive	
-Arsenopyrite	trace	micro	
-Tetrahedrite	trace	micro-vfg	
-Galena	trace	micro	



TS ID: **11-20**
DDH: **CMR08-11b, 285.8m**
Sample: **NS11-20**

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

Very weakly foliated massive barite with abundant disseminated sulfide - mostly pyrite and sphalerite, and lesser chalcopyrite. No banding, all massive with local concentrations of cpy or sph.

Thin Section Observations:

Gangue is all barite, coarse. Pyrite is granular, sub-euhedral. Sphalerite after pyrite, growing around and within fractures in pyrite. One large stringer through section containing mostly Sph and Cpy. Cpy after Sph - cpy disease and growing around Sph. Relatively abundant tetrahedrite in this sample, and typically associated with galena and aspy. Galena replaces tetrahedrite?. Often see typical strange texture of tetra, aspy, cpy ± galena. No magnetite.

Geochemistry:

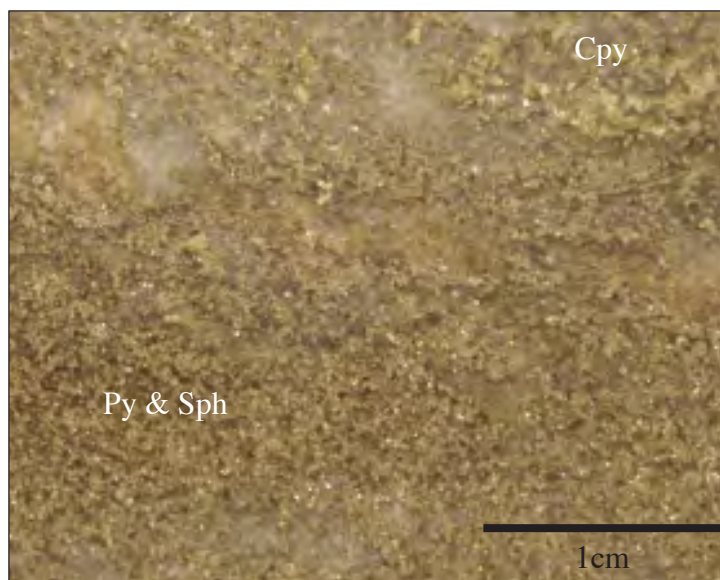
High Sb and Hg. Sb likely from abundant tetrahedrite. Relatively high Ag as well, possibly within Tetrahedrite. Very high REEs. No evidence as to why.

Mineralogy:

-Barite	50%
-Sphalerite	20%
-Pyrite	20%
-Chalcopyrite	10%
-Tetrahedrite	0.5%
-Galena	trace

Grain Size:

vfg-fg
micro-mg
vfg-fg
micro-fg
micro-fg
micro-vfg



TS ID: 11-21
DDH: **CMR08-11b, 290.6m**
Sample: NS11-21

Lithology: **Barite Ore**
Alteration:

Hand Sample Observations:

White to grey massive barite, interbanded with sulfide. Sulfide is disseminated throughout, but concentrated in sulfide-rich bands. Sulfide is dominantly honey-brown/yellow sphalerite, with lesser Pyrite, galena and chalcopyrite. Mineralization is vfg. Banding is parallel a moderate foliation, and <5 mm thick.

Thin Section Observations:

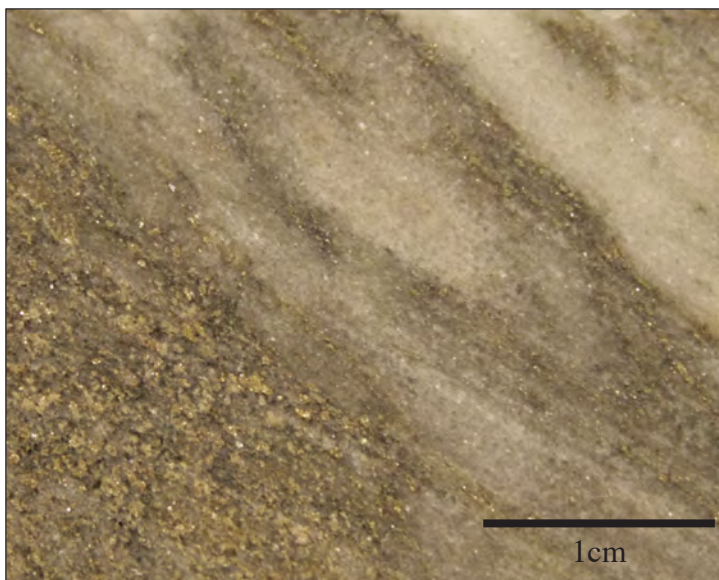
Sample is barite and sphalerite dominated ore. Sample appears to have thin shears, or veinlets of muscovite and sulfide cut through undeformed, more equant barite crystals. Around these veinlets, barite crystals are elongate parallel foliation, and sheared-looking. Quartz is present locally throughout barite, and in large concentration where the most sulfide is. Part of sample resembles 11-19.

Mineralogy:

-Barite	60%
-Quartz	10%
-Muscovite	1%
-Sphalerite	15%
-Pyrite	10%
-Galena	2%
-Chalcopyrite	0.5%
-Tetrahedrite	trace
-Arsenopyrite	trace

Grain Size:

vfg
vfg
micro
vfg-fg
vfg-fg
vfg-fg
vfg
vfg
micro



TS ID: **11-22**
DDH: **CMR08-11b, 296.1m**
Sample: **NS11-22**

Lithology: **Chert** (Cpy stringer)
Alteration:

Hand Sample Observations:

Clast supported quartz breccia may have been chert (primary exhalative). Hydrothermal quartz breccia clasts (grey) have white quartz matrix. Sulfide stringers cut variably through sample, following matrix, containing Chalcopyrite (3%), pyrite (5%), and dark grey metallic mineral - sulfosalts? (2%). Locally unit contains sphalerite, although none visible in sample. Locally Chlorite (or other green mica) within sulfide stringers.

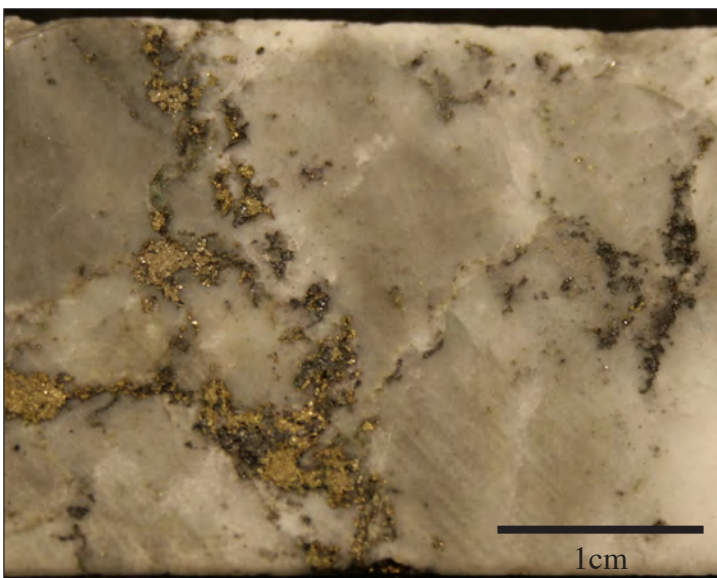
Thin Section Observations:

Sample is mostly quartz, vfg groundmass cut by coarser, thin quartz veinlets, and later, thicker, and even coarser quartz-sulfide-muscovite veinlets.

Sulfides occur as stringers, except for minor vfg disseminated pyrite grains throughout the chert. Pyrite, chalcopyrite and Sphalerite are the dominant sulfides. Nearly 1% tetrahedrite(?) also occurs associated with the Cpy. Under RL, it is medium grey, isotropic, associated with Cpy, Gal, and locally Cu and Diginite(?). Diginite is grey-Blue, and occurs around the edges of Tetrahedrite, and locally Galena. Pyrite often appears as aggregates? (kind of creamy - could it be Po?)

Mineralogy:

-Quartz	90%
-Muscovite	trace
-Chalcopyrite	3%
-Pyrite	3%
-Sphalerite	3%
-Tetrahedrite??	~1%
-Galena	trace
-Diginite	rare trace



TS ID: 11-23
DDH: **CMR08-11b, 301.1m**
Sample: **NS11-23**

Lithology: Altered Tuffaceous-volcaniclastic? rock
Alteration: Variable quartz, sericite, carb, barite, albite

Hand Sample Observations:

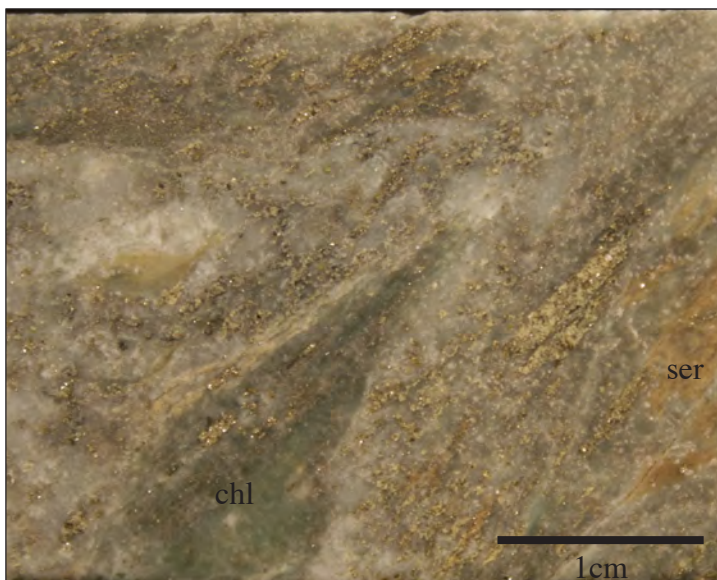
Strongly quartz-sericite-sulfide altered fragmental rock. Appears polyolithic, likely due to variable selective alteration of fragments - see image. Carbonate alteration occurs as very small (<1mm) round blebs throughout - may have been amygdules? Sulfide is disseminated, with local aggregates of pyrite (10%) and sphalerite (5%).

Thin Section Observations:

Quartz-Sericite groundmass, with coarser 'stringers?' of plag-barite-qtz-musc-sulfide. Complicated texture. Rare trace galena with Sph-Tetrahedrite locally.

Mineralogy:

-Quartz	40%
-Muscovite	40%
-Carbonate	7%
-Barite	1%
-Plagioclase	1%
-Sphalerite	5%
-Pyrite	5%
-Tetrahedrite	<1%
-Chalcopyrite	trace
-Galena	rare trace



TS ID: 11-24
DDH: **CMR08-11b, 307.1m**
Sample: NS11-24

Lithology: **altered volcanoclastic (hyaloclastite?)**
Alteration: **strong selective quartz-sericite**

Hand Sample Observations:

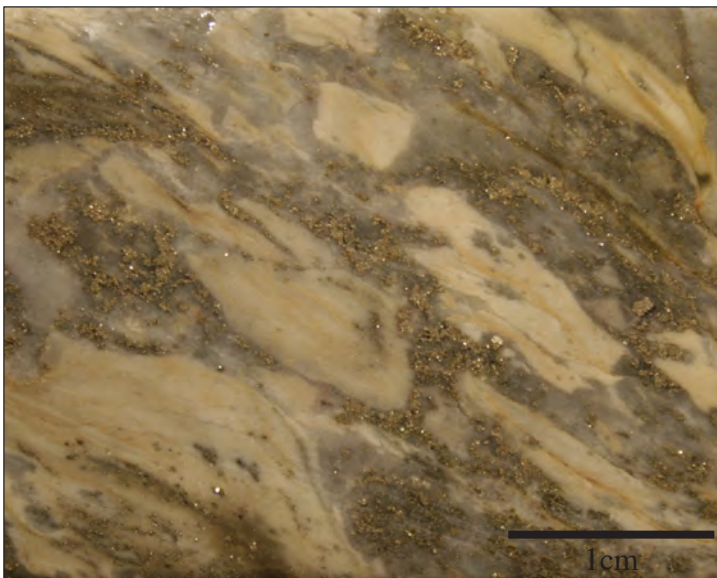
Pervasive quartz alteration of matrix and clasts, with selective sericite alteration of clasts/fragments. Frags are very hard and silicified, but sericite is visible. Clasts are angular, locally curvilinear and may be altered, deformed hyaloclastite. Sulfide makes up much of matrix along with translucent quartz. Sulfide is mainly pyrite (15%). No significant base or precious metal mineralization.

Thin Section Observations:

Coarse Qz veins cut through vfg qtz-musc clasts. Clasts are broken apart locally - jigsaw. Pyrite as vfg to vcg anhedral disseminated throughout veins, and as massive aggregates. Mostly within qtz-veins.

Mineralogy:

-Quartz	50%
-Muscovite	35%
-Pyrite	15%
-Chalcopyrite	rare trace
-Sphalerite	rare trace



TS ID: 11-25
DDH: **CMR08-11b, 315.4m**
Sample: NS11-25

Lithology: **altered volcanoclastic (hyaloclastite?)**
Alteration: **strong pervasive quartz, weak sericite**

Hand Sample Observations:

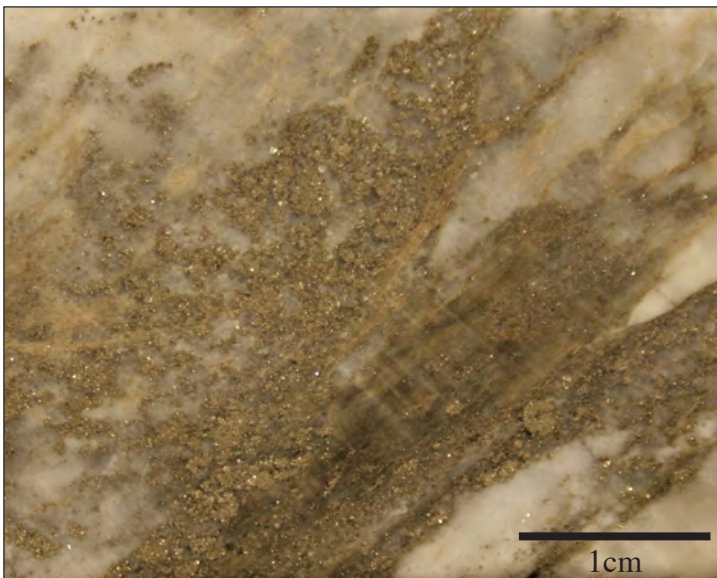
Similar to above sample, with large quartz altered clasts floating in a sulfide matrix. Clasts are fractured and broken, and up to 3cm across (in sample anyhow). Clasts are blocky and irregular. Minor sericite locally in matrix, and as thin veinlets filling fractures in clasts and through matrix. Matrix is mostly fg pyrite, and quartz. Pyrite forms as aggregates - (colliform??) and disseminations.

Thin Section Observations:

Clasts of fg qtz-muscovite, cut by coarser qtz-veins, and also bands of sericite (clasts?). Pyrite as euhe-dral, fg-cg disseminations restricted to qtz-muscovite stringers. Sph as vfg speckles disseminated with pyrite.

Mineralogy:

-Quartz	50%
-Muscovite	30%
-Pyrite	20%
-Sphalerite	<1%



TS ID: 11-26
DDH: **CMR08-11b, 319.8m**
Sample: NS11-26

Lithology: altered Hyaloclastite, false polymict?
Alteration: strong selective quartz and sericite

Hand Sample Observations:

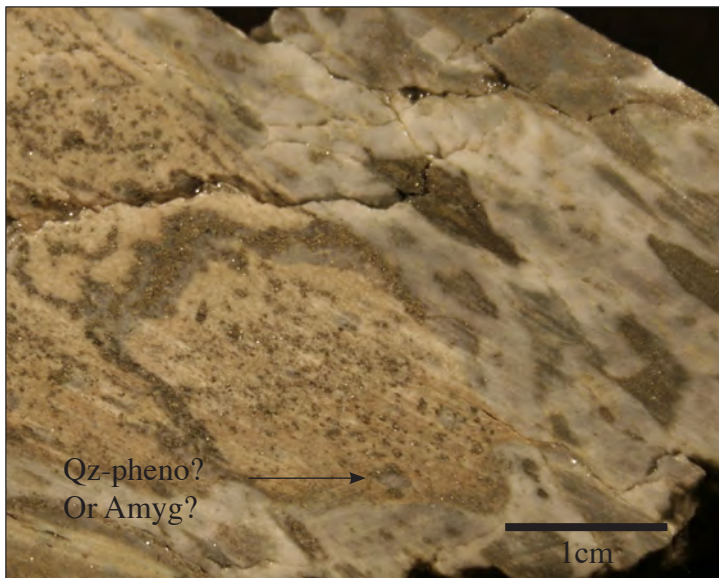
Matrix-supported breccia, with hyaloclastic fragments. Clasts are curvilinear, angular, and locally jigsaw fit. Clasts appear polymictic, but may be an effect of alteration. Smaller clasts are dark grey, while large clasts are lighter coloured, and amygdaloidal (or quartz-phyric??). Pervasive quartz alteration of the matrix may give it a more matrix-supported look than original(?).

Thin Section Observations:

Hyaloclastite? Clasts are muscovite-pyrite and very porous(?). Matrix is quartz-muscovite. Large clast has pods(?) of fuzzy vfg quartz. Wormy texture. Also pods, or augens of qtz-sulfide in larger clasts (amygs?). Vfg sphalerite disseminated throughout as tiny droplets. Pyrite as very coarse euhedral to subhedral crystals, and also as fg splatterings through clasts.

Mineralogy:

-Quartz	35%
-Muscovite	50%
-Pyrite	15%
-Sphalerite	1%



TS ID: 11-27
DDH: **CMR08-11b, 332.1m**
Sample: NS11-27

Lithology: altered volcanoclastic
Alteration: strong pervasive chl, ser, weak perv quartz

Hand Sample Observations:

Large chloritic clasts within a quartz-sericite altered matrix. Sulfide (pyrite) is disseminated throughout, and concentrates in bands parallel to foliation. Chlorite clasts are lenticular, elongate parallel foliation, and from 1mm to 6cm across. Likely an altered, deformed volcanic breccia (hyaloclastite??).

Thin Section Observations:

Clasts of chlorite in a quartz-rich matrix. Much of fg sulfide is within the clasts, as subhedral to euhedral pyrite and elongate tabs of sphalerite.

Mineralogy:

-Quartz	50%
-Chlorite	30%
-Sericitite	2%
-Carbonate	3%
-Pyrite	15%
-Sphalerite	1%



TS ID: 13-01
DDH: **CMR08-13, 120.2m**
Sample: NS13-01

Lithology: altered feldspar-phyric basalt
Alteration: mod pervasive chl-ser, mod sel. carb-ser-quartz

Hand Sample Observations:

Weakly pervasively magnetic, weakly carb altered feldspar phenos, and pervasive chlorite (meta?). Feldspars are elongate parallel a weak foliation. Streaks of Sericite parallel foliation? Subtle Po?Py?.

Thin Section Observations:

What appear to have been feldspar phenos(?) altered to quartz, muscovite, carbonate, and chlorite. Groundmass is sub-micro dark grungy, and chlorite and muscovite. Numerous small chlorite phenos. Fewer larger altered Feldspar phenos. Cut by chl-carb-sulfide veins. Patches of groundmass locally contain more muscovite, or more chlorite. Altered feldspar phenos are now very diffuse, and irregularly shaped. Sulfides are mostly in veins, and locally as blebs.

Mineralogy:

-Chlorite	70%
-Muscovite	20%
-Carbonate	5%
-Quartz	5%
-Pyrrhotite	3%
-Sphalerite	trace
-Chalcopyrite	trace
-Leucoxene	trace



TS ID: 13-02
DDH: **CMR08-13, 159.8m**
Sample: NS13-02

Lithology: Feldsphyric basalt
Alteration: weak perv chl, weak sel. quartz

Hand Sample Observations:

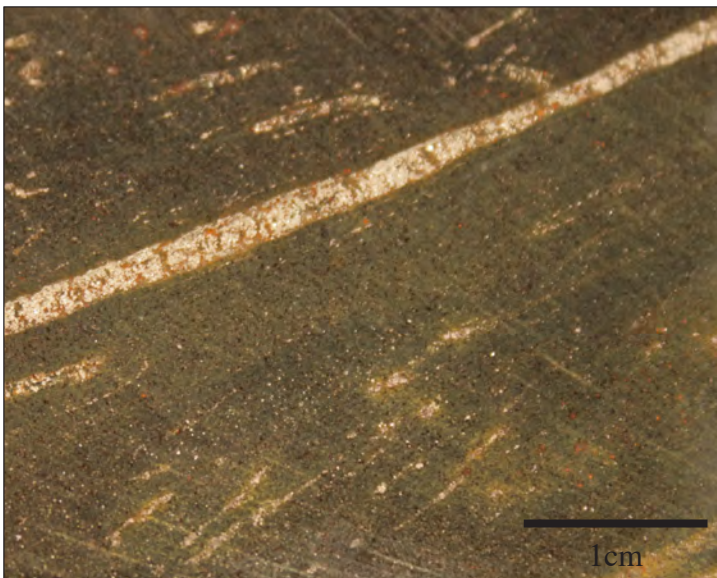
Weakly pervasively magnetic. Pervasive chlorite (although probably meta), Pyrite as stringers and disseminations, as well as dashes parallel foliation.

Thin Section Observations:

Fine Chlorite, biotite(?) and plagioclase phenos throughout grungy dark matrix. Chl--quartz-sulfide veins cut sample. Locally larger quartz phenos (amygs??). Coarse pyrite crystals (sub-euhedral), locally replaced by Cpy and Po and rarely Sph. Locally Po contains inclusions of Py.

Mineralogy:

-Chlorite	50%
-Biotite	10%
-Plagioclase	30%
-Quartz	<1%
-Pyrrhotite	3%
-Pyrite	7%
-Chalcopyrite	trace
-Sphalerite	trace
-Leucoxene	trace



TS ID: 13-03
DDH: **CMR08-13, 165.2m**
Sample: NS13-03

Lithology: altered volcaniclastic
Alteration: strong pervasive-selective quartz-ser-pyrite

Hand Sample Observations:

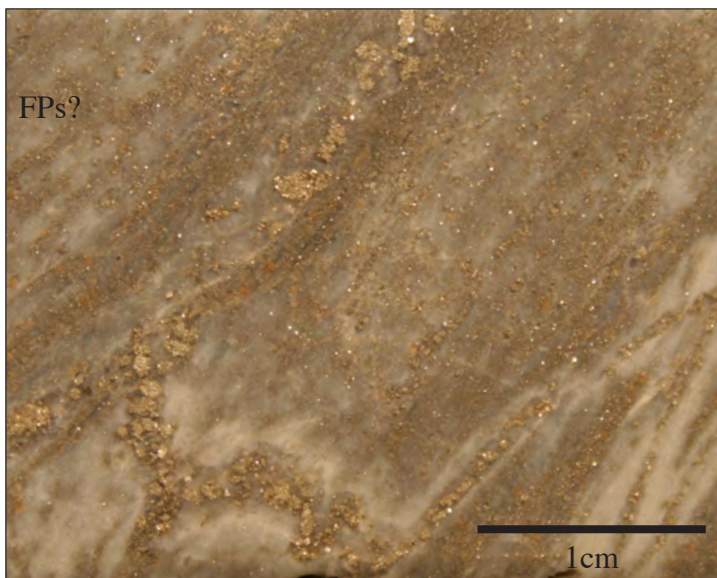
Likely a coherent massive mafic volcanic, with possible feldspar phenos(?), cut by numerous alteration stringers of pyrite, with quartz-sericite selvages.

Thin Section Observations:

Groundmass is mostly vfg muscovite, with minor vfg quartz. Cut by coarse quartz-chlorite-sulfide veins. Chlorite is clear? Disseminated mg quartz and sulfide throughout, as diffuse alteration (2nd-phase?). Sulfide is sub-euhedral fg to vcg pyrite cubes, with rare trace Cpy and Sph. Disseminated leucoxene throughout.

Mineralogy:

-Muscovite	60%
-Quartz	20%
-Chlorite	1%
-Pyrite	20%
-Chalcopyrite	trace
-Sphalerite	rare trace
-Leucoxene	trace



TS ID: 13-04
DDH: **CMR08-13, 173.6m**
Sample: NS13-04

Lithology: Pyrrhotite-Chalcopyrite Stringers
Alteration: intense quartz, weak-mod muscovite

Hand Sample Observations:

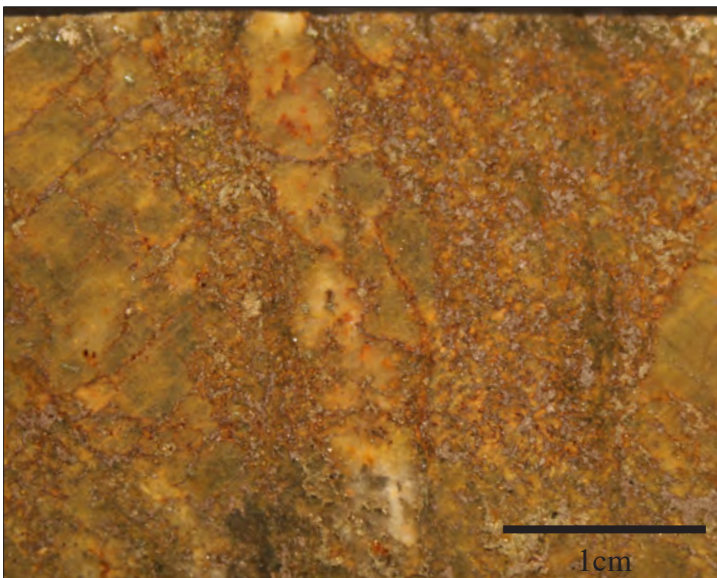
Brecciated quartz clasts within a matrix cut by thin quartz-pyrrhotite-chalcopyrite stringers. Banded over 2-5 cm intervals with more clast-supported zones and more Po-rich zones. Up to 10% chalcopyrite within matrix with Po.

Thin Section Observations:

Coarse quartz veinlets cutting vfg quartz-chlorite matrix - (intensely silicified mafic volcanic?). >50% veinlets of varying size. Sericite veinlets cut through all (except sulfide?). Sulfide veinlets composed of Cpy, Po, and minor Sph. Trace Py replaces Po around edges and fractures with as bird's eye texture. Cpy also replacing Po around edges and fractures.

Mineralogy:

-Quartz	65%
-Muscovite	10%
-Albite	trace
-Chlorite	trace
-Pyrrhotite	10%
-Chalcopyrite	10%
-Sphalerite	trace
-Pyrite	trace



TS ID: **13-05**
DDH: **CMR08-13, 178.6m**
Sample: **NS13-05**

Lithology: Pyrrhotite-chalcopyrite stringers
Alteration: strong quartz, mod muscovite

Hand Sample Observations:

Pyrrhotite and chalcopyrite stringers through a quartz-muscovite gangue.

Thin Section Observations:

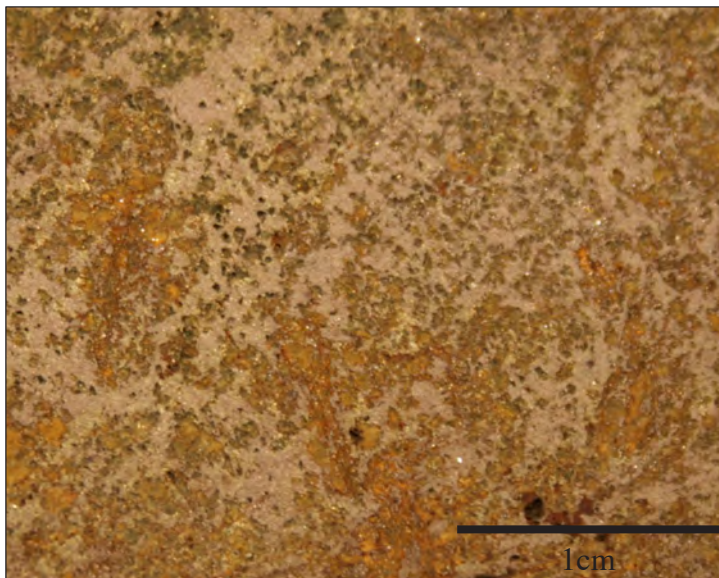
Sulfide stringers cut through equant quartz groundmass. Discontinuous muscovite stringers also cut by sulfides. Sphalerite has deep red IRs. Po replaced around edges and fractures by colloidal pyrite (bird's eye). Sulfide is massive po replaced by stockworks of cpy. Local megacrysts of pyrite, up to 2 mm. Possible trace carbonate(?) or Fe-Carb locally as grungy, orange oxidized grains. Minor thin veinlets of pyrite-carbonate (possibly Fe-Carb) cut all.

Geochemistry:

Anomalous Sn (23ppm).

Mineralogy:

-Quartz	25%
-Muscovite	15%
-Carbonate(??)	trace
-Pyrrhotite	40%
-Chalcopyrite	15%
-Pyrite	2%
-Sphalerite	2%



TS ID: 13-06
DDH: **CMR08-13, 191.7m**
Sample: NS13-06

Lithology: altered volcanoclastic (hyaloclastite)
Alteration: strong pervasive quartz-sericite

Hand Sample Observations:

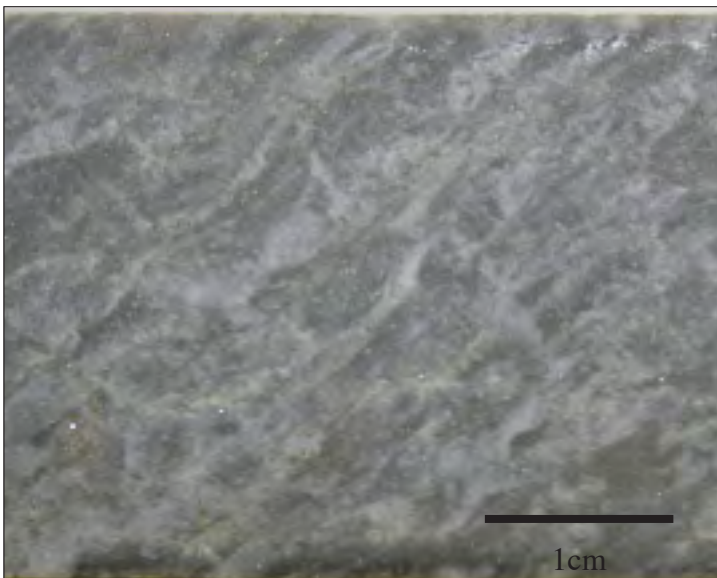
Altered hyaloclastite, with typical curvilinear fragments indicating in situ quenching and brecciation. Alteration locally masks primary texture.

Thin Section Observations:

Clasts are sericite-pyrite altered, with lesser quartz, vs matrix which is coarser, and mostly quartz with lesser sericite.

Mineralogy:

-Quartz	40%
-Muscovite	40%
-Pyrite	20%
-Chalcopyrite	trace
-Sphalerite	trace



TS ID: 13-07
DDH: **CMR08-13, 197.4m**
Sample: NS13-07

Lithology: altered volcanoclastic
Alteration: strong quartz-muscovite

Hand Sample Observations:

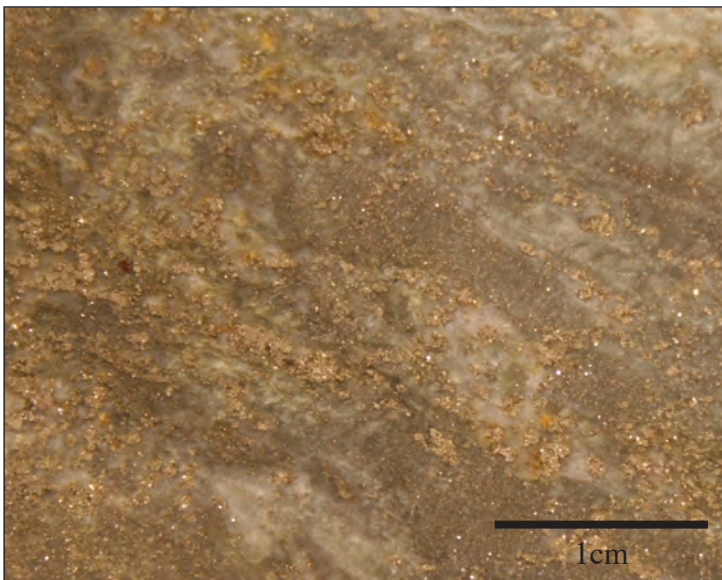
Altered volcanoclastic, with 1 mm - 3 cm clasts. Clasts have wispy to curvilinear outlines, often with a jig-saw fit. Clasts are muscovite altered. Matrix is composed of granular pyrite. Some clasts exhibit a darker outline.

Thin Section Observations:

Clasts are pervasively muscovite altered, with abundant disseminated micro-vfg, euhedral-subhedral pyrite. Matrix to the clasts is vfg-fg quartz, muscovite and sulfide. Minor albite locally(?) as cloudy, irregularly shaped crystals often partially replaced by muscovite. Not well twinned, however sample contains 0.4% Na₂O, suggesting 3-5% albite. Albites are not equant as quartz. Much of muscovite is microcrystalline or smaller, as cryptocrystalline sericite. Pyrites within clasts are micro-vfg. Pyrites within matrix are vfg-fg and as aggregates.

Mineralogy:

-Muscovite	50%
-Quartz	25%
-Albite	5%
-Pyrite	20%
-Chalcopyrite	1%
-Sphalerite	1%



TS ID: 13-8
DDH: CMR08-13, 212.2m
Sample: NS13-08

Lithology: Barite Ore
Alteration:

Hand Sample Observations:

Massive sulfide and barite.

Thin Section Observations:

Mostly Barite and Pyrite. Rare traces of muscovite here and there, no preferred orientation. Outlines of barite are grungy, and altered. Pyrite as aggregates of rounded, subhedral crystals. Pyrite NOT fractured as seen in many other samples. Sph and Cpy surround pyrite. Rare trace of microcrystalline galena with chalcoppyrite and within pyrites.

Geochemistry:

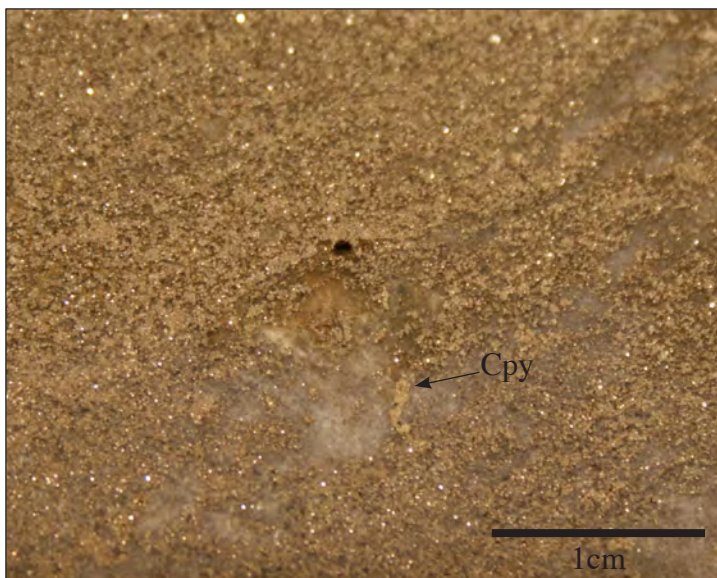
Very low Hg compared to other Barite ores, possibly due to low sphalerite content.

Mineralogy:

-Barite	60%
-Muscovite	rare trace
-Pyrite	35%
-Chalcopyrite	5%
-Sphalerite	<1%
-Galena	rare trace

Grain Size:

vfg-fg
micro
vfg-fg
vfg-fg (massive?)
micro
micro



TS ID: **13-09**
DDH: **CMR08-13, 229.0m**
Sample: **NS13-09**

Lithology: Barite-Carbonate Ore
Alteration:

Hand Sample Observations:

Granular mix of vfg euhedral-subhedral pyrite and vfg calcite and barite. Chalcopyrite spatially associated with larger calcite blebs/patches.

Thin Section Observations:

Domainal gangue - part of sample is dominated by barite with minor carbonate, other part is dominated by carbonate with local pods of barite grains. Contact between two domains has intermixed barite and carbonate. Carbonate is replacing barite (pic) - observed locally near domain contact, between barite grains, and surrounding and replacing barites. Most of chalcopyrite is present within barite-gangue domain. Texturally, the sample is all the same. Somewhat rounded, subhedral pyrite grains disseminated throughout. Local concentrations of chalcopyrite and sphalerite surround pyrites. Pyrites are full of little holes - fluid inclusions?

Geochemistry:

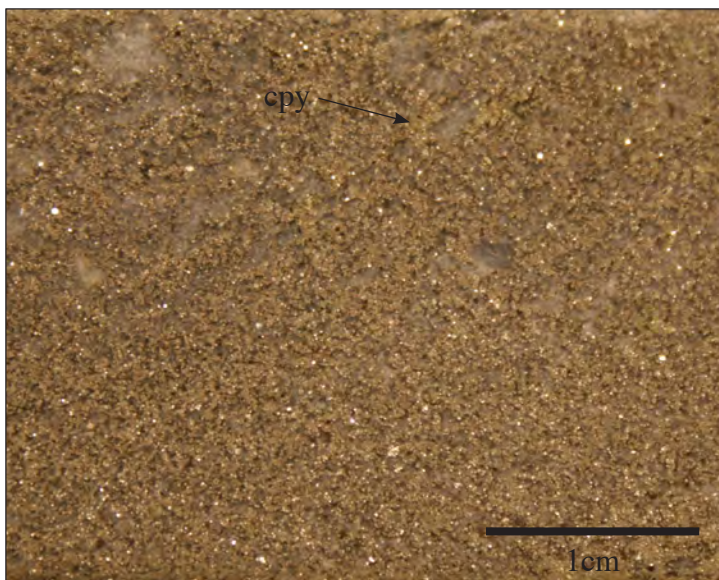
Moderate Ca, Mn and Mg, correlative with carbonate. Very low Sb and As unlike most barite ores. Very low Cd. Low Hg compared to barite ores. Low Au and Ag as well.

Mineralogy:

-Carbonate	40%
-Barite	20%
-Pyrite	30%
-Sphalerite	7%
-Chalcopyrite	3%

Grain Size:

vfg-mg
vfg-fg
vfg-fg
vfg-fg
vfg-fg



TS ID: **13-10**
DDH: **CMR08-13, 239.7m**
Sample: **NS13-10**

Lithology: Barite-Carbonate Ore
Alteration:

Hand Sample Observations:

Massive sulfide, quartz(?), barite(?) and carbonate. Bands of barite/calcite define a weak foliation. Local boudins of barite(?) form augens.

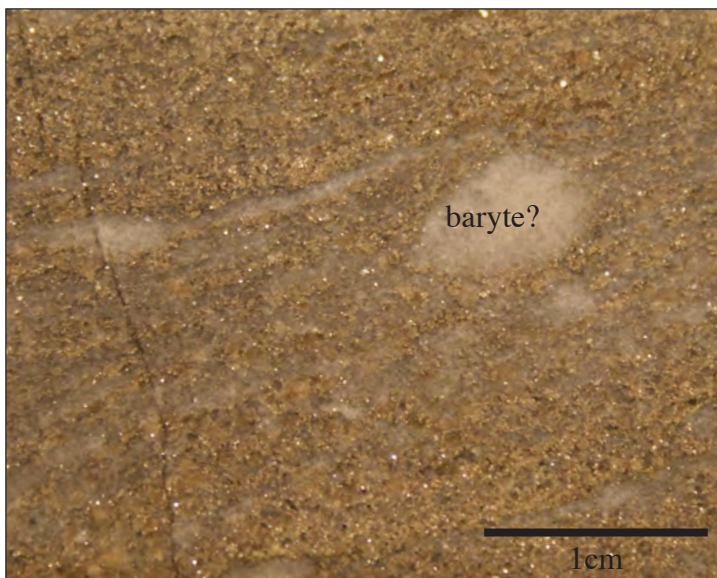
Thin Section Observations:

Appears to be barite-sulfide cut by stringers of carbonate. Carbonate replaces barite(?). Throughout the rounded anhedral recrystallized barite grains are large, euhedral, oscillatory zoned, polygonal crystals of (barite/quartz?) These crystals may be primary? Polygonal crystals have been weakly replaced by carbonate - appear corroded around rims. Two distinct domains of basically the same thing. One domain has more barite-carb and is fg, other domain is more sulfide, and more large euhedral xtals of quartz? and large anhedral crystals of carbonate.

Pyrite overgrows both the anhedral calcite and the barite, but not the euhedral quartz?.

Mineralogy:

-Barite	25%
-Carbonate	35%
-Muscovite	trace
-Pyrite	30%
-Galena	trace
-Chalcopyrite	1%
-Sphalerite	trace



TS ID: 13-11
DDH: **CMR08-13, 242.7m**
Sample: NS13-11

Lithology: Altered volcaniclastic (Tuff?) (Py-Sph Stringers)
Alteration: intense quartz-muscovite, weak carb

Hand Sample Observations:

Locally larger patches of pyrite and carbonate together. Weak foliation defined by muscovite (better seen on back of sample).

Thin Section Observations:

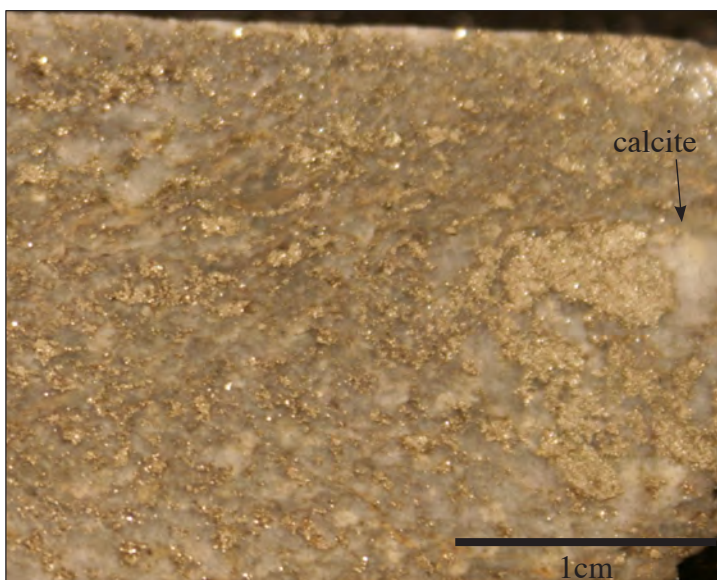
Quartz-muscovite altered groundmass, cut by disconnected stringers of coarse quartz-pyrite. Fine grained crystals of carbonate disseminated throughout, and appear partially replaced by quartz and muscovite around rims - may have been amygdules? Also disseminated large grains of sub- to euhedral albite, partially replaced by quartz and muscovite - may have been phenocrysts? Ba-feldspar throughout, anhedral and partially replaced by muscovite (likely Ba-rich musc). Locally domains/pods of muscovite and pods of vfg equant quartz. Chlorite fans disseminated, typically replacing albite? and associated with coarse sulfide. Late carbonate veins up to 1 mm wide cut everything.

Geochemistry:

Approximately 11,000 ppm Ba present in sample, likely as barium-feldspar and as Ba within muscovites. Contains over 1% Na₂O as well, suggesting both albite and Ba-feldspar present.

Mineralogy:

-Quartz	25%
-Muscovite	30%
-Ba-Feldspar	7%
-Albite	3%
-Carbonate	5%
-Chlorite	2%
-Barite?	trace?
-Pyrite	25%
-Sphalerite	3%
-Chalcopyrite	1%



TS ID: 13-12
DDH: **CMR08-13, 251.0m**
Sample: NS13-12

Lithology: altered volcanoclastic (Tuff?)
Alteration: strong quartz-ser

Hand Sample Observations:

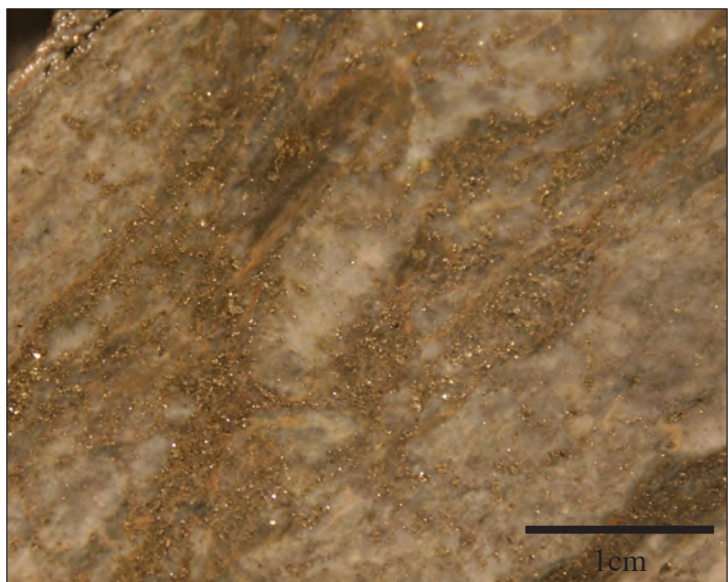
Strongly altered, moderately foliated volcanoclastic of sorts. Clasts are rounded, and altered with fuzzy edges - so not a good hyaloclastite. Clasts are more quartz-sericite altered, and matrix is more pyrite.

Thin Section Observations:

Quartz clasts separated by musc-py stringers. May be in part tuffaceous?

Mineralogy:

-Quartz	40%
-Sericitic	40%
-Pyrite	10%
-Chalcopyrite	trace
-Sphalerite	trace



TS ID: 13-13
DDH: **CMR08-13, 293.2m**
Sample: NS13-13

Lithology: altered volcaniclastic
Alteration: strong pervasive quartz-ser-pyrite

Hand Sample Observations:

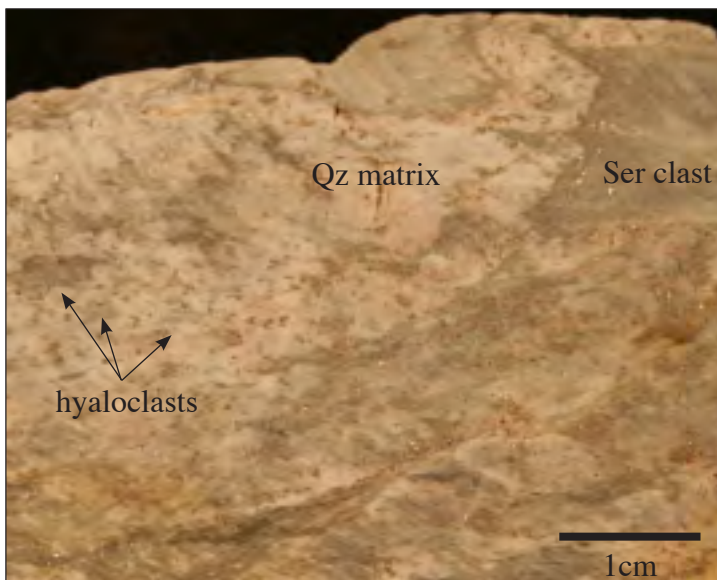
Quartz altered matrix, more grey coloured, sericite altered clasts. Clasts are curvilinear, from 3mm-2cm in size and locally jigsaw fit (see photo). Vfg pyrite forming on margins of clasts, fading inwards towards center of clast. Py disseminated through qz-rich matrix. Can see hints of small clasts within matrix that have been overprinted, and are now just ghosts.

Thin Section Observations:

Quartz matrix? with muscovite clasts?. Disseminated pyrite mostly within matrix. Pyrite is very fine.

Mineralogy:

-Quartz	60%
-Muscovite	30%
-Pyrite	10%
-Chalcopyrite	trace
-Sphalerite	trace



TS ID: 13-14
DDH: **CMR08-13, 363.9m**
Sample: NS13-14

Lithology: altered volcaniclastic
Alteration: intense sericite, subtle local carbonate

Hand Sample Observations:

Layered volcaniclastic? Or sedimentary rock? Subtle compositional layering approximately 1cm scale. Thin pyrite stringers cut parallel to layering. Very fine phenos? or xtal fragments? within layers - appear to be altered to sericite (check thin section).

Thin Section Observations:

Sample is mostly very fine grained (sedimentary?) muscovite - weakly crenulated. small round quartz eyes locally - amyg? rounded qtz grains? Pyrite as sub-euhedral crystals within quartz-sulfide veins cutting parallel foliation, and disseminated throughout sericite. Trace carbonate with Qz-Sulfide veins. Trace amounts of fan-shaped mineral as well.

Mineralogy:

-Muscovite	70%
-Quartz	20%
-Carbonate	trace
-Pyrite	10%
-Sphalerite	trace
-Chalcopyrite	trace



TS ID: 13-15

DDH: **CMR08-13, 392.5m**

Sample: NS13-15

Lithology: altered volcaniclastic

Alteration: strong pervasive sericite, selective carb

Hand Sample Observations:

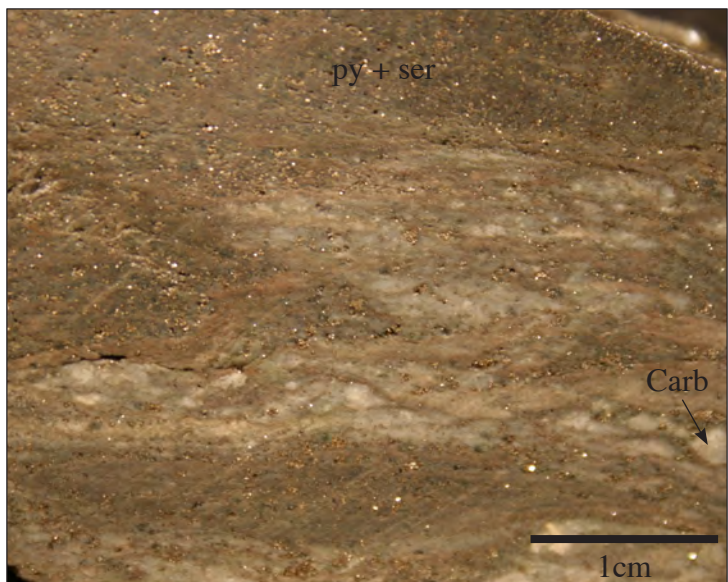
Large, internally fragmented clasts of sericite and carbonate within a mainly pyrite matrix.

Thin Section Observations:

Complex texture. Mainly quartz-sericite, with local carbonate and a distinct clear mineral, greenish under XPL. Sample is folded. Looks like clasts of sericite-pyrite and minor quartz in a quartz-rich matrix. More sulfide in clasts.

Mineralogy:

-Quartz	50%
-Muscovite	30%
-Chlorite?	2%
-Carbonate	<1%
-Pyrite	10%



TS ID: 13-16
DDH: **CMR08-13, 427.4 m**
Sample: NS13-16

Lithology: altered volcaniclastic
Alteration: strong pervasive quartz-pyrite-sericite

Hand Sample Observations:

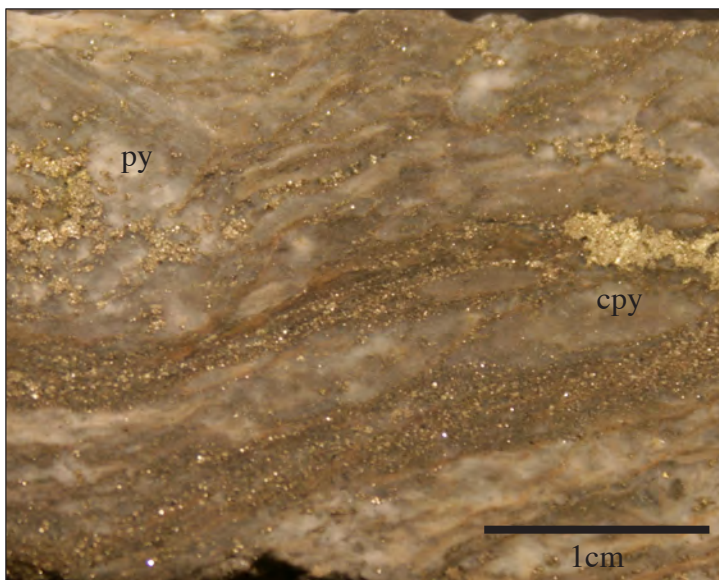
Very strong quartz and pyrite alteration, with lesser sericite. Very strung out clasts, exhibiting possible amygds or qz-phenos? Clasts are elongate parallel a moderate foliation. Clasts float in a pyrite-rich matrix. Minor local chalcopyrite (3%) as blebs within and between clasts.

Thin Section Observations:

Boudinaged coarse quartz (veins?) surrounded by muscovite. Coarse pyrite and Cpy with qtz-veins. Band of 'layered?' sericite and finer pyrite cut by coarser qtz // foliation? Complex texture.

Mineralogy:

-Quartz	60%
-Muscovite	20%
-Pyrite	20%
-Chalcopyrite	3%
-Sphalerite	trace



TS ID: 13-17
DDH: **CMR08-13, 458.3m**
Sample: NS13-17

Lithology: altered volcaniclastic
Alteration: strong pervasive sericite-quartz

Hand Sample Observations:

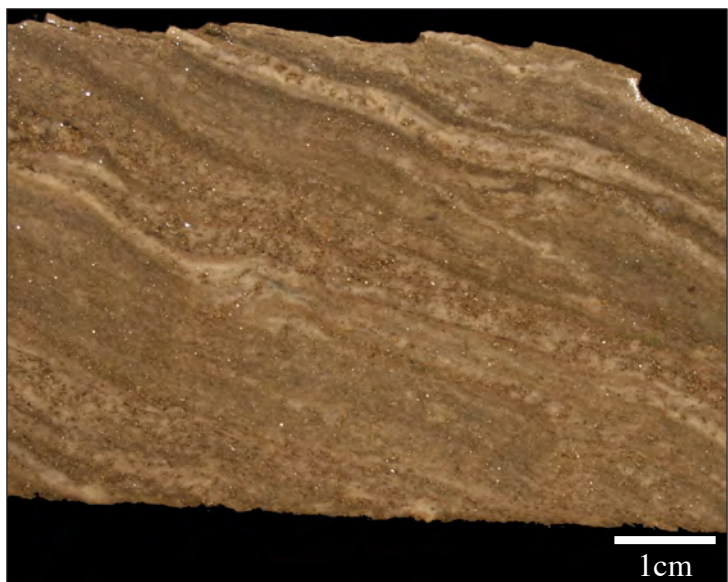
Finely layered, strongly quartz-sericite altered rock. May have been a volcaniclastic? Perhaps a resedimented fragmental. A chance that it is simply a strongly altered and foliated coherent volcanic... however not likely. Very subtle local carbonate alteration. Layering is mm to <1cm scale. Small round white fragments within darker material.

Thin Section Observations:

Elongate quartz clasts floating in a muscovite matrix. Diss subhedral-euhedral pyrite.

Mineralogy:

-Quartz	40%
-Muscovite	40%
-Pyrite	10%
-Chalcopyrite	rare trace
-Sphalerite	rare trace



TS ID: 13-18
DDH: **CMR08-13, 503.7m**
Sample: NS13-18

Lithology: volcaniclastic (pumice breccia)
Alteration: strong quartz-sericite

Hand Sample Observations:

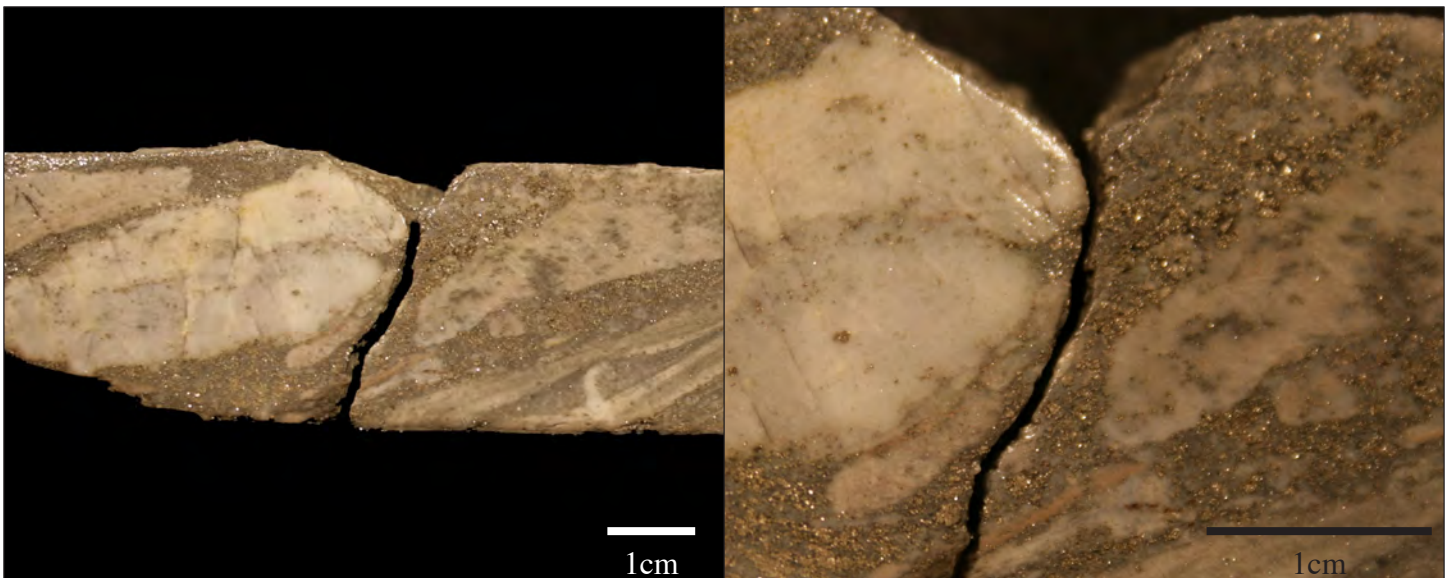
Highly vesicular, pumaceous/scoriaceous clasts within a qz-pyrite altered matrix. Clasts are quite rounded, and elongate parallel a weak foliation. May be resedimented pumice breccia? Clasts are quartz altered. Clasts range from 1mm to 3cm.

Thin Section Observations:

Large fragment/clast appears to have possible relict perlitic texture? Matrix appears sedimentary? Other clast appears to be a fragment of sedimentary volcaniclastic? Matrix is coarse quartz and sulfide, with lesser coarse muscovite - chaotic melange. Dark perlitic texture in clasts is sericite? Clasts have local rounded concentrations of coarse quartz - may be amygs of sorts? Or qtz-eyes. Sericite is crenulated. Trace Cpy growing intergranular to the coarse qtz in matrix. Also nearby is mystery opaque. Py is fg diss within clasts, and coarse, subhedral aggregates in matrix.

Mineralogy:

-Quartz	60%
-Muscovite	30%
-Pyrite	10%
-Sphalerite?	trace
-Chalcopyrite	rare trace



TS ID: 13-19
DDH: **CMR08-13, 550.6m**
Sample: NS13-19

Lithology: altered volcaniclastic
Alteration: moderate sericite-quartz

Hand Sample Observations:

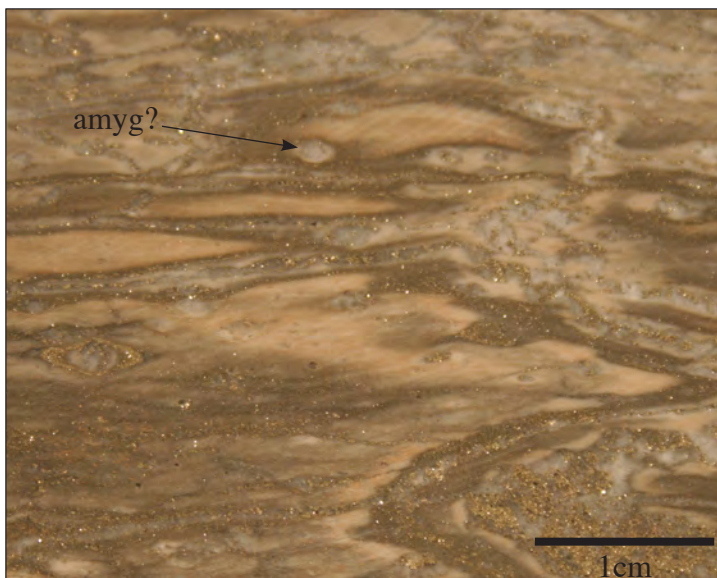
Domainally altered, with halos, volcaniclastic - breccia. Qz-pyrite filled amygs retain augen shape. Clasts have been stretched, and elongate parallel a weak foliation. May be a hyaloclastite? that has been altered. Clasts are lapilli size, from 2mm across to 3cm across (width). Clasts are somewhat jigsaw fit - although altered, still appear wispy. Wispy from alteration? Or from molten pyroclastic emplacement? (probably alt.)

Thin Section Observations:

Volcanic glass fragments separated by thin, coarse qtz-sulfide veins. Perlitic-like texture to clasts, with dark sericite(?) Weak crenulation. Clasts are vfg. Fine dusting of diss pyrite in clasts. Coarse aggregates in veins/matrix. Same poikilitic sphalerite as 13-18 locally. No Cpy observed.

Mineralogy:

-Quartz	50%
-Muscovite	40%
-Pyrite	10%
-Sphalerite	trace



TS ID: 14-01

DDH: **CMR08-14, 153.3m**

Sample: none

Lithology: massive basalt

Alteration: mod pervasive quartz-ser-chl, weak carb

Hand Sample Observations:

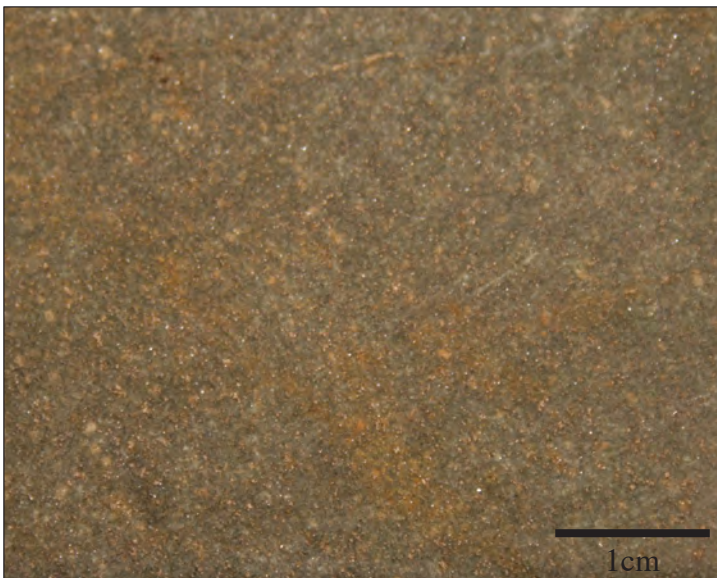
Weakly magnetic, subtly chl-carb altered massive coherent mafic volcanic. No visible foliation. Alteration overprinting metamorphic assemblage.

Thin Section Observations:

Groundmass is muscovite needles randomly oriented in massive chlorite-quartz. Skeletal carbonate and sulfides disseminated throughout (filling pore spaces?). Minerals are well sorted. Very thin quartz-sulfide veinlets cut locally. Sulfide is mostly Po, with trace Cpy and Sph associated. Local trace Py, oxidized and tarnished, replacing Po.

Mineralogy:

-Chlorite	40%
-Muscovite	30%
-Quartz	20%
-Carbonate	1%
-Pyrrhotite	10%
-Pyrite	trace
-Chalcopyrite	trace
-Sphalerite	trace



TS ID: 14-02
DDH: **CMR08-14, 161.2m**
Sample: none

Lithology: altered Basalt
Alteration: intense quartz, mod ser

Hand Sample Observations:

Likely a massive coherent volcanic, that has been intensely pervasively quartz-sericite and pyrrhotite altered - plus cut by Po stringers. Locally appears fragmental, but may be result of alteration.

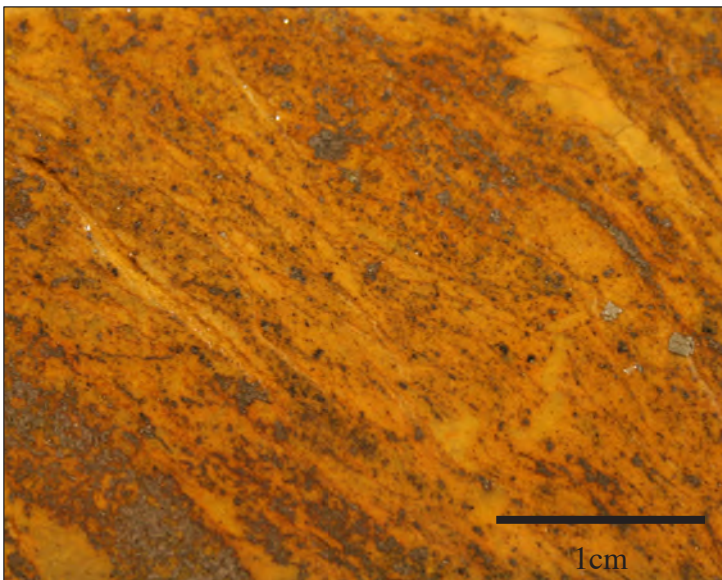
Thin Section Observations:

Fine grained granophyric equant quartz and muscovite, grungy and oxidized (from Po?). Cut by coarser quartz, and quartz-sulfide veins, and a stockwork of hairline dark black/brown sericite?? Qtz-sulfide veins and sericite veinlets account ~20% of sample.

Sulfide is mainly Po, as veins and diss, with minor Py as replacement colloids (Bird's Eye).

Mineralogy:

-Quartz	75%
-Muscovite	15%
-Pyrrhotite	10%
-Pyrite	<1%
-Chalcopyrite	<1%
-leucoxene	trace



TS ID: 14-03
DDH: **CMR08-14, 165.5m**
Sample: none

Lithology: altered volcanoclastic (qz-sulfide bx?)
Alteration: intense quartz-ser (domainal)

Hand Sample Observations:

Intensely altered possible volcanoclastic - with clasts(?) altered to quartz and sericite, within a sericite-pyrite matrix. Trace Chalcopyrite(?) with pyrite.

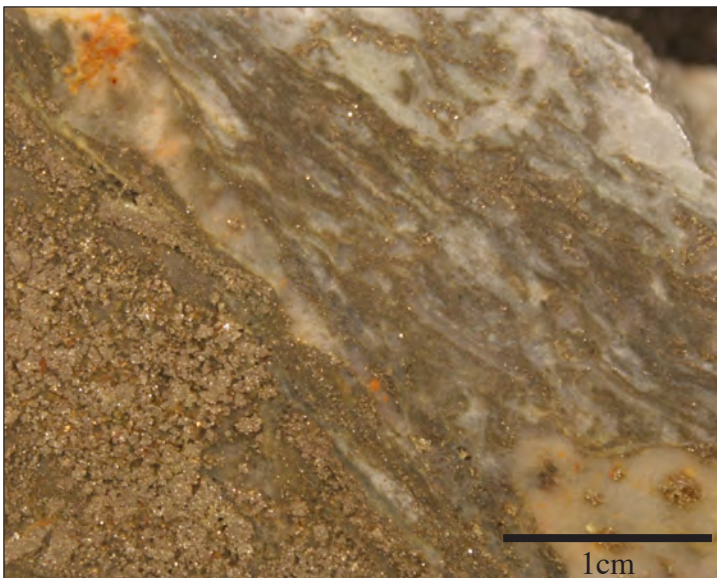
Thin Section Observations:

Part of section looks less altered, and appears to be mainly vfg muscovite matrix with quartz amygdules throughout, cut by numerous thin quartz-sulfide veinlets. The rest of the sample is mainly large quartz-sulfide veins. Flooded by fg equant quartz and granophyric quartz-muscovite, cut later by coarse quartz-sulfide veins. Alteration front?

Sulfide is anhedral to euhedral pyrite crystals and aggregates, with Cpy locally replacing and surrounding. Minor Sph with Cpy. Py is vfg to vcg, coarser in larger veins. Minor grey min w Py-inclusions, mostly within least altered, sericite rich zone (with amygs).

Mineralogy:

-Quartz	65%
-Muscovite	15%
-Pyrite	20%
-Chalcopyrite	1%
-Sphalerite	trace
-ilmenite(?)	trace



TS ID: 14-04
DDH: **CMR08-14, 174.0m**
Sample: none

Lithology: Sphalerite-Pyrrhotite stringers
Alteration: intense perv quartz, strong sel. Ser, wk chl

Hand Sample Observations:

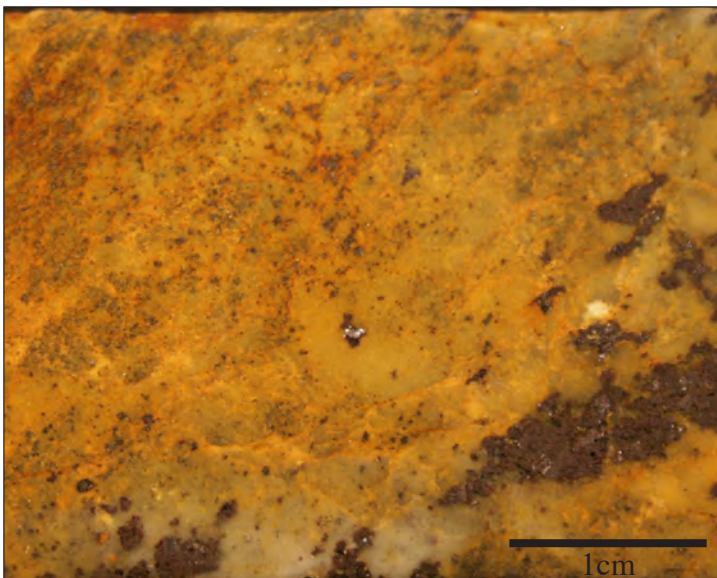
Intensely, pervasively altered rock - possibly at one point a coherent volcanic. Appears as though initial intense pervasive quartz alteration has been hydrothermally(?) brecciated by stockwork sericite alteration. Coarse grained, burgundy sphalerite stringers locally. Very minor Po disseminated throughout, giving rock subtle magnetism and rusty orange stain.

Thin Section Observations:

Pervasive quartz groundmass brecciated by stockwork of rusty muscovite/sericite. Quartz is recrystallized mosaic. Muscovite is vfg to microcrystalline. Locally, coarse chlorite fans occur around pyrrhotite. Sulfide is mainly Po, with minor Cpy and Sph. Large vein of Sph cuts edge of thin section. Po is disseminated and discontinuous stringer style. Quartz is coarser around sulfides. Local coarse fans of chlorite disseminated throughout.

Mineralogy:

-Quartz	65%
-Muscovite	25%
-Chlorite	1%
-Pyrrhotite	7%
-Sphalerite	3%
-Chalcopyrite	<1%



TS ID: 14-05
DDH: **CMR08-14, 183.6m**
Sample: none

Lithology: semi-massive pyrite-rich ore
Alteration: intense quartz, weak sericite

Hand Sample Observations:

Rock has been replaced(?) by mostly colloform pyrite (50%), with minor burgundy, cg sphalerite (1%), and fg chalcopyrite disseminated (tr). Gangue is quartz.

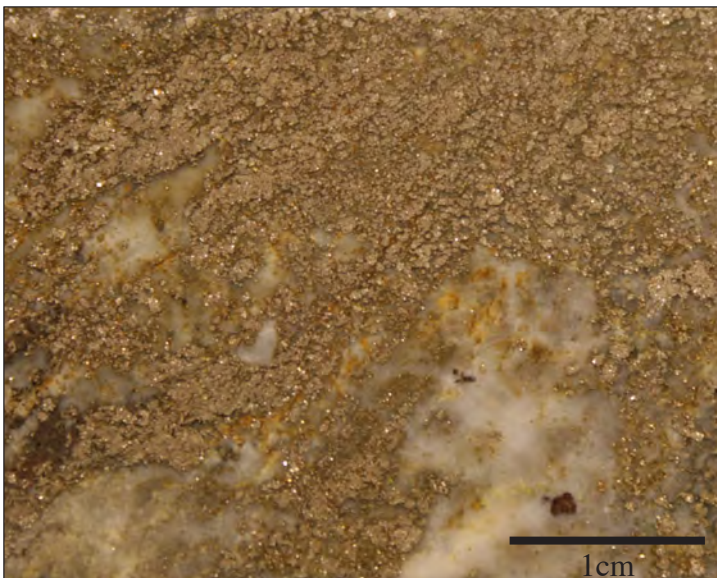
Thin Section Observations:

Mostly quartz and Pyrite. In general, looks like patches of very fine quartz, with trace chlorite needles between quartz grains (intensely silicified volcanic?) cut by coarser quartz-sulfide and sericite veins. Thin seams of sericite cut and surround coarse quartz.

Pyrite grains are sub-anhedral to massive, and heavily fractured. Cpy occurs within Pyrite fractures, locally replacing Pyrite. Sphalerite is only local, also within fractures, and locally replacing Pyrite. Sphalerite tends to form larger masses, and exhibits Cpy-disease, whereas Cpy occurs as tiny blebs within fractures mostly.

Mineralogy:

-Quartz	60%
-Muscovite	8%
-Chlorite	trace
-Pyrite	30%
-Sphalerite	1%
-Chalcopyrite	1%



TS ID: 14-29
DDH: **CMR08-14, 185.3m**
Sample: none

Lithology: Massive Pyrite Ore (+sph stringer)
Alteration: mod musc, wk carb, subtle chl

Hand Sample Observations:

Sample is mostly pyrite and dark-red/burgundy sphalerite, with quartz gangue. Pyrite is granular with interstitial quartz. Sample is locally vuggy, suggesting weathering of sulfides. Sphalerite is as stringers through massive pyrite?

Thin Section Observations:

Mostly coarse quartz, sericite, pyrite and sphalerite. Trace coarse calcite crystals with sphalerite. Sphalerite replaces pyrite, around rims and forming atoll-like structures. Minor cpy within pyrite fractures, and replacing py and sphalerite locally. Also cpy as cpy-disease within sphalerite. Py as fg-mg, sub-anhedral crystals, and are heavily fractured, and often aggregate. . Sph has deep red IRs. Gangue is quite variable - from vfg mosaic of quartz, to pods of grungy randomly oriented vfg muscovite, and locally minor carbonate. Minor albite occurs throughout, although may be mistaken for quartz. Locally albite exhibits lamellar twinning, but not always. Carbonate as large coarse crystals, quite degraded looking, and possibly early - altered. Trace chlorite grains (fans) locally.

Geochemistry:

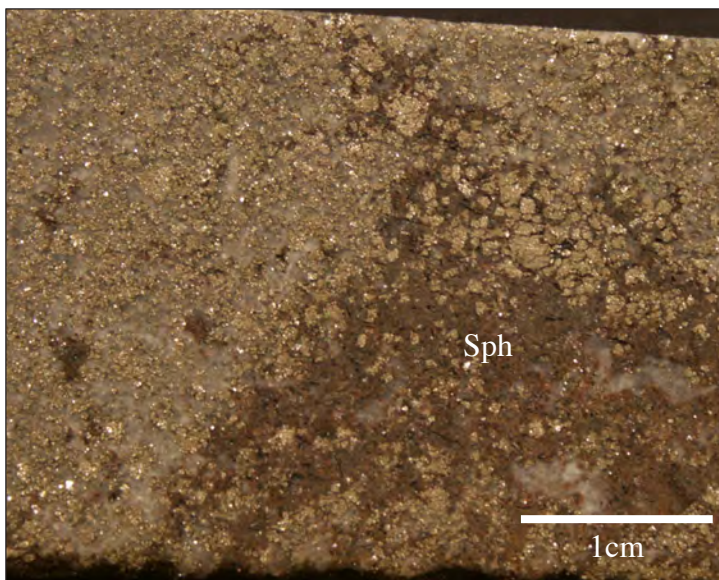
0.6% Na₂O, suggesting possibly about 6% albite within sample.

Mineralogy:

-Quartz	30%
-Muscovite	5%
-Carbonate	trace
-Albite	5%
-Chlorite	trace
-Pyrite	30%
-Sphalerite	30%
-Chalcopyrite	1%

Grain Size:

vfg-fg
micro-vfg
fg
vfg-fg
vfg
fg-mg
fg-mg
micro-vfg



TS ID: 14-30
DDH: **CMR08-14, 187.8m**
Sample: none

Lithology: Massive Sulfide (+barite)
Alteration: weak sericite

Hand Sample Observations:

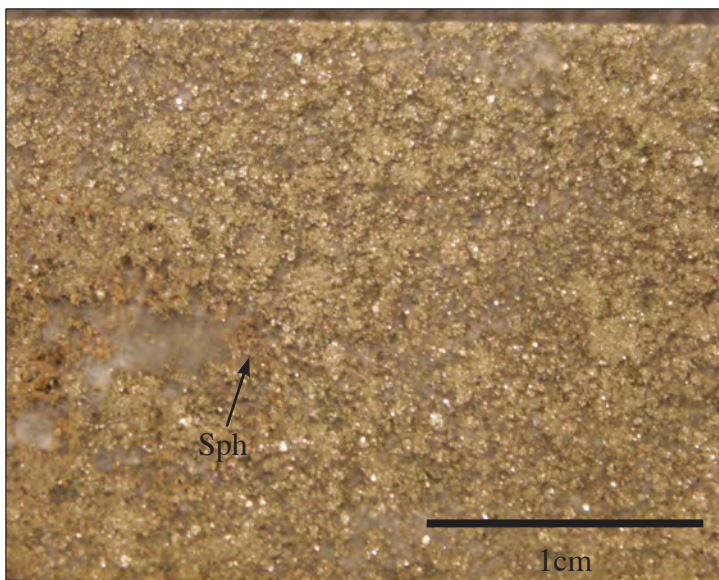
Sample is Py-Cpy and Sph (light brown). fg-mg. 20% Cpy, 60%Py, 10%Sph. More Sph near and around Qz patches.

Thin Section Observations:

Quartz exhibits an interesting texture, where it is very coarse and clean around sulfides, becoming finer grained and grungy-looking away from sulfides. Local albite, likely from late stringers. Local Barite, mostly on one side of the section. Cpy replaces Py. Trace Cpy-disease in Sph.

Mineralogy:

-Quartz	50%
-Muscovite	5%
-Barite	0.5%
-Plagioclase	trace
-Pyrite	30%
-Sphalerite	10%
-Chalcopyrite	10%



TS ID: 14-31
DDH: **CMR08-14, 196.6m**
Sample: none

Lithology: Massive Pyrite Ore
Alteration:

Hand Sample Observations:

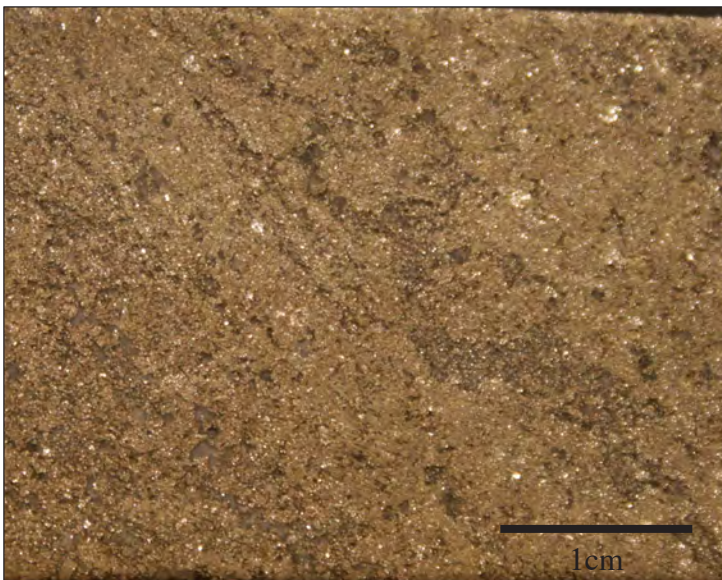
Layered fg-cg Py and Cpy with Qz. Layers are faint. 70%Py, 15-20%Cpy.

Thin Section Observations:

Very coarse pyrite, surrounded by Cpy. Cpy replacing pyrite - Cpy inclusions in pyrite. Pyrite cubes eaten away by cpy. Minor Sph with Cpy surrounding pyrite. Minor quartz, barite and muscovite as gangue, with feldspar (Albite). Pale honey-brown IRs in sphalerite. Albite in later cross-cutting stringers

Mineralogy:

-Quartz	1%
-Muscovite	5%
-Barite	1%
-Plagioclase	trace
-Pyrite	50%
-Chalcopyrite	40%
-Sphalerite	1%



TS ID: 14-06
DDH: **CMR08-14, 200.4m**
Sample: none

Lithology: Py-Cpy Stringer Ore
Alteration: intense quartz, strong albite, mod muscovite

Hand Sample Observations:

Intermingled quartz, plagioclase and pyrite, with minor local blebs of chalcopyrite.

Thin Section Observations:

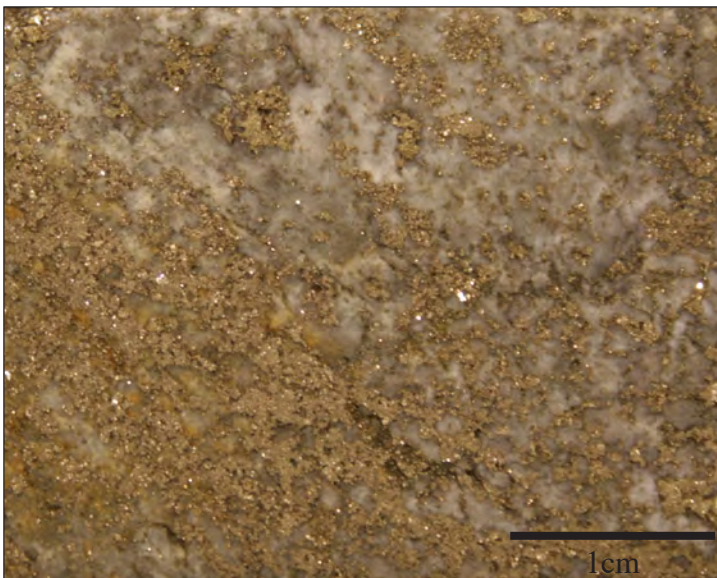
Stringers of sulfide and albite cut through pervasively quartz-muscovite and pyrite altered, vfg mosaic groundmass, with coarser grained (further recrystallized) quartz and muscovite surrounding the sulfides. Albite is very coarse, lamellar twinned, and cloudy. Albite may be domainal? Or later? because not all stringers are associated with albite - often just with quartz and muscovite. Thin hairline muscovite veinlets also network through quartz-muscovite groundmass. Disseminated pyrite throughout groundmass. Most sulfides occur as discontinuous stringers, coarse, heavily fractured pyrites surrounded and replaced by chalcopyrite and rarely by sphalerite. Annealing and recrystallization likely disconnected stringers.

Mineralogy:

-Quartz	50%
-Albite	20%
-Muscovite	5%
-Pyrite	15%
-Chalcopyrite	10%
-Sphalerite	trace

Grain Size:

micro-fg
vfg-mg
crypto-vfg
vfg-fg
vfg-fg
vfg



TS ID: 14-07
DDH: **CMR08-14, 209.0m**
Sample: none

Lithology: massive pyrite ore
Alteration: subtle quartz-sericite

Hand Sample Observations:

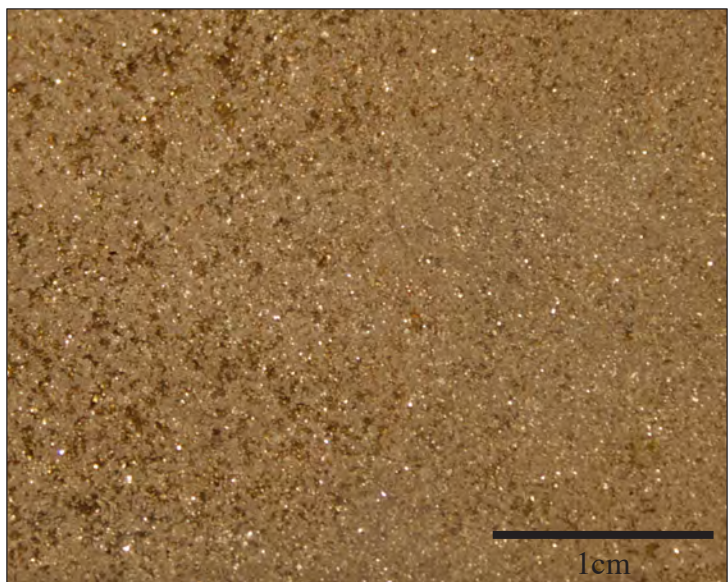
Massive fg pyrite. No foliation visible.

Thin Section Observations:

Mostly Pyrite. Fine grained anhedral crystals, fractured, with Cpy filling fractures. Trace sphalerite locally. Trace Arsenopyrite as well, roughly focused along a stringer across the middle? Aspy replaces and cuts Py. Sulfide replaces and overprints all gangue (which is minor qtz-ser).

Mineralogy:

-Pyrite	85%
-Chalcopyrite	10%
-Sphalerite	trace
-Arsenopyrite	trace
-Quartz	2%
-Muscovite	3%



TS ID: 14-08
DDH: **CMR08-14, 216.7m**
Sample: none

Lithology: Massive Pyrrhotite Ore
Alteration:

Hand Sample Observations:

Massive pyrrhotite containing large megacrystals of carbonate. Chalcopyrite replaces pyrrhotite around calcite growths(/frags?), especially larger ones.
No Qz? like in 160.9m CMR08-11b?

Thin Section Observations:

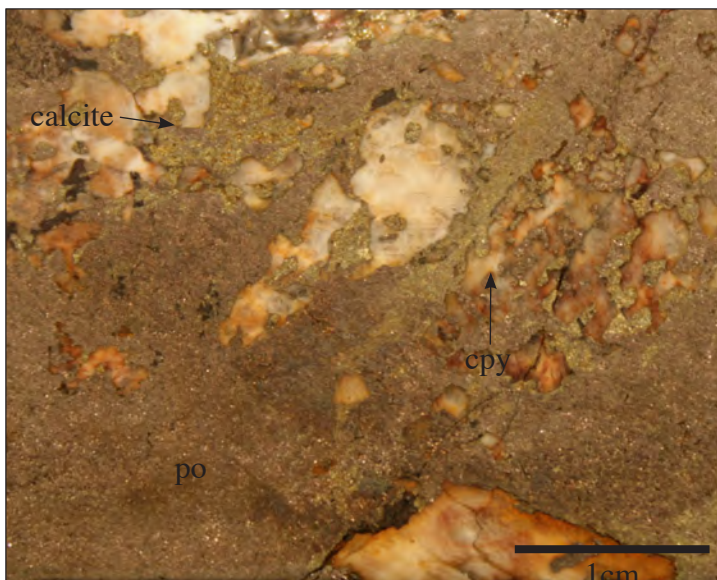
Sample is mostly massive Po, with lesser Cpy throughout. Abundant Cpy localized around large carbonate crystals. Sphalerite common as well, exhibiting very fine Cpy-disease. Carbonate fills open spaces(?) as single mega-crystals. No silicates or sulfates observed. Cpy replaces pyrrhotite around edges and fractures. Pyrite is present as bird's eye colloform replacement along fractures locally. Pyrite replacement of Po occurred before Cpy - evidence observed of cpy replacing both po and pyrite locally (pic).

Mineralogy:

-Carbonate	20%
-Pyrrhotite	60%
-Chalcopyrite	15%
-Sphalerite	5%
-Pyrite	trace

Grain Size:

mg-cg (-vcg)
massive
massive
fg-cg
micro



TS ID: **14-09**

DDH: **CMR08-14, 217.2m**

Sample: **none**

Lithology: Chert/Tuff Ore

Alteration: strong pervasive quartz, selective sulfide-carb

Hand Sample Observations:

Massive, possibly layered(?) chert cut parallel a foliation by very thin pyrite-chalcopyrite and sphalerite stringers. Unit is very porous, with pores filled by sulfides. Would chert be porous? Maybe it's a tuff? Weak carbonate alteration within pores as well, and in local veinlets/stringers.

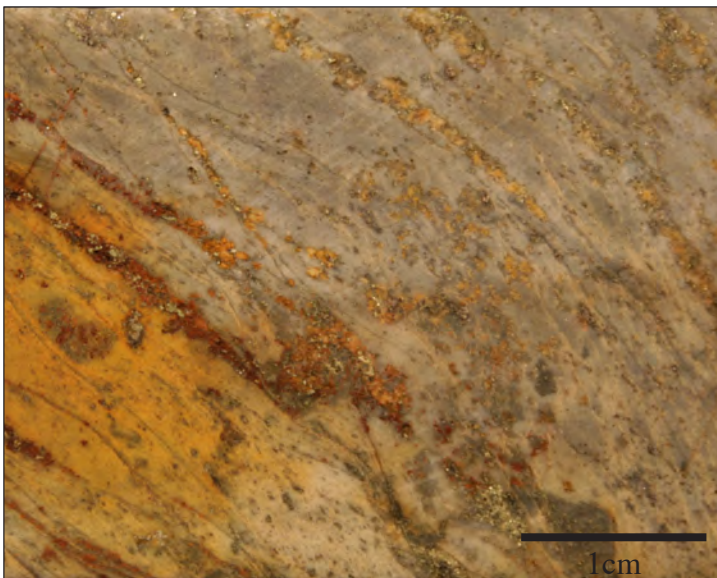
Thin Section Observations:

Quartz, Carbonate (Fe-Carb?), and sulfide veinlets cutting a vfg groundmass of quartz, muscovite and grunge?? Dickite alteration of fids? or quartz? Fan-shaped, greenish mineral, with undulating extinction?. Mostly Po and Cpy with vnlets, filling in between grains. Lesser sphalerite as well, with dark red IR. Trace disseminated subhedral Pyrite locally. Thin Sph stringers perpendicular to other veinlets. Fan-mineral (chl?) veinlets observed cutting quartz veins locally.

Very weak crenulations observed at 20x, and abundant very fine muscovite in groundmass.

Mineralogy:

-Quartz	70%
-fan-mineral (Chl?)	10%
-Muscovite	10%
-Carbonate	3%
-Pyrrhotite	3
-Chalcopyrite	3
-Sphalerite	1%
-Pyrite	trace



TS ID: **14-32**
DDH: **CMR08-14, 218.2m**

Lithology: Tuffaceous Rock (Mineralized)
Alteration: quartz-sericite-chlorite-Sx

Hand Sample Observations:

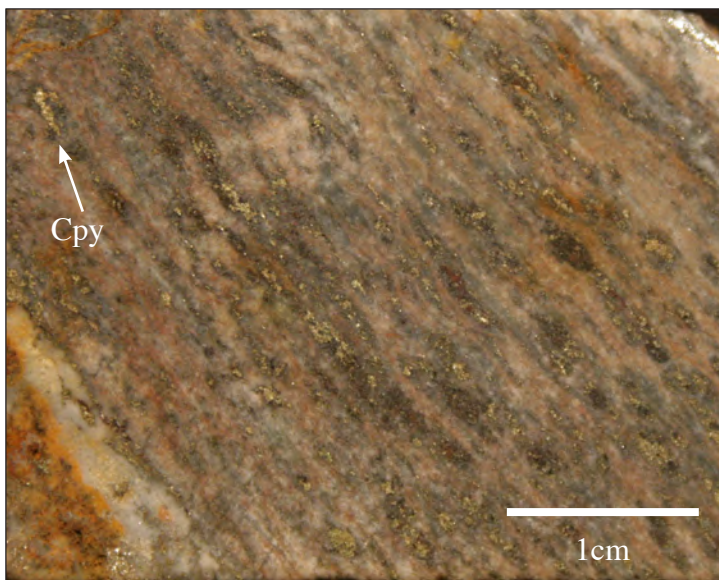
Weakly layered Chert(?), with fg disseminated Po, and disseminated Cpy (replacing Po??), 1-2% Cpy. Sx is strung out a bit // foliation/layering.

Thin Section Observations:

Domainally altered feldspar crystal-rich tuff. Crystals of feldspar have halo of quartz, which preserved the crystal. Locally, quartz has replaced large domains of crystals - can still see crystal habits, but entire area shares the same extinction of one large crystal. Matrix is mostly sericite, vfg. Feldspars are randomly oriented. Domainally altered flds-rich tuff? Cpy and Sph filling abundant fractures crosscutting section. Mostly as parallel stringers. Cpy is locally quite oxidized - tarnished.

Mineralogy:

-Quartz	30%
-Sericite	35%
-Plagioclase	15%
-Chlorite	5%
-Chalcopyrite	15%
-Sphalerite	1%
-Pyrrhotite	trace



TS ID: 14-33
DDH: **CMR08-14, 221.7m**
Sample: none

Lithology: Carbonate-Sphalerite Ore
Alteration:

Hand Sample Observations:

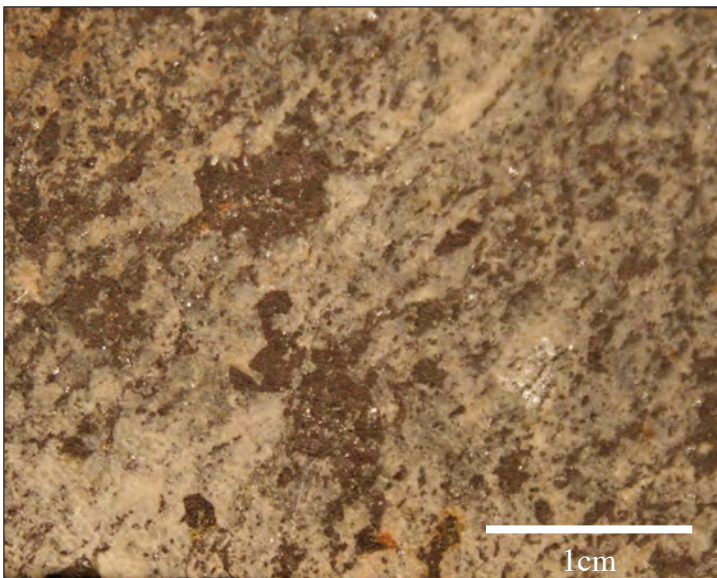
Weakly foliated massive carbonate with burgundy sphalerite as clots and stringers.

Thin Section Observations:

Mostly carbonate with interstitial sphalerite. Muscovite rosettes within large Sph crystals, and throughout carbonate. Po-disease(?) in sphalerite. Very tarnished/oxidized Po and Cpy xtals locally with Sph. Po and Cpy forming at edges of Sph and within fractures. Also Cpy-disease?

Mineralogy:

-Carbonate	60%
-Sphalerite	35%
-Muscovite	3%
-Chalcopyrite	1%
-Pyrrhotite	1%



TS ID: 14-10
DDH: **CMR08-14, 223.0m**
Sample: none

Lithology: Carbonate-Sphalerite Ore
Alteration: weak quartz-chlorite

Hand Sample Observations:

Rock is mainly carbonate, with dark red/burgundy sphalerite disseminated throughout, along with chlorite, chalcopyrite, and local pyrite. Weak foliation apparent from preferential alignment of certain minerals along foliation planes (not quite stringers). Rock is relatively coarse grained.

Thin Section Observations:

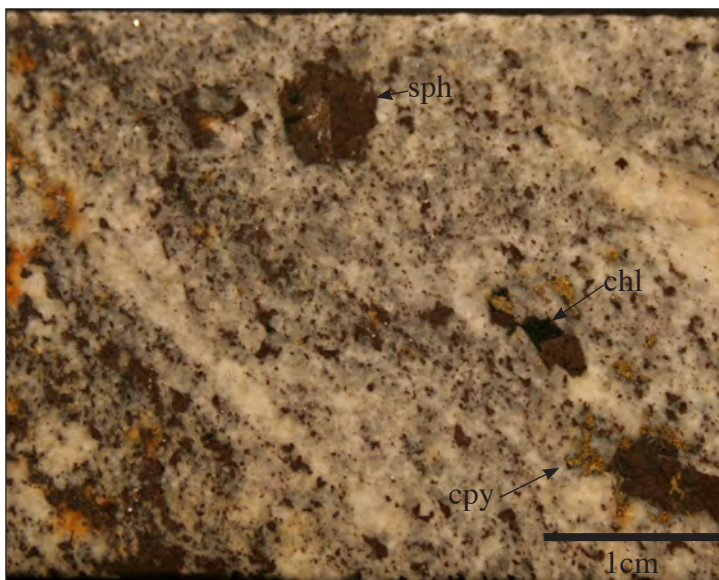
Mostly recrystallized, equant fg-mg carbonate mosaic. Minor quartz and chlorite adjacent with sulfides locally. Sulfide is mainly sphalerite, with lesser chalcopyrite and trace pyrite. Quartz is cloudy, and may be albite? Rounded pyrrhotite blebs disseminated throughout, and locally replaced by bird's eye textured colloform pyrite. Trace disseminated euhedral pyrite. Pyrrhotite also massive, replacing (or being replaced by?) chalcopyrite, Sphalerite exhibits a Pyrrhotite-Disease, similar to cpy-disease.

Mineralogy:

-Carbonate	65%
-Quartz?	1%
-Chlorite	1%
-Chalcopyrite	2%
-Sphalerite	25%
-Pyrrhotite	1%
-Pyrite	trace

Grain Size:

fg-cg
fg
vfg
fg
fg-mg
micro-vfg
micro-vfg



TS ID: 14-11
DDH: CMR808-14, 225.0m

Lithology: Quartz-carbonate exhalative/Tuff
Alteration: strong selective-pervasive quartz-carbonate

Hand Sample Observations:

Two 'beds' within altered exhalative. Finely layered cherty seds and more massive, calcareous seds. A sharp contact parallel to the layering, but undulating, and cuts layering on 'side' surface of sample. A subtle foliation is sub-parallel layering. Speckles of sulfide disseminated throughout, and locally elongate blebs parallel foliation. Sulfide is Po.

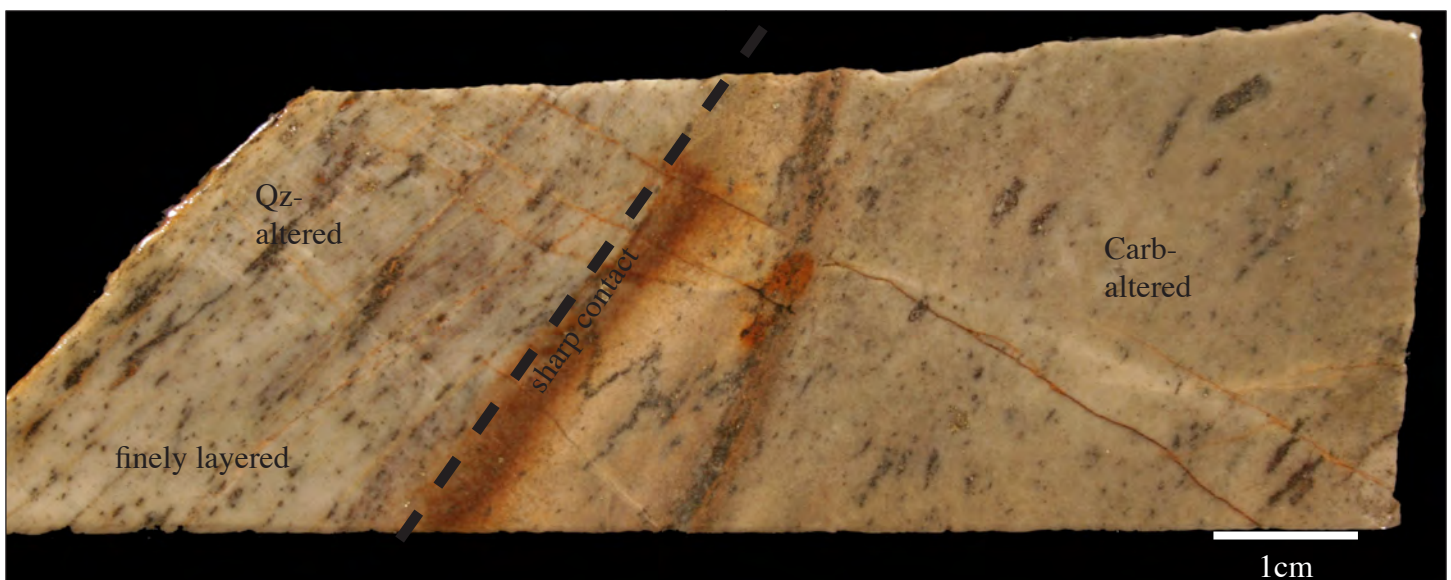
Thin Section Observations:

Mostly quartz, carbonate and feldspar (Ba-rich), and minor micro muscovite. Muscovite also as hairline veinlets throughout. Granophyric texture. Half of sample has more carbonate than other half, other half has more muscovite and quartz. Looking at 2 different layers in a tuff? Contact appears very weakly sheared. Cut by a few thin stringers of quartz-carbonate-chlorite-muscovite and pyrrhotite-sphalerite±chalcopyrite. Po-sph-py also disseminated throughout. Chlorite fans adjacent disseminated sulfides.

Ba-feldspar is anhedral, partially replaced by muscovite and quartz. Orange mineral throughout may be Fe-Carb? This mineral disseminated and in veinlets. Leucoxene disseminated throughout. Much of matrix I can't identify.... may be zeolites? Same dark grey cloudiness as Ba-feldspar, but no crystal shape.

Mineralogy:

-Quartz	40%
-Chlorite	10%
-Feldspar	10%?
-Carbonate	20%
-Fe-Carbonate?	5%
-Muscovite	10%
-Pyrrhotite	3%
-Chalcopyrite	trace
-Sphalerite	1%
-Pyrite	trace
-Leucoxene	1%



TS ID: 14-12

DDH: CMR08-14, 229.1m

Sample: none

Lithology: Quartz-Carb Tuffaceous rock (Ba-Flds?)

Alteration: intense selective-pervasive quartz-carbonate

Hand Sample Observations:

Sample is altered tuff/exhalative. Minor disseminated and blebs of vfg pyrite throughout (1%).

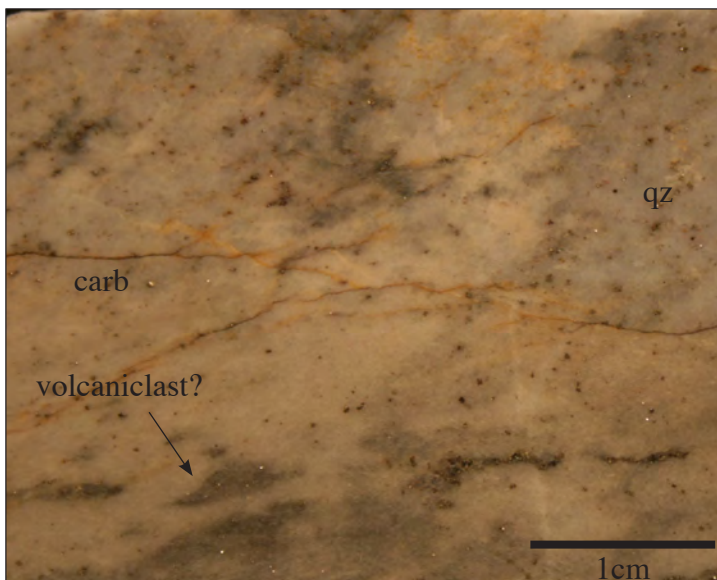
Thin Section Observations:

Mostly Quartz and Carbonate, with lesser micro muscovite. Cut by hairline muscovite veinlets. Fine disseminated subhedral Py aggregates throughout, with trace amounts of Sphalerite associated. Sph has honey-brown to red IRs. A few thin veins of quartz-carbonate-chlorite and pyrite-sphalerite. Chlorite also adjacent disseminated pyrite-sphalerite.

Possible Ba-feldspar grains disseminated throughout - slightly coarser, darker and cloudier than quartz. Locally crenulations observed where muscovite concentrates.

Mineralogy:

-Quartz	45%
-Carbonate	45%
-Muscovite	3%
-Chlorite	trace
-Pyrite	3%
-Sphalerite	trace
-Feldspar (Ba?)	1-2%



TS ID: 14-13
DDH: **CMR08-14, 230.8m**
Sample: none

Lithology: Carbonate-sulfide breccia/Stringer-Zone
Alteration: weak chl

Hand Sample Observations:

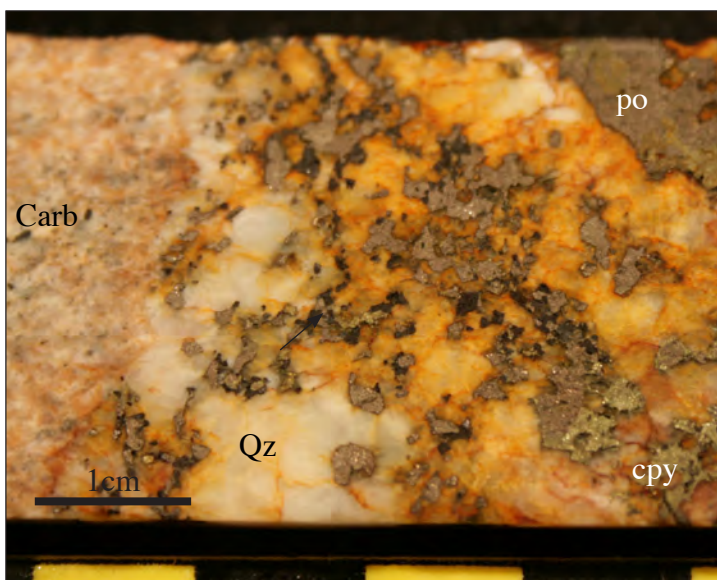
Sample is mostly pinkish carbonate (rhodochrosite?), with quartz-sulfide (vein? or clast?) through the middle, and sulfide clasts/stringers? within carb. Most of sulfide is in chunky white quartz vein(?). Sulfide is Po and Cpy.

Thin Section Observations:

Sample is domain of very coarse quartz and domain of coarse carbonate, as huge space filling crystals with sulfide stringers(?). Stringers are disconnected by recrystallization? Colloidal carbonate? Fe-carb? filling space between qtz-crystals (pic). Pyrite replacing Po locally as bird's eye colloform crystals around the edge. Trace cpy-disease in sphalerite. Sphalerite and pyrrhotite occur together, and chalcopyrite replaces pyrrhotite(?). Locally carbonate replacing quartz, but typically occurring together. Strange worm-like mineral, may be epidote, as concentrations adjacent sulfides locally. Fan-shaped chlorite locally adjacent sulfides.

Mineralogy:

-Quartz	50%
-Carbonate	10%
-Chlorite	1%
-Epidote?	3%
-Pyrrhotite	20%
-Pyrite	2%
-Sphalerite	10%
-Chalcopyrite	7%



TS ID: 14-14
DDH: **CMR08-14, 236.1m**
Sample: none

Lithology: Tuff & calcareous Chert (+ Py-Sph stringer)
Alteration: Strong quartz-muscovite, mod albite, wk carb

Hand Sample Observations:

Strongly quartz altered, and cut by a white quartz vein(?), with carbonate around margins. Or may be interlayered tuff and chert? Some remnant FPs?, altered and squashed. Abundant pyrite around vein, fading away from vein.

Thin Section Observations:

Two zones within section - a zone of mainly quartz that may be 'chert' and a zone of completely altered tuff?. Contact of the two zones is cut by a pyrite-albite-carbonate stringer that pinches and swells. Chert is mosaic of vfg quartz with disseminated fg carbonate, and disseminated sulfides. Small stringer of sphalerite present within chert section. Tuff is pervasively muscovite altered groundmass, with abundant rounded aggregates of albite(?) grains. Aggregates vary in size from vfg-mg, and often string together forming networks. These albite(?) aggregates may have been feldspar phenocrysts? or tuffaceous lapilli?. Tuff has microcrystalline, disseminated leucoxene throughout. Late muscovite vein cuts perpendicular to foliation. Disseminated microcrystalline-vfg pyrite throughout tuff section. Pyrite within vein is coarser grained to massive. Trace sphalerite and galena within the chert section, as micro-vfg grains intergranular or within pyrites. Trace chalcopyrite and sphalerite within pyrites within the py-albite-carb stringer. No chlorite observed.

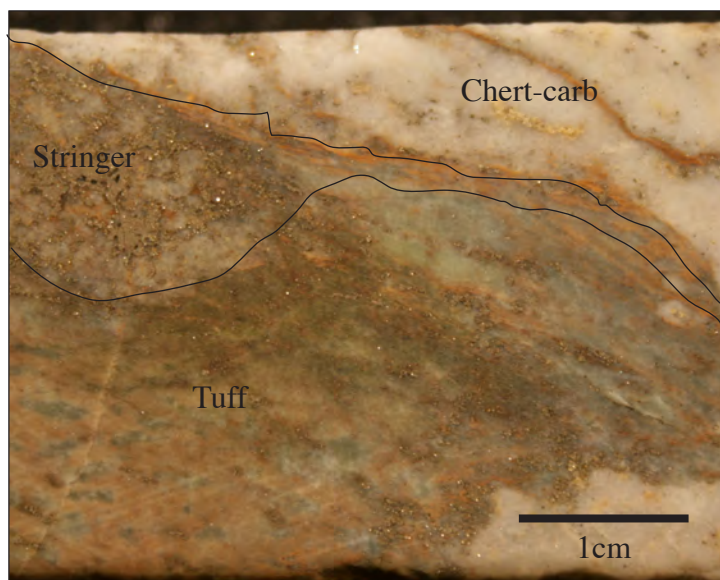
Note - could be albite stringers cutting between a Ba-feldspar Tuff, and a chert.

Mineralogy:

-Muscovite	40%
-Feldspar	30%
-Quartz	15%
-Carbonate	5%
-Pyrite	10%
-Sphalerite	1%
-Chalcopyrite	trace
-Galena	trace
-Leucoxene	<1%

Grain Size:

micro
micro-fg
micro-vfg
vfg-fg
vfg-fg
vfg-fg
vfg
micro
micro



TS ID: 14-15
DDH: **CMR08-14, 245.1m**
Sample: none

Lithology: altered volcaniclastic
Alteration: Strong Quartz-Sericite

Hand Sample Observations:

Strongly pervasively altered volcaniclastic? lapilli-sized 'clasts' are mostly quartz, within ser-py matrix. Rock is quite fissile. Lapilli mostly oriented parallel a moderate foliation. Matrix supported. Py is vfg.

Thin Section Observations:

Mostly sericite schist, with abundant quartz clasts/augens that are broken and brecciated by sericite. Possible lapilli? Rare trace Cpy replacing pyrite locally. Speckled vfg Sph disseminated locally.

Mineralogy:

-Quartz	40%
-Muscovite	50%
-Pyrite	10%
-Sphalerite	trace
-Chalcopyrite	rare trace



TS ID: 14-16

DDH: **CMR08-14, 255.8**

Sample: none

Lithology: altered volcanoclastic (Hyaloclastite)

Alteration: moderate Quartz-Sericite

Hand Sample Observations:

Mod-strongly ser-py altered (with minor qz) hyaloclastite. Clasts are curvilinear, and elongate parallel a weak foliation. matrix is py-ser-qz, with lapilli size qz-altered clasts (1-3mm). Can see remnant elongate FP's in larger clasts(?). Dark grey, vfg pyritic rim around larger clasts. Clasts are mostly Ser altered. Clasts are elongate and wispy.

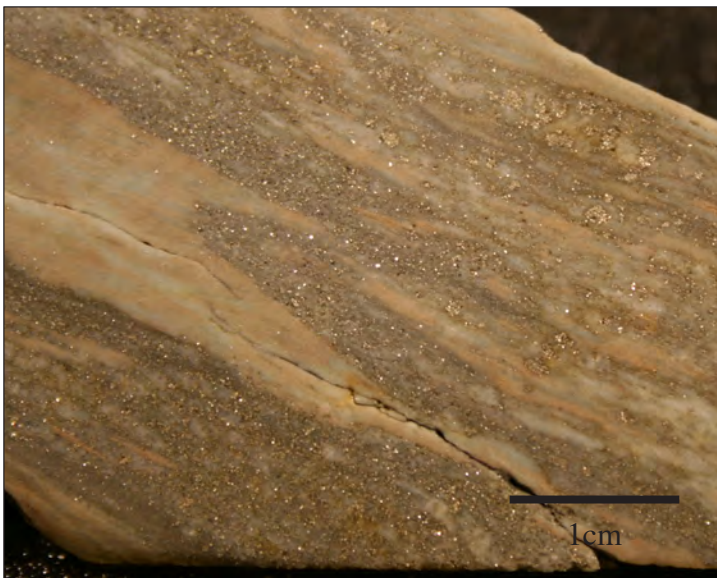
Thin Section Observations:

Very fine grained muscovite-sericite clast within coarse qtz-sulfide-muscovite matrix. Within coarse matrix have aggregates of quartz, rounded, that resemble lapilli - however they are likely broken veins, occurring as bands.

Vfg disseminated Sph within clasts - little to no pyrite. Sub-euhedral pyrite grains and aggregates disseminated throughout matrix (coarse). Rare Cpy replacing Py. Rare Sph disseminated with Py.

Mineralogy:

-Quartz	40%
-Muscovite (+sericite)	50%
-Pyrite	10%
-Sphalerite	trace
-Chalcopyrite	rare trace



TS ID: 14-17

DDH: **CMR08-14, 268.9m**

Sample: none

Lithology: altered volcanoclastic (Hyaloclastite)

Alteration: moderate qz, weak sericite, subtle chl-carb

Hand Sample Observations:

Hyaloclastite. Matrix supported. Clasts are curvilinear, 5mm to 2cm across, weakly elongate, and completely chlorite altered. Matrix is weakly-moderately quartz altered. Fine gr Py forming around margins of clasts, and replacing clasts. Weak sericite alteration in matrix.

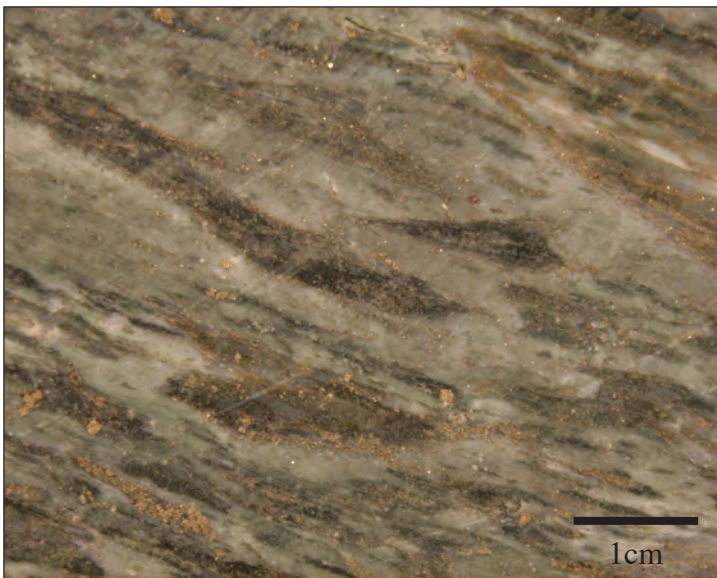
Thin Section Observations:

Weakly altered hyaloclastite. Clasts are zeolite? or chlorite? Not very altered. Highly vesicular. Brownish grungy mineral filling vesicles. Matrix is quartz and chlorite (weak silicification). Large clasts(?) patchily altered to sericite (muscovite). Large patches of quartz in matrix may just be local stronger alteration? Fg disseminated Sphalerite flecks throughout the clasts (not in matrix). Rare Cpy as Cpy-disease in Sph, and very rarely as local blebs

Thin QVs cut through matrix. Coarse carbonate crystals locally within clasts, replacing? Locally associated with chlorite replacing clasts as well (greener than the 'zeolite?'). Locally, Po and Cpy with coarse Quartz in matrix (hydrothermal). Spatial assoc with carb-chl?

Mineralogy:

-Quartz	35%
-Chlorite ($\pm$ zeolite?)	45%
-Muscovite	15%
-Carbonate	trace
-Pyrite	5%
-Sphalerite	1%
-Pyrrhotite	trace
-Chalcopyrite	trace



TS ID: 14-18
DDH: **CMR08-14, 286.3m**
Sample: none

Lithology: Altered volcaniclastic/Hyaloclastite
Alteration: moderate chl-carb-quartz

Hand Sample Observations:

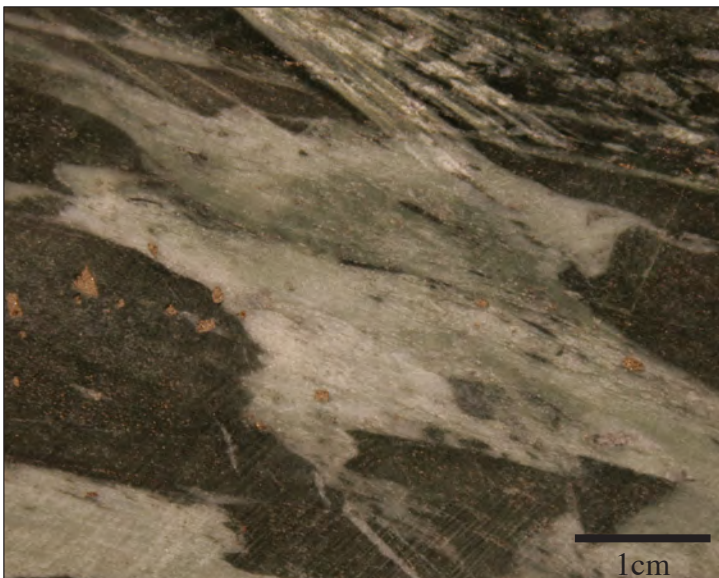
Chl-altered curvilinear clasts, clast supported, with qz-carb altered matrix. Clasts are large, up to several cm across. Both Py and Po disseminated within matrix and clasts (1% total). Much less altered overall than UH.

Thin Section Observations:

Chloritic clasts within a quartz-carbonate-muscovite matrix. Qz-Carb not equigranular, all anhedral xtals. Sulfide is mostly in clasts - not much in matrix. Coarse quartz-carb-sulfide veins(?) cut clasts. Local sericite/muscovite veinlets within matrix. Po disseminated throughout. Fine grained lath-shaped opaque - sphalerite? disseminated throughout clasts (leucoxene?). Probably ilmenite - altered to Leucoxene? Clasts are chlorite, and grungy mineral (zeolite??) Rare cpy and sph with Po.

Mineralogy:

-Quartz	25%
-Carbonate	25%
-Chlorite	30% (plus grungy min - zeolite?)
-Muscovite	5%
-Pyrrhotite	1%
-Leucoxene	1%
-Sphalerite	rare trace
-Chalcopyrite	rare trace



TS ID: 14-19
DDH: **CMR08-14, 317.9m**
Sample: none

Lithology: altered volcanoclastic/breccia
Alteration: strong sericite-carb, selective quartz

Hand Sample Observations:

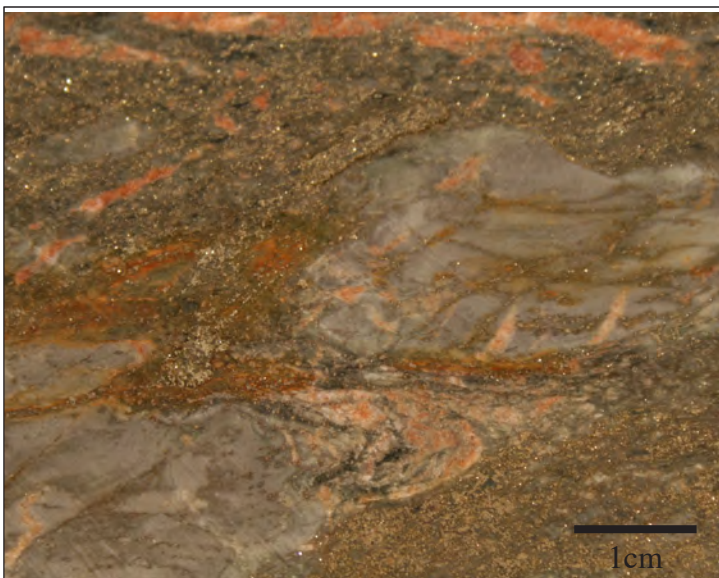
Strongly altered volcanoclastic(?). Large qz-altered clasts up to 3 cm across, within a pyrite matrix. Clasts are fractured and filled with py. Orange/pink Fe-Carb veinlets cut throughout. Very minor Ser throughout. Up to 25-30% vfg Py.

Thin Section Observations:

Large quartz-rich qtz-ser clasts within a grungy, sericite-rich matrix. Quartz-clasts are cut by meandering carbonate veins. Much of samples is stained brown with possible Fe-carbonate. Little to no quartz in matrix, just sericite and carbonate.

Mineralogy:

-Quartz	10%
-Muscovite	50%
-Carbonate (+Fe-carb)	30%
-Pyrite	10%
-Pyrrhotite	rare trace
-Ilmenite	<1%
-Chalcopyrite	rare trace



TS ID: 14-20
DDH: **CMR08-14, 336.0m**
Sample: none

Lithology: altered volcanoclastic
Alteration: strong carb, mod qz, weak ser

Hand Sample Observations:

Strongly Carb-altered volcanoclastic? Large dark grey fg clasts, matrix(?) is lapilli-sized clasts of carb($\pm$ qz?) within fine sulfidic matrix? Need thin-section. Minor small Chl-clasts as well in 'matrix'

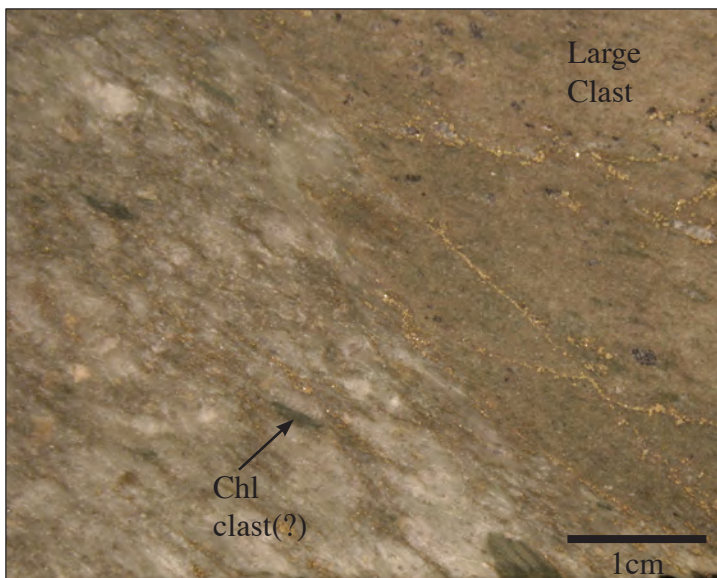
Thin Section Observations:

Very fine grained matrix of granophyric texture - quartz and muscovite. Cut by veins of very coarse carbonate and sulfide. Contact within thin section, with another unit - massive. Large clast? Pervasively carbonate altered? Brecciated section could be fluid conduit? Clast is mainly sub-microscopic and cannot be identified - volcanic! Zeolites? With minor muscovite and abundant coarse carbonate throughout (50% of clast). Ilmenite mainly present within the large clast - much less within the brecciated section (replaced?). Muscovite veinlets within breccia zone.

Mineralogy difficult to discern, as most is sub-microscopic.

Mineralogy:

-Quartz	35%
-Muscovite	5%
-Carbonate	50%
-Pyrite	5%
-Ilmenite	3%



TS ID: 14-21

DDH: **CMR08-14, 360.0m**

Sample: none

Lithology: altered volcanoclastic

Alteration: mod sericite, weak quartz-chl-carb

Hand Sample Observations:

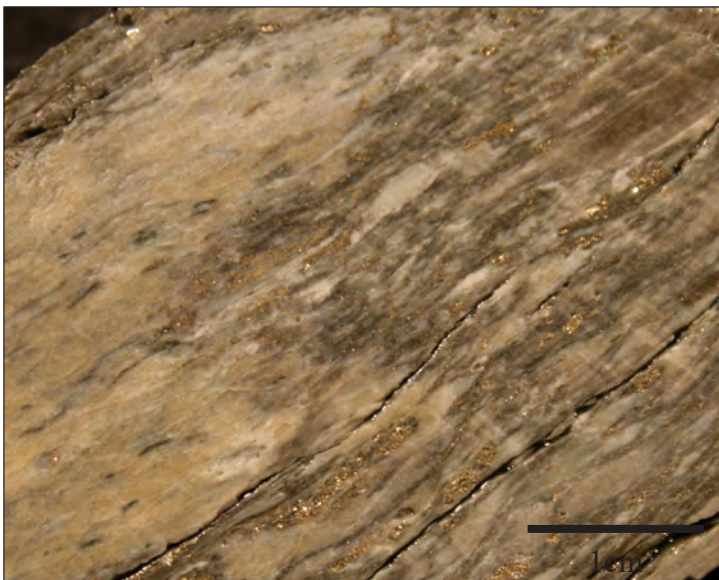
Strongly sericitic schist - ser-qz-py altered volcanoclastic, mostly lapilli sized clasts, with lesser large cm-scale clasts. Clasts are rounded, perhaps resedimented, or partially destroyed by alteration. Very minor local Carb alteration, localized to fractures (may be re-mobilized). Py as thin stringers //foliation. Little to no Py in large clasts. Sample is strongly foliated.

Thin Section Observations:

Possibly altered tuff of lapilli and smaller pumice? Vfg disseminated pyrite distributed variably, localizing in horizons, or replacing pumice fragments(?). Matrix is mainly vfg muscovite and sericite. Local concentrations of chlorite, especially around large hydrothermal pyrite grains. Local coarse carbonate crystals, also associated with chl-sulfide. Minor quartz also associated with carb-chl-sulfide. So pervasive mod sericite alteration of tuff, followed by selective weak qtz-chl-carb-sulfide stringers (very fine). Local trace spatterings of leucoxene throughout. Locally occurring with sphalerite (sph replaces??).

Mineralogy:

-Muscovite	70%
-Carbonate	10%
-Chlorite	2%
-Quartz	5%
-Pyrite	5%
-Sphalerite	1%
-Leucoxene	trace



TS ID: **14-22**
DDH: **CMR08-14, 385.6m**

Lithology: Chert with Py-Sph Stringers
Alteration: strong qz-py, weak carb

Hand Sample Observations:

What appears to be exhalative chert, cut by thick Py-stringers, or perhaps interlayered with Py. Bedding is not apparent. Carb gangue with Py. Very minor Ser with Py.

Thin Section Observations:

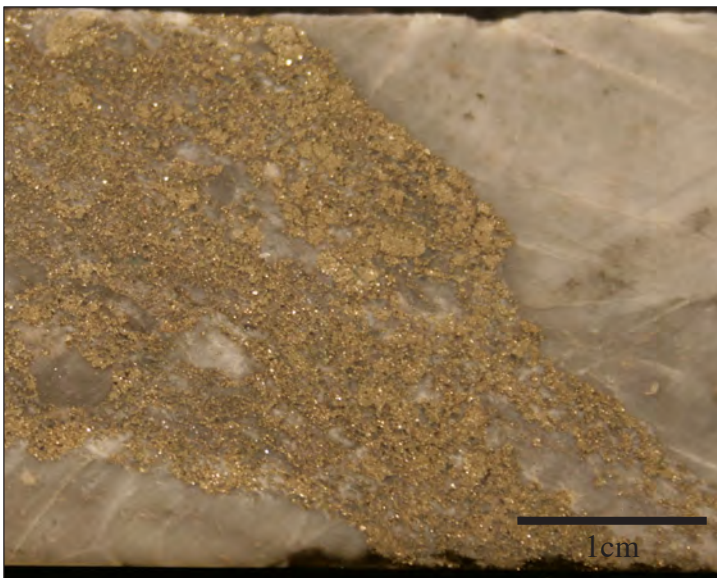
Very fine chert, with equant quartz grains, and trace amounts of muscovite. Fractures through chert have coarser quartz grains (re-crystallized).

Pyrite grains are sub-anhedral aggregates, heavily fractured, locally with Sphalerite in and around them. Very fine disseminated pyrite throughout chert as well. Sphalerite has very pale yellowish IRs.

2 forms of carbonate? Strongly lamellar and strongly twinned.

Mineralogy:

-Quartz	50%
-Muscovite	Trace
-Carbonate	10%
-Pyrite	40%
-Sphalerite	trace



TS ID: **14-23**
DDH: **CMR08-14, 431.7m**
Sample: **none**

Lithology: Chert with Py-Sph Stringer
Alteration: strong qz

Hand Sample Observations:

Similar to above, although siliceous section does not have same cherty texture. Cut by a vein (or clast or layer) of fine-grained Py and Galena(?). Galena stringers cut into Chert from vein.

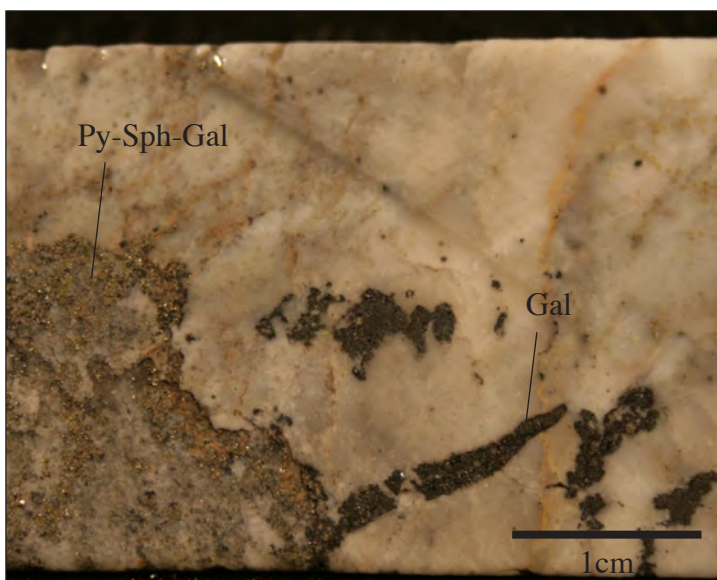
Thin Section Observations:

Chert sample, mostly quartz as very fine equant mosaic. Variably coarser, as recrystallized fractures. Cut by quartz-sulfide stringers. Trace carbonate within select sulfide stringers. Sulfide is mainly galena and Pyrite, and trace Sphalerite (pale yellow-brown IR). Pyrite is subhedral grains and aggregates, heavily fractured. Galena and Sphalerite surround pyrite, and fill fractures. Sph and Gal likely came later. Rare trace chalcopyrite observed in fractures within pyrite with Sph and Gal.

Separate galena-stringers distinct from Py-Gal-Sph vein. Gal stringers locally contain carbonate, whereas the Py-Sph-Gal only contains quartz.

Mineralogy:

-Quartz	75%
-Carbonate	trace
-Pyrite	10%
-Galena	8%
-Sphalerite	7%
-Chalcopyrite	trace



TS ID: 14-24
DDH: **CMR08-14, 438.0m**
Sample: none

Lithology: Massive Pyrite Ore (Py-Sph-Cpy)
Alteration: Strong Carb

Hand Sample Observations:

Sample is mostly coarse pyrite, cut by Calcite veins with Sph and Cpy at rims. Sph is burgundy (high Fe-content).

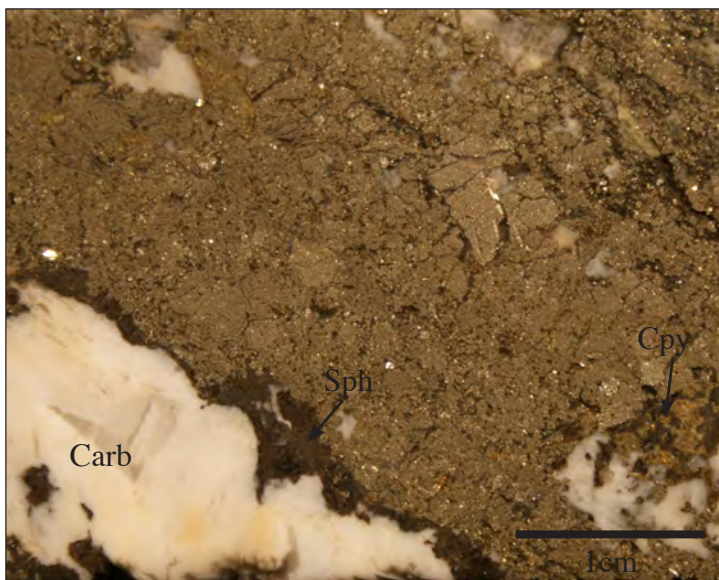
Thin Section Observations:

Gangue is megacrysts of carbonate, with smaller round quartz inclusions, and locally megacrysts of quartz interstitial to carbonate, filling space. Sulfide is mostly pyrite, with dark red/burgundy sphalerite and Cpy around carbonate. Trace epidote and muscovite interstitial to sulfides as well, locally.

Sulfide is mg to megacrysts (>1cm) of pyrite, heavily fractured and brecciated, and very heavily brecciated locally by thin veinlets of carb with lesser musc and epidote. Fractures in pyrite also filled with massive Cpy and Sph. Sph locally exhibits Cpy-disease. Pyrite very friable.

Mineralogy:

-Carbonate	10%
-Muscovite	trace
-Quartz	3%
-Epidote	trace
-Pyrite	75%
-Sphalerite	7%
-Chalcopyrite	7%



TS ID: 14-25
DDH: **CMR08-14, 439.7m**
Sample: none

Lithology: Massive Pyrrhotite Ore
Alteration:

Hand Sample Observations:

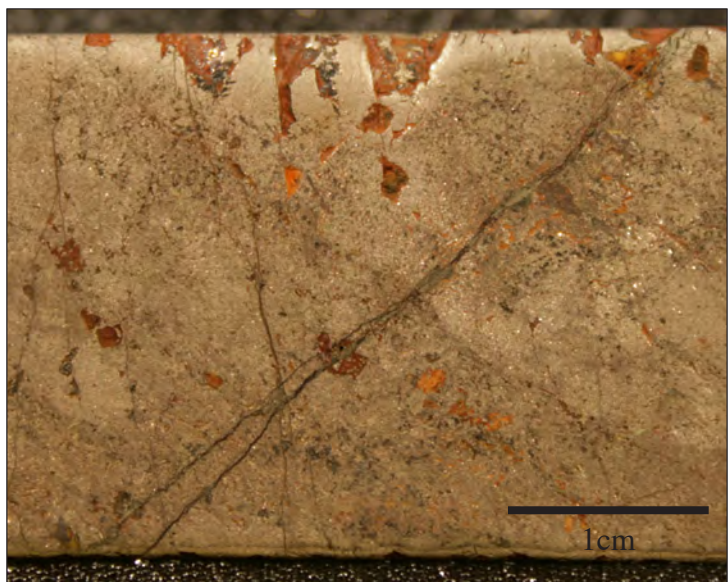
Sample is massive Po, with minor dark grey sulfide disseminated (<1%).

Thin Section Observations:

Massive Po, with minor Cpy and Sph within fractures and openings. 2 large, degraded carbonate crystals - no other gangue (<3mm).

Mineralogy:

-Carbonate	trace
-Pyrrhotite	99%
-Sphalerite	1%
-Chalcopyrite	trace



TS ID: 14-26

DDH: **CMR08-14, 443.7m**

Sample: none

Lithology: altered volcanoclastic (?)

Alteration: very strong Qz-Py, weak Carb

Hand Sample Observations:

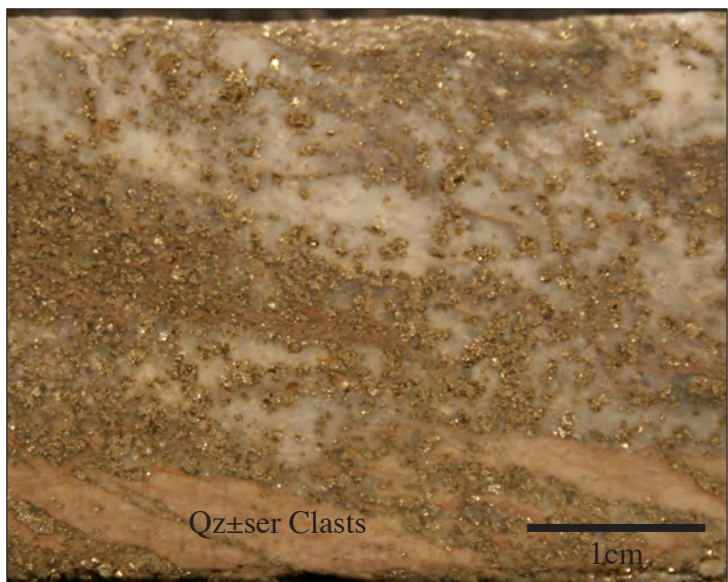
Qz-Py altered rock, with local wispy qz-((ser)) clasts. Py is disseminated within quartz, to the point of becoming massive (50% Py). Clasts are <1cm.

Thin Section Observations:

Recrystallized quartz, fg-vcg, equant and variable. Coarsest grained around sulfides (pyrite). Coarse grained aggregates of Py and Quartz within a fg quartz matrix. Minor degraded, replaced Carbonate crystals (anhedral) disseminated throughout fg quartz. Local zones of muscovite (clasts?) with qz and pyrite.

Mineralogy:

-Quartz	70%
-Muscovite	10%
-Carbonate	trace
-Pyrite	20%



TS ID: 14-27
DDH: **CMR08-14, 458.7m**
Sample: none

Lithology: Altered **Volcaniclastic (Tuff?)**
Alteration: **strong Qz-Ser-(Py)**

Hand Sample Observations:

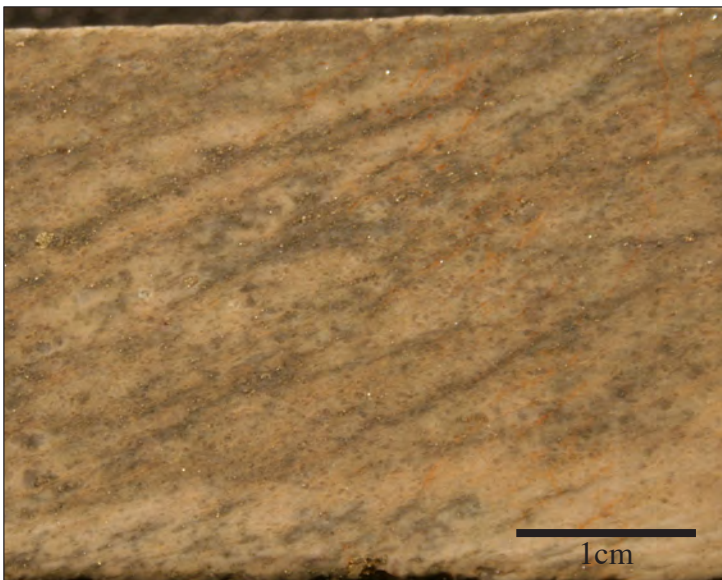
Fine-grained qz-ser-(py) schist. Weakly layered. Original rock-type. unknown Vfg to fg Py disseminated throughout (1%). A single thin py-carb vein cuts //foliation.

Thin Section Observations:

Coarse Quartz-Carb-Epidote aggregates within a fg quartz-muscovite matrix. Locally highly degraded remnant crystals of carbonate, mostly replaced around the edges by quartz, and recrystallized to vfg anhedral grains(?).

Mineralogy:

-Quartz	40%
-Epidote?	1%
-Muscovite	50%
-Pyrite	10%



TS ID: 17-01
DDH: **CMR08-17, 208.8m**
Sample: none

Lithology: Feldspar-phyric basalt
Alteration: weak perv chl-carb

Hand Sample Observations:

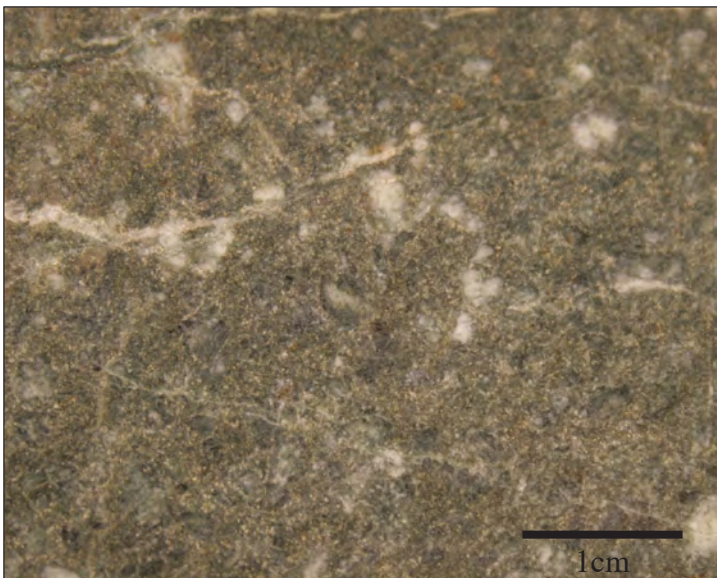
Massive coherent feldspar-phyric mafic volcanic. Cut by several thin to hairline calcite veinlets at various angles. No prominent foliation. Abundant fine cream-coloured speckles - leucoxene? Feldspars are subhedral to anhedral, often white to translucent, or white with translucent rims. Trace disseminated fg pyrite.

Thin Section Observations:

Mafic volcanic, with very large subhedral feldspar phenos. Phenos locally replaced in part by carbonate, quartz, and chlorite. Trace degraded altered olivine disseminated throughout. As well as carbonate and muscovite. Trace Cpy and Py locally as very fine blebs, encased in sphalerite. Carbonate replacing finer feldspar in matrix?

Mineralogy:

-Chlorite	40%
-Plagioclase	30%
-Carbonate	25%
-Muscovite	1%
-Olivine	1%
-Ilmenite	2%
-Chalcopyrite	trace
-Sphalerite	trace
-Pyrite	trace



TS ID: 17-02
DDH: **CMR08-17, 242.4m**
Sample: none

Lithology: Brecciated, altered mafic volcanic
Alteration: moderate sel. quartz-ser-pyrite

Hand Sample Observations:

Variable volcanic breccia - may have hydrothermal breccia component (left side of photo). Clasts are subangular, variable altered making the rock a false polymict(?). Breccia may be local overall in lithology?? - see core. Clasts range from 1mm-2cm across, and are somewhat elongate parallel foliation. The more hydrothermal breccia looking clasts are more blocky, angular and in-situ looking. Also they are not as elongate parallel foliation. Minor (1-3%) pyrite is present as thin slivers parallel foliation, through matrix.

Thin Section Observations:

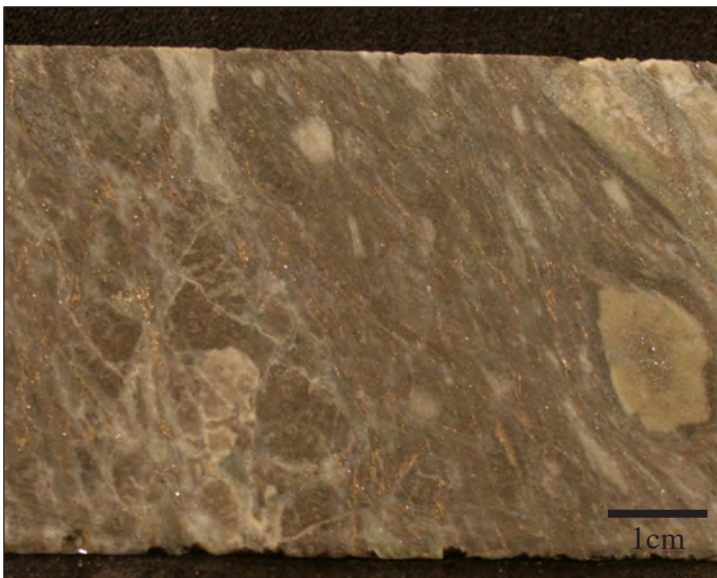
Feldspar-phyric, amygdaloidal basalt(?) cut by thick, vfg qtz-muscovite-sulfide stringers. All cut again by thinner, coarse quartz-muscovite-sulfide veins. Free feldspar phenos and lenticular basalt clasts floating in fg qz-musc-sulf stringers.

Feldspar-phyric basalt has been subtly altered to muscovite, and now composition is mainly twinned plagioclase needles, randomly oriented, with minor muscovite between grains. May have been amygdaloidal? which are now qtz-filled.

Sulfide is ultra-fine grained disseminated pyrite throughout basalt, with mg sub-euhedral pyrite as aggregates and disseminations in the fg qtz-musc-sulf stringers. Thin coarse grained qtz-sulfide veins have coarser pyrite aggregates. Minor Ilmenite disseminated throughout, locally concentrated in veinlets.

Mineralogy:

-Feldspar	50%
-Quartz	20%
-Muscovite	20%
-Pyrite	10%
-Ilmenite	1%



TS ID: 17-03
DDH: **CMR08-17, 258.6m**
Sample: none

Lithology: **altered, foliated feldspar-phyric volcanic**
Alteration: **mod perv/sel sericite, weak sel. quartz-chl**

Hand Sample Observations:

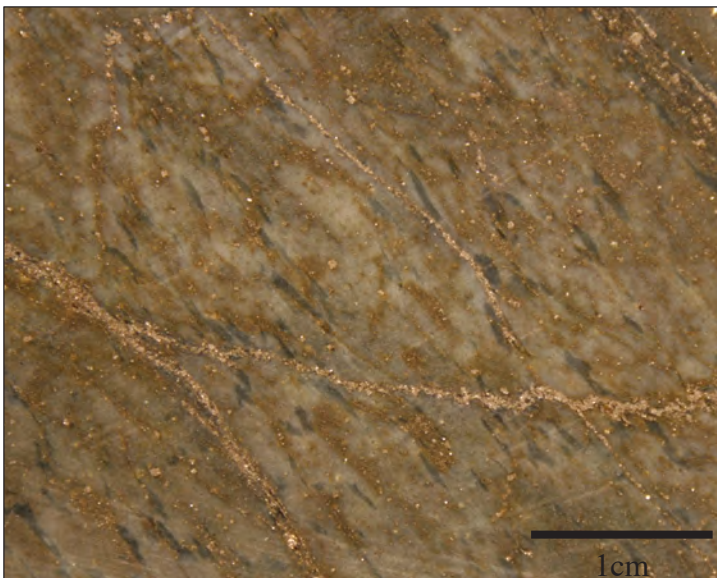
Moderately foliated, moderately altered feldspar-phyric volcanic (mafic?). Feldspars (10%) have been altered green to chlorite(?confirm w TS). Altered feldspars are strung out to slivers/lentils parallel foliation. Groundmass has been pervasively altered to sericite and quartz, although alteration along previous texture (perlite?) has caused a pseudobreccia, or false breccia texture. Thin, sharp pyrite stringers cut sub-parallel to foliation, with conjugate cross-foliation stringers.

Thin Section Observations:

Feldspar-phyric volcanic. Groundmass is fg feldspar needles (randomly oriented) and interstitial muscovite. Feldspar phenos are flattened, elongate, wispy, completely altered to muscovite, and look like fiamme. Cut by albite-chl-quartz-sulfide veins. Quartz amygs variably throughout. Sulfide in veins is mainly Pyrite, with trace Sph and Cpy locally replacing along fractures and edges. Sph locally exhibits Cpy disease.

Mineralogy:

-Feldspar	60%
-Muscovite	30%
-Chlorite	5%
-Quartz	1%
-Pyrite	7%
-Chalcopyrite	trace
-Sphalerite	trace
-Ilmenite	trace



TS ID: 17-04
DDH: **CMR08-17, 275.4m**
Sample: none

Lithology: **altered feldspar-phyrlic mafic volcanic**
Alteration: **strong perv ser, mod perv qtz, weak perv carb
subtle chlorite**

Hand Sample Observations:

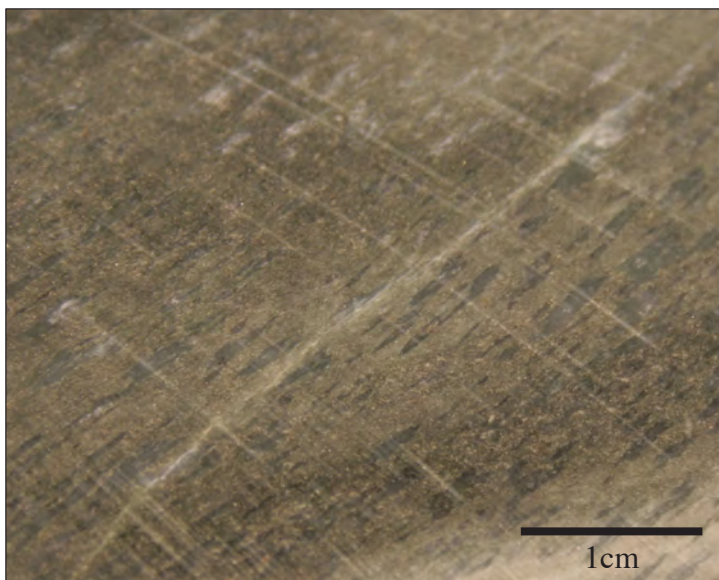
Weakly, pervasively altered, weakly foliated mafic feldspar-phyrlic volcanic. Feldspars (20%) are altered to sericite(?), and strung out as slivers/lentils parallel foliation. Groundmass is aphanitic, pervasively weakly chlorite altered (metamorphic?), weakly sericitic(?) and weakly calcite-altered.

Thin Section Observations:

Feldspar phenos appear green in handsample, but are completely muscovite altered. Phenos are flattened, elongate, and look like fiamme. Groundmass is fg muscovite and rounded quartz. Possibly minor chl within matrix? Minor disseminated carbonate throughout groundmass. Grungy extremely degraded and altered olivines disseminated throughout - dark punky blebs. Rare trace sulfide locally. Minor Chlorite within phenos. Sample is weakly crenulated.

Mineralogy:

-Muscovite	75%
-Quartz	20%
-Carbonate	2%
-Olivine	2%
-Chlorite(?)	1%
-Ilmenite(?)	3%
-Pyrite	trace
-Chalcopyrite	trace
-Sphalerite	trace



TS ID: 17-05
DDH: **CMR08-17, 285.6m**
Sample: none

Lithology: **altered, foliated feldspar-phyric mafic volcanic**
Alteration: **moderate perv Ser-Carb-(quartz?)**

Hand Sample Observations:

Moderately foliated, moderately pervasive altered feldspar-phyric mafic volcanic. Feldspars are strung out as slivers/lentils parallel foliation. Feldspars are altered to chlorite(?) and/or sericite(?). Groundmass is pervasively moderately altered to carbonate (calcite) and sericite ($\pm$ quartz?).

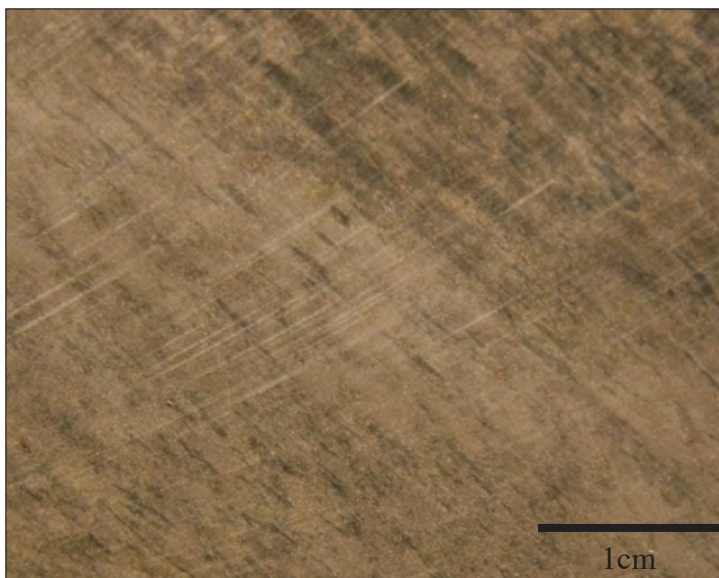
Thin Section Observations:

Very fine, nearly aphanitic mafic volcanic, with large feldspar phenos completely altered to muscovite, flattened, and now look like fiamme. Phenos appear dark green in hand sample. Orthopyroxenes remain, however are often degraded and altered to grungy dark spots, fg, disseminated throughout. Groundmass is mainly muscovite and lesser carbonate(?) with minor quartz(?), however it is so fine grained, modality is difficult to discern.

Rare trace sulfides, including pyrite, chalcopyrite and sphalerite (a few specks throughout). Trace vfg disseminated ilmenite (leucoxene?) throughout.

Mineralogy:

-Muscovite	70%
-Quartz	7%
-Orthopyroxene	7%
-Carbonate	15%
-Ilmenite(?)	1%
-Pyrite	rare trace
-Chalcopyrite	rare trace
-Sphalerite	rare trace



TS ID: 17-6
DDH: **CMR08-17, 296.7m**
Sample: none

Lithology: Altered Volcaniclastic
Alteration: strong perv quartz-musc, weak carb, subtle chl-ep

Hand Sample Observations:

Altered, foliated, volcanic fragmental. Matrix supported. Clasts range from 1 mm (amygs?) to 2 cm across, and are elongate parallel a moderate foliation. Clasts are typically completely quartz-muscovite altered, especially the larger clasts. Larger clasts exhibit small tension gashes locally filled with carbonate veins. Small white 1 mm clasts in matrix also carbonate altered - may have been amygdules. Matrix is mostly pyrite, with carb/qz/ser(?) gangue.

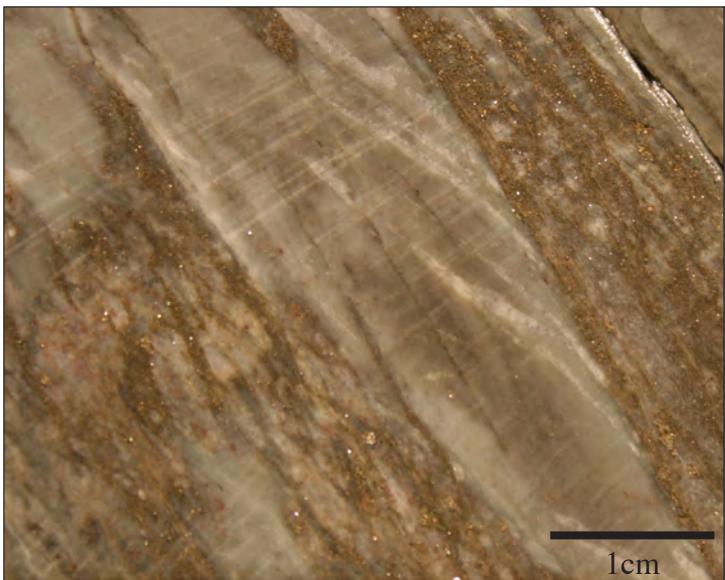
Thin Section Observations:

In general - pervasively quartz-muscovite altered, vfg 'clasts', possibly originally volcaniclastic, within a coarser, strongly altered matrix of quartz-carbonate-muscovite-sulfide + chlorite. Minor disseminated, prismatic epidote throughout sample (clasts and matrix) - high relief, elongate and acicular. Chlorite as small fan-shaped grains throughout 'matrix'. Smaller 'clasts' within matrix are surrounded by a ring of sulfide, and may have been amygdules, filled with quartz-carbonate + minor muscovite. All clasts are elongate parallel a weak foliation

Pyrite is mainly sub-euhedral, aggregates and disseminations within matrix/stringers. Trace diss specks of sphalerite in clasts, and coarser grains within matrix.

Mineralogy:

-Quartz	35%
-Muscovite	35%
-Carbonate	20%
-Epidote	trace
-Chlorite	trace
-Pyrite	10%
-Sphalerite	<1%



TS ID: 17-07
DDH: **CMR08-17, 305.6m**
Sample: none

Lithology: Altered Volcaniclastic
Alteration: strong perv qtz-ser, weak sel. qtz-ser-albite-pyx

Hand Sample Observations:

Strongly altered volcanic fragmental(?). Clasts are very elongate, strung out parallel a strong foliation. Clasts resemble pumice/scoria - with pyrite-filled vesicles?? Clasts are completely quartz $\pm$ sericite altered. Matrix is pyrite and qz+ser?

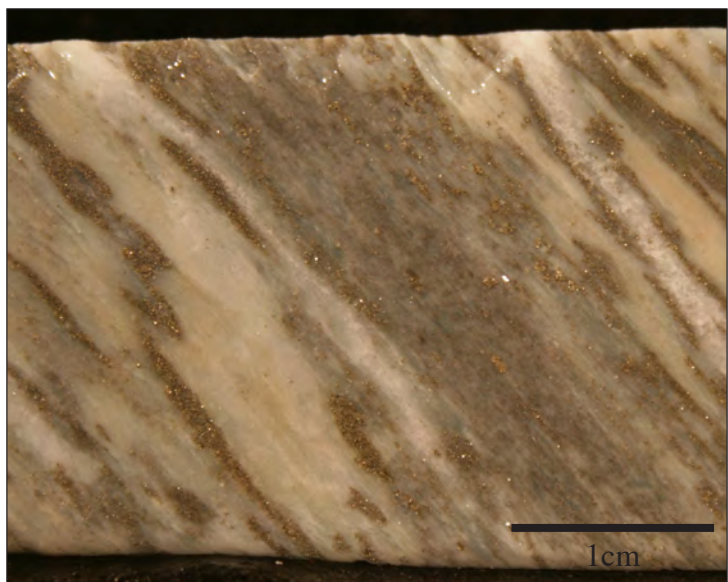
Alternate description - folded pyrite stringers? folded, boudinaged stringers through an altered foliated fragmental creates the pumice look?

Thin Section Observations:

Quartz-muscovite groundmass cut by numerous quartz-musc-sulfide-albite-orthopyroxene(?) veins. May be trace Carb in veins as well? Quartz-musc in veins locally exhibits granophyric texture.

Mineralogy:

-Quartz	45%
-Muscovite	45%
-Plagioclase	1%
-Orthopyroxene??	1%
-Carbonate	<1%
-Pyrite	10%
-Chalcopyrite	trace
-Sphalerite	rare trace



TS ID: 17-08

DDH: **CMR08-17, 310.4m**

Sample: none

Lithology: altered foliated volcanic

Alteration: Intense pervasive quartz-sericite

Hand Sample Observations:

Strongly altered volcanic fragmental. Larger clasts show hints of what may be feldspars?? Or other clasts? Need thin section. Could clasts be altered feldspars? Probably not. Clasts are 1mm-2cm across, and elongate parallel a moderate foliation. Could be either altered, foliated autobreccia, or partially welded, and then altered and foliated ignimbrite or pyroclastic

Autobreccia or Pyroclastic? Or just hydrothermal breccia?

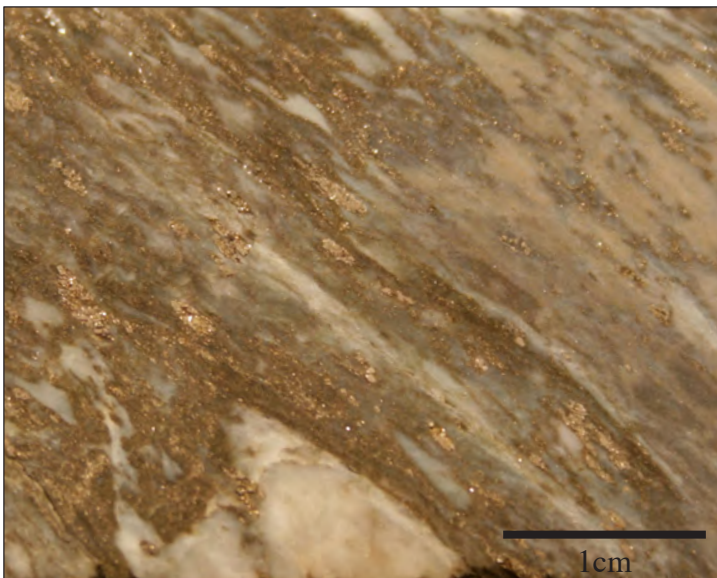
Thin Section Observations:

Groundmass is mostly muscovite with subordinate quartz. Possible clasts(?) of quartz with lesser muscovite. Are these clasts or altered feldspars, or just veins? Part of sample (least brecciated?) is mostly muscovite. Rest is heavily brecciated qtz-musc, brecciated by hairline muscovite/sericite stockwork.

Sulfide is fg to cg sub-anhedral pyrites with Sphalerite (replacing py?)

Mineralogy:

-Quartz	35%
-Muscovite	55%
-Pyrite	10%
-Sphalerite	2%



TS ID: 17-09
DDH: **CMR08-17, 318.5m**
Sample: none

Lithology: **Py-Sph Stringer Ore**
Alteration: **intense quartz, weak ser (veins)**

Hand Sample Observations:

Weakly foliated, intensely altered rock. May have been volcanoclastic fragmental. Alteration is dominantly pervasive quartz, with very minor sericite as veinlets. Pyrite and pale honey-brown sphalerite occur as vfg-fg discontinuous stringers.

Thin Section Observations:

Pervasively, intensely quartz altered groundmass with trace vfg muscovite needles interstitial to quartz grains. Thin/hairline sericite/muscovite + sulfide veins cut through quartz. Also present are rounded, quartz-sericite-sulfide 'clasts' or amygdules, up to 2 mm across. Quartz is recrystallized to coarser grained around veins. Sericite has not generally been recrystallized to muscovite - remains grungy, cloudy web of cryptocrystalline hairline stringers. Minor muscovite present locally.

Trace albite observed within stringers. Fg, irregular shapes, and only locally exhibiting nice twinning. Albite difficult to spot from quartz - so there may be more than 'trace'.

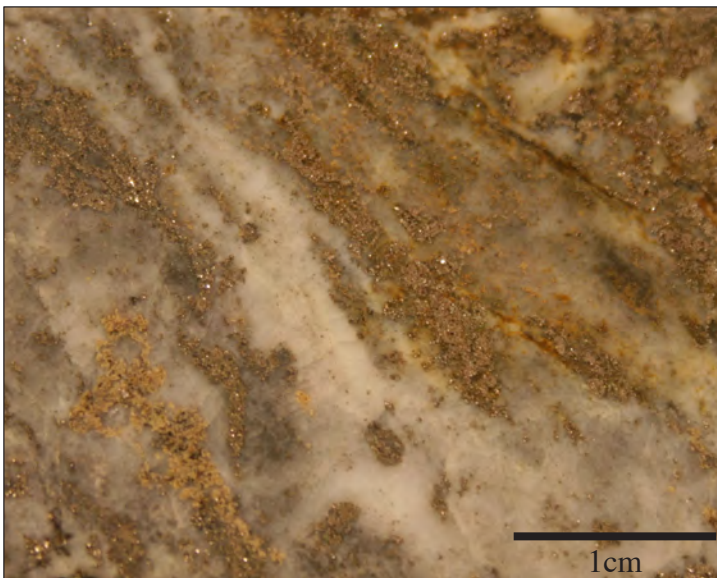
Pyrite is mainly small, rounded grains forming aggregates and packed tightly within veins. Get stringers of sphalerite, stringers of pyrite, and stringers of both. Minor chalcopyrite in some stringers. Sph and cpy are coarse to massive.

Mineralogy:

-Quartz	80%
-Sericate (+musc)	2%
-Albite	trace
-Pyrite	10%
-Sphalerite	7%
-Chalcopyrite	trace

Grain Size:

micro-fg
micro-vfg
vfg-fg
micro-vfg
fg-mg
massive?-fg



TS ID: 17-10
DDH: **CMR08-17, 326.6m**
Sample: none

Lithology: Py-Sph-Cpy Stringer Ore
Alteration: Intense quartz, strong selective albite, wk musc.

Hand Sample Observations:

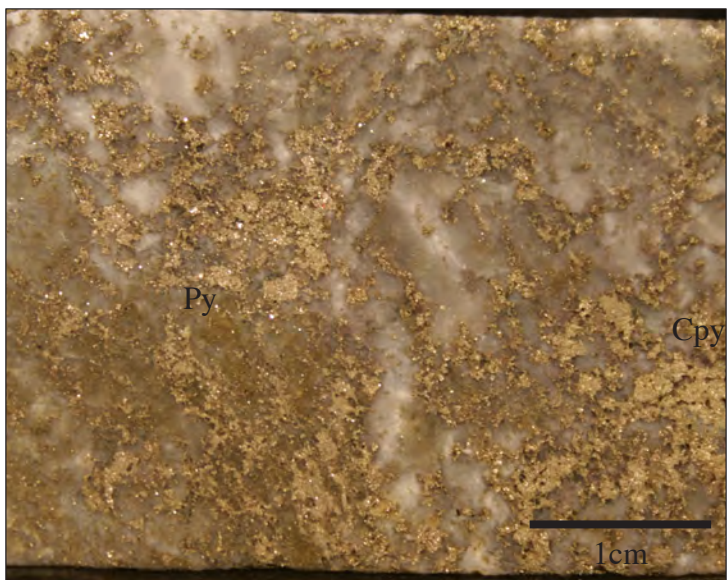
Completely quartz altered rock cut by sulfide stringers. Quartz is locally brecciated with small angular quartz clasts within sulfide.

Thin Section Observations:

Strongly quartz-altered rock, cut by sulfide stringers. Minor chlorite as fg crystals within sulfide veins. Fine grained pervasive quartz cut by coarser grained quartz and quartz-albite-sulfide veins, Likely Cu-Zn + Na rich fluid cut through, recrystallizing earlier quartz-pyrite. Plagioclase crystals, coarse, within sulfide stringers. Muscovite present pervasively throughout, and especially concentrated around veins. Also coarser muscovite within veins.

Mineralogy:

-Quartz	50%
-Muscovite	5%
-Albite	5%
-Chlorite	1%
-Chalcopyrite	15%
-Pyrite	15%
-Sphalerite	5%



TS ID: 17-11
DDH: **CMR08-17, 330.0m**
Sample: none

Lithology: Pyrite-Chalcopyrite (Sphalerite) Stringer Ore
Alteration: intense quartz, mod sericite, mod albite, wk chl

Hand Sample Observations:

Completely quartz altered rock, with aggregate pyrite stringers, locally replaced by chalcopyrite (up to 5%). Local fg green mineral (chlorite?).

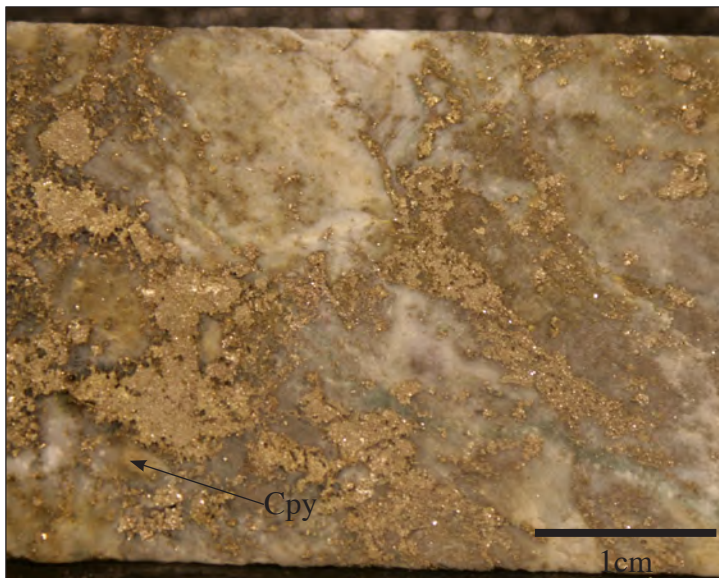
Thin Section Observations:

Very fine grained, completely pervasively quartz-sericite altered groundmass cut by coarser quartz-plagioclase-sulfide stringers and thin webs of sericite veinlets. Minor chlorite as medium green, weakly pleochroic, fg crystals within stringers. Quartz is recrystallized coarser around stringers. Albite is not always twinned and can be difficult to identify. Muscovite is micro to cryptocrystalline, and mostly as sericite.

Pyrite is microcrystalline and tightly packed to coarse grained megacrysts replaced in part by chalcopyrite. Minor pale Sph within stringers.

Mineralogy:

-Quartz	60%
-Albite	10%
-Muscovite	7%
-Chlorite	<1%
-Pyrite	15%
-Chalcopyrite	7%
-Sphalerite	<1%



TS ID: 17-12
DDH: **CMR08-17, 337.9m**
Sample: none

Lithology: Massive Pyrite Ore
Alteration: Strong quartz-chlorite

Hand Sample Observations:

Quartz breccia dominated by pyrite and chalcopyrite. Two episodes of pyrite? Dominant pervasive fg pyrite, overprinted by coarse subhedral disseminated crystals. Later pyrite then overprinted by chalcopyrite(?).

Thin Section Observations:

Abundant pyrite-chalcopyrite with chlorite and quartz gangue. Finely dispersed anhedral pyrite. Cpy fills cracks and surrounds pyrite.

Two distinct episodes of mineralization. Finer quartz-chlorite and pyrite, and coarser grained quartz-chlorite-pyrite-chalcopyrite. Possibly Cu-rich fluids coming in and recrystallizing pyrite and quartz, to form coarser grains.

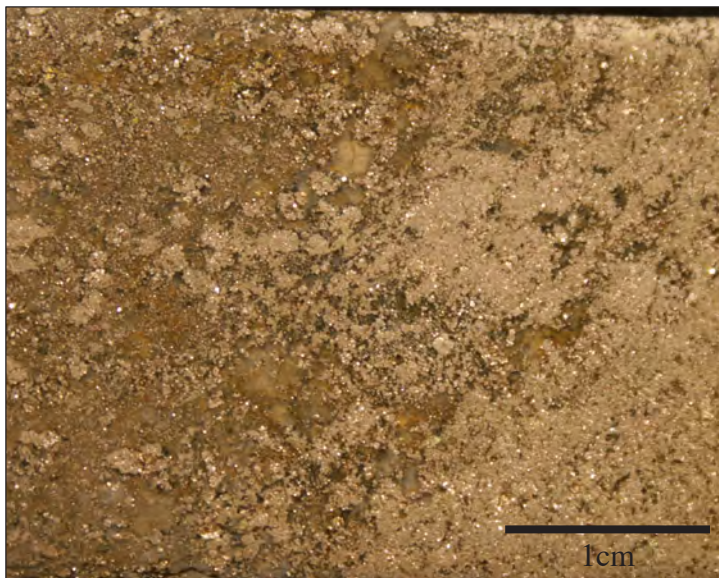
Geochemistry:

Less Na here than in above stringer zone - and no albite observed. Albite gone to chl?

Mineralogy:

-Quartz	30%	micro-fg
-Chlorite	15%	crypto-vfg
-Muscovite	5%	crypto-micro (for sure)
-Pyrite	35%	micro-fg
-Chalcopyrite	15%	massive?
-Sphalerite	trace	vfg-fg

Grain Size:



TS ID: 17-13
DDH: **CMR08-17, 342.4m**
Sample: none

Lithology: Chert-Pyrite breccia
Alteration: intense quartz, moderate sericite

Hand Sample Observations:

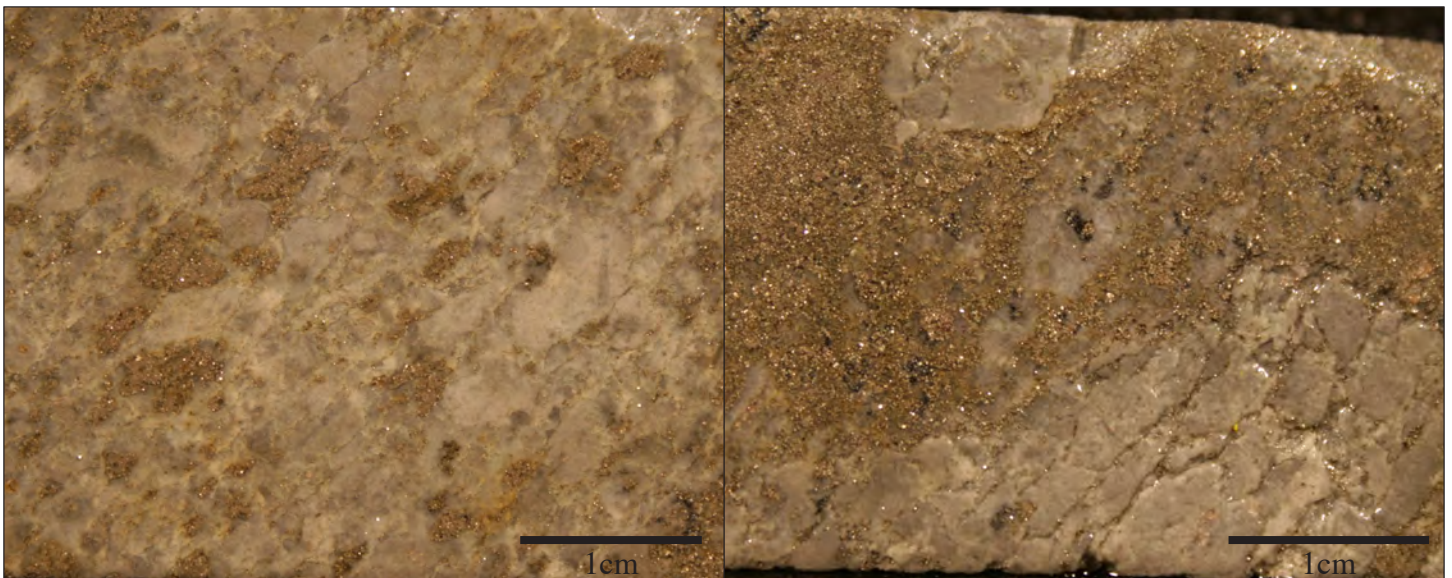
Quartz sulfide breccia. Quartz clasts are angular (hydrothermal breccia?). Bands of sulfide cut through quartz breccia parallel a weak foliation. Quartz clasts float in sulfide bands, and locally sulfide clasts float in quartz breccia in quartz bands (see photos).

Thin Section Observations:

Very fine quartz, with local 'clasts?' or patches of coarse quartz. Thin sericite seams cut throughout. Aggregates of pyrite as finely dispersed anhedral

Mineralogy:

-Quartz	70%
-Sericate	20%
-Pyrite	10%
-Sphalerite	trace
-Chalcopyrite	trace



TS ID: 17-14

DDH: **CMR08-17, 344.1m**

Sample: none

Lithology:

Massive sulfide (pyrite + chalcopyrite)

Alteration:

intense quartz-sulfide

Hand Sample Observations:

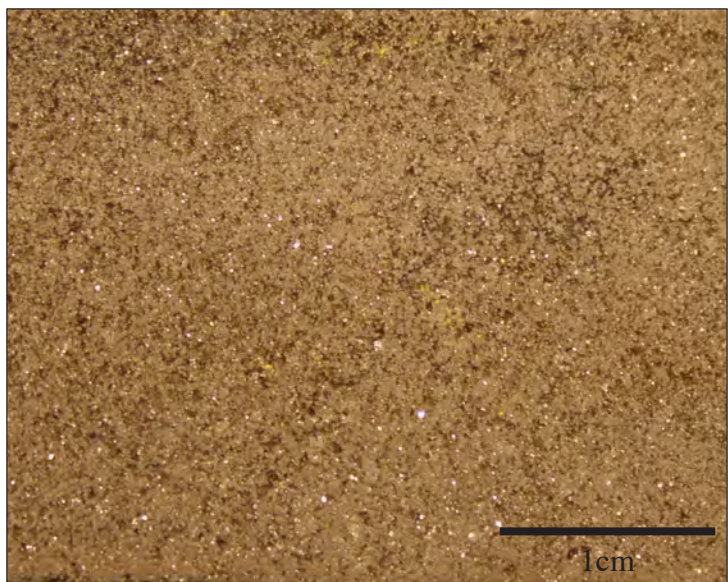
Massive fg pyrite and chalcopyrite (10%?).

Thin Section Observations:

Massive pyrite, with lesser Cpy as inclusions and locally replacing (and between xtals, and filling fractures)

Mineralogy:

-Quartz	5%
-Muscovite	trace
-Pyrite	85%
-Chalcopyrite	5%
-Sphalerite	1%
-Tetrahedrite	??



TS ID: **17-15**
DDH: **CMR08-17, 345.9m**
sample: **none**

Lithology: **Chert**
Alteration:

Hand Sample Observations:

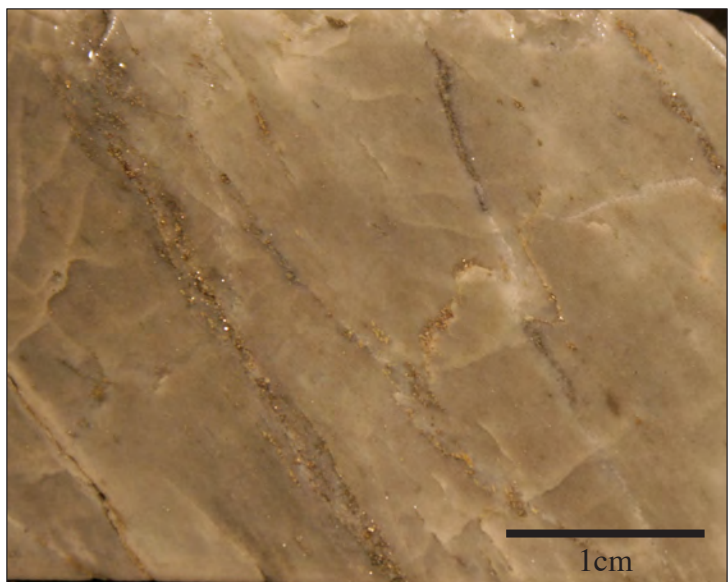
Massive chert, cut by minor thin pyrite stringers (3%).

Thin Section Observations:

Thin Py-Sphalerite stringers cut a vfg quartz groundmass (chert), with minor very fine muscovite. Sphalerite has pale honey brown IRs. Py is sub-euhedral grains and aggregates. Sphalerite is anhedral. Stringers that cut at high angles to foliation are tightly folded. Very fine Py also disseminated throughout chert.

Mineralogy:

-Quartz	85%
-Muscovite	10%
-Pyrite	3%
-Sphalerite	2%



TS ID: 17-16
DDH: CMR08-17, 347.5m
Sample: none

Lithology: Barite Ore
Alteration:

Hand Sample Observations:

Moderately foliated, banded barite and sulfide. Bands are thin, 1-5 mm and loosely defined. Sulfide is mostly dark blue-grey sphalerite which may be covellite coated, minor chalcopyrite, galena, and pyrite (5%).

Thin Section Observations:

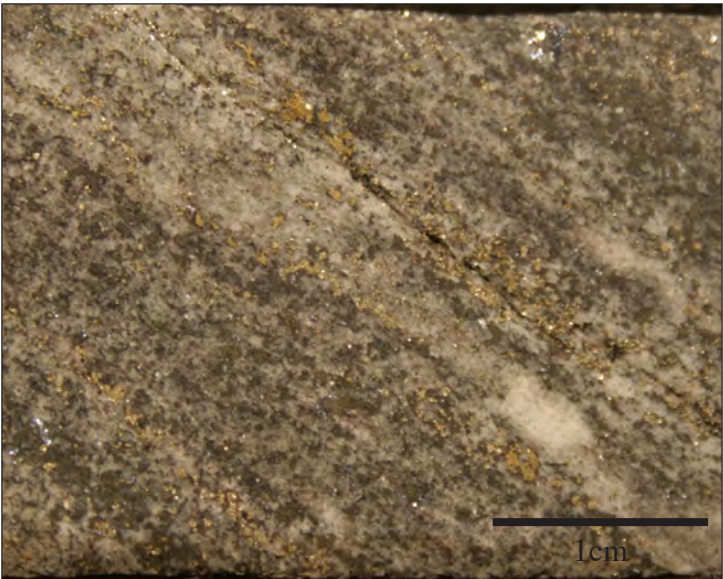
Sample is mostly barite and lesser quartz gangue, with stringers of sphalerite with lesser Cpy and Galena. Barite contacts are very grungy, altered looking. Sphalerite typically exhibits Cpy-disease, and trace covellite coating fractures through Sph, Cpy and Py. Sphalerite edges are ragged and form around sub-euhedral pyrite cubes. Cpy and galena grow around Sphalerite. Trace tetrahedrite with galena-sph-cpy. Trace arsenopyrite disseminated throughout. Aspy is sub-euhedral crystals. No magnetite observed.

Mineralogy:

-Barite	70%
-Quartz	5%
-Muscovite	rare trace
-Sphalerite	15%
-Pyrite	10%
-Chalcopyrite	3%
-Galena	2%
-Covellite	trace
-Tetrahedrite	trace
-Arsenopyrite	trace

Grain Size:

vfg-fg
vfg
micro
vfg-fg
vfg-fg
micro-vfg
micro-vfg
crypto
micro-vfg
micro-vfg



TS ID: 17-17
DDH: CMR08-17, 351.2m
Sample: none

Lithology: Py-Sph stringers (Tuff)
Alteration: intense quartz, strong ser, carb, and chl?

Hand Sample Observations:

Clasts of strongly chlorite? altered lithic material within a cherty matrix. Clasts are deformed and elongate parallel a moderate foliation. Rock is cut by numerous hairline, rusty Fe-Carb? veinlets. Chlorite clasts range up to 1 cm across (within this sample).

17-18, in the same unit, has amygs in the 'chert' clasts - so obviously completely silicified volcanic. This could be the same.

Thin Section Observations:

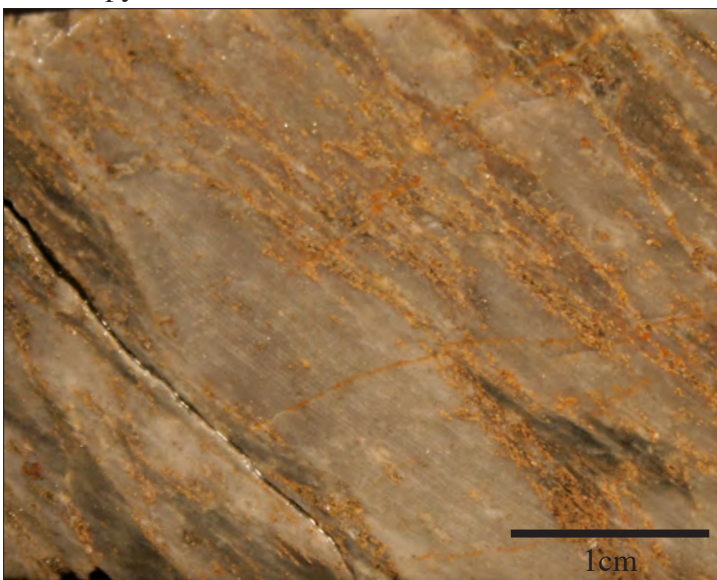
The TS doesn't contain any of the Chl-clasts. Pervasive quartz groundmass, with minor interstitial muscovite, and vfg sulfide disseminated. Throughout groundmass are small local pods sericite, and pods of carbonate that may have been feldspars and amygdules. Thin hairline muscovite veinlets network throughout matrix. Larger, coarser quartz, muscovite, carbonate (Fe-Carb?) and sulfide veins cut everything. Quartz grains within these veins are elongate, and being replaced around the rims by muscovite - creating a jagged, comb-like look to the quartz. The 'quartz' within the veins may be is feldspar??. Darker than the qtz, and do see some deformed twinning locally. In which case there is little to no quartz within stringers, only coarse recrystallized quartz surrounding the stringers.

Carbonates within the veins are very coarse, and grungy and may be Fe-Carb?. Carbonate within the amygdules is partially replaced by the recrystallized mosaic of quartz. Late, thin carbonate veins also cut perpendicular to the dominant foliation.

Sulfide is mainly coarse pale honey-brown sphalerite, and sub-euhedral Pyrite grains, with trace Cpy within stringers, and vfg disseminated Py-sph $\pm$ cpy throughout groundmass.

Mineralogy:

-Quartz	60%
-Muscovite	20%
-Carbonate	10%
-(Ba,K)-Feldspar	5%
-Pyrite	5%
-Sphalerite	5%
-Chalcopyrite	trace



TS ID: **17-18**
DDH: **CMR08-17, 361.1m**
sample: **none**

Lithology: Altered volcaniclastic(?)
Alteration: strong quartz-chlorite

Hand Sample Observations:

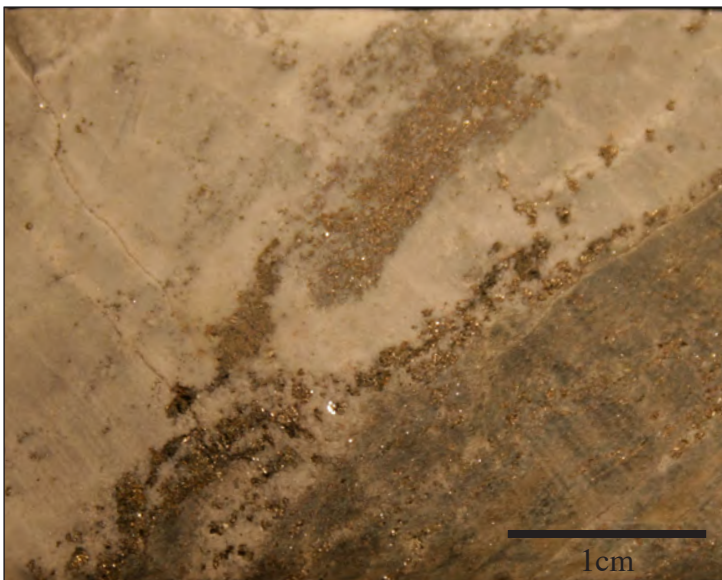
Sample shows sharp contact between white chert and green chloritic ser-py altered lithic(?) fragment or volcaniclastic. Overall drill core alternates back and forth chert to chloritic lithic, suggesting interlayering or perhaps large clastic fragments.

Thin Section Observations:

Half of sample is completely quartz-altered, the other half is completely muscovite altered. May be domainal alteration, or large preferentially altered clasts within a matrix? Or alternating chert/tuff sequence. Quartz-dominated area contains abundant small, round, carbonate filled amygdules.

Mineralogy:

-Quartz	40%
-Muscovite	30%
-Carbonate	10%
-Pyrite	15%
-Sphalerite	5%
-Chalcopyrite	trace



TS ID: 17-19
DDH: **CMR08-17, 365.4m**
Sample: none

Lithology: Alt'd Feldsphyric volcanic?
Alteration: mod perv chl-ser, mod selective qtz-chl

Hand Sample Observations:

Sample of strongly chloritic rock, with possible feldspars, and either strongly silicified sections, and/or quartz-altered/chert clasts within. Need thin section to show feldspars/amygs. Small pyrite crystals and aggregates disseminated throughout (5%).

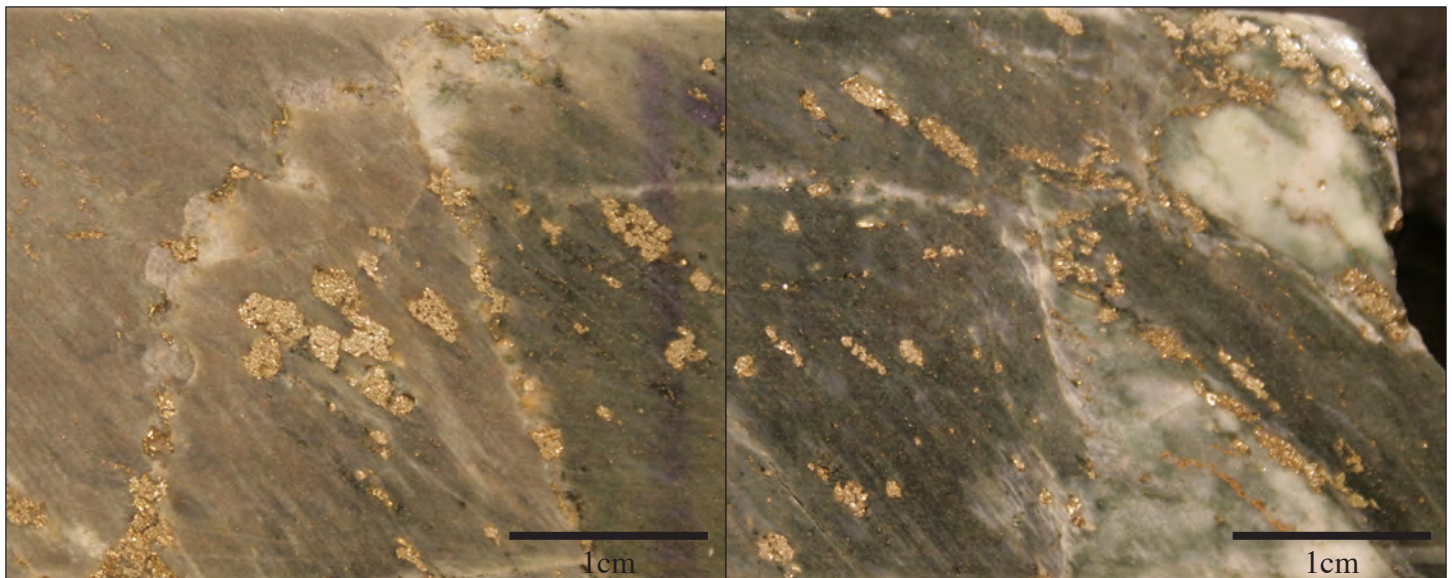
Thin Section Observations:

Mafic tuff? - now weakly crenulated fg chlorite and muscovite, with several elongate, flattened clasts of sub-microscopic quartz(?) and vfg chlorite. Qtz-Chl-Pyrite veins cut rock. Clasts may be flattened scoria? Could clasts be feldspars? Very large chlorite phenos throughout, and especially coarse near sulfides.

Vfg ilmenite spattered throughout as elongate sub-anhedral laths. Local aggregates of quartz-chlorite and sulfides replacing? or nucleating locally. Sulfides are very coarse pyrite, blebs of Cpy, and trace Sph. Cpy and Py also within qtz-veins

Mineralogy:

-Muscovite	50%
-Chlorite	5%
-Quartz	5%
-Muscovite	40%
-Pyrite	5%
-Chalcopyrite	1%
-Sphalerite	trace
-Ilmenite	1%



TS ID: **17-20**
DDH: **CMR08-17, 377.9m**
Sample: **none**

Lithology: Chert?
Alteration: Intense Qtz-Ser-Py

Hand Sample Observations:

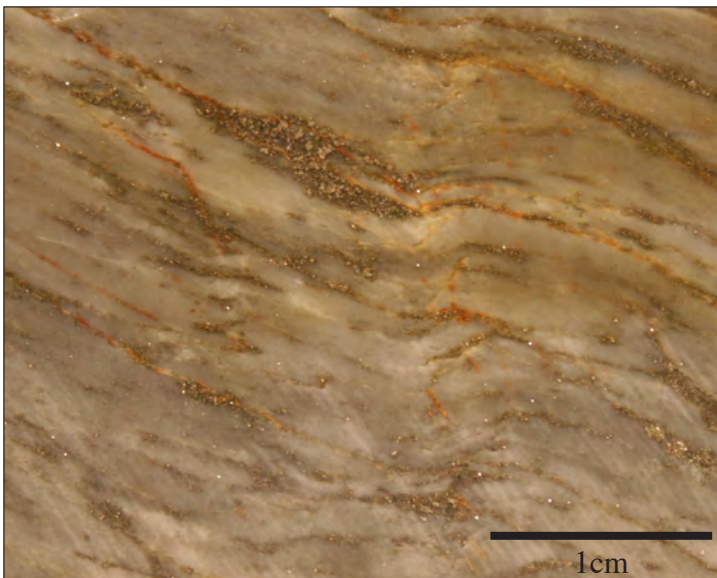
Clast supported chert fragmental. Lapilli sized clasts, elongate and lenticular. Matrix is pyrite.

Thin Section Observations:

Qtz-Ser schist, with Pyrite stringers. Do not know protolith. May have been a chert? But lots of sericite with qtz, and qtz is not equant and clean.... so it kinda looks like alteration. Local micro C-S fabric in qtz-ser. Qtz-Py stringers exhibit coarse quartz and euhedral, coarse pyrite grains.

Mineralogy:

-Quartz	70%
-Sericite	20%
-Pyrite	10%
-Sphalerite	0.5%



TS ID: 17-22
DDH: **CMR08-17, 393.0m**
Sample: none

Lithology: altered feldspar-phyric basalt
Alteration: moderate perv. chlorite-sercite-carb

Hand Sample Observations:

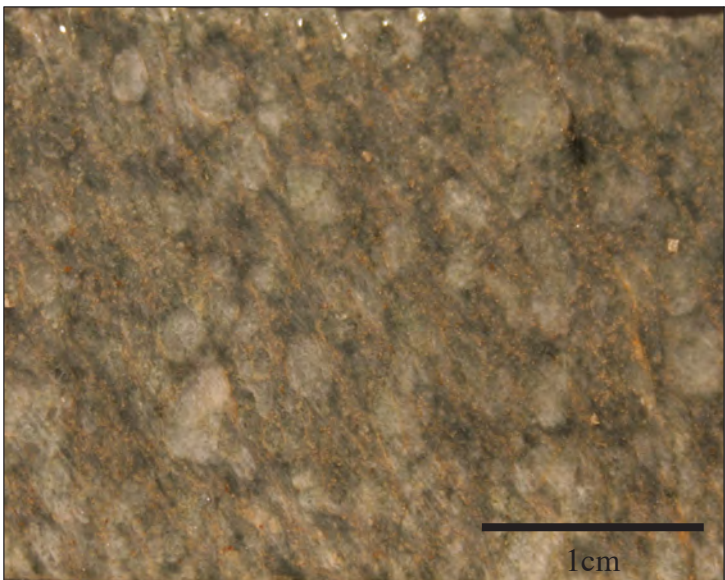
weakly chlorite and carbonate altered feldspar phyric mafic volcanic. Abundant anhedral feldspars - rounded (30%), 1-3mm.

Thin Section Observations:

Feldspar-phyric strongly altered volcanic. Groundmass is mostly Sericite, and lesser chlorite and minor feldspar. Smaller carbonate phenos throughout as well. Flds phenos are altered to chl-musc-carb.

Mineralogy:

-Muscovite	40%
-Carbonate	15%
-Plagioclase	25%
-Chlorite	20%
-Pyrite	1%
-Sphalerite	trace
-Ilmenite	trace



TS ID: 18-01
DDH: **CMR08-18, 218.3m**
Sample: none

Lithology: Altered amygdaloidal tuff?
Alteration: intense Sericite, weak quartz

Hand Sample Observations:

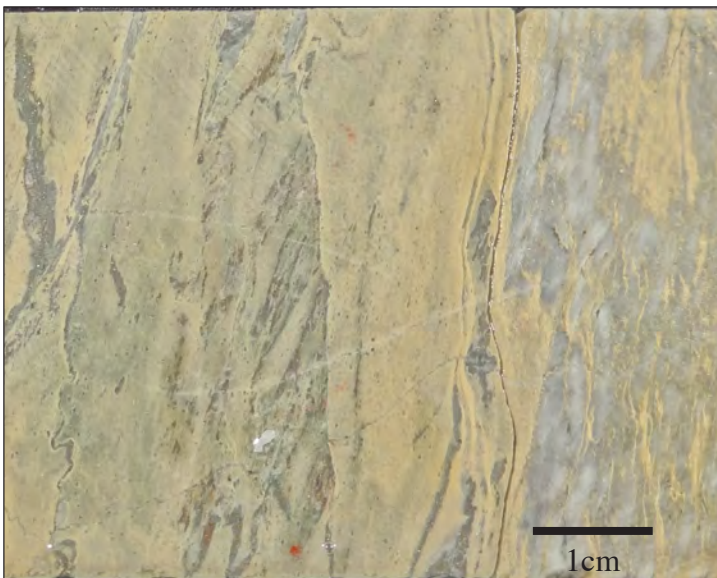
Very strongly Sericite, and weak-mod altered Qz alteration. Pervasive. Thin stringers of vfg Py. Yellowish colour to the rock. Weak fabric. May have been a massive mafic volcanic unit.

Thin Section Observations:

Groundmass of vfg muscovite/sericite with abundant vfg opaques (leucoxene). Minor discontinuous dark disjunctive cleavage. Rounded, weakly flattened, lenticular amygs up to 0.5mm across filled with Quartz and minor muscovite. Amygs unevenly distributed, <1%. Cut by folded, meandering veinlets of Qtz-Musc-Carb-Chl-Sph-Py with varying amounts of Chl vs Carb. Veins with more chl contain more sph in general. Logged as cherty argillite. Likely an altered amygdaloidal tuff?

Mineralogy:

-Muscovite	90%
-Quartz	5%
-Chlorite	1%
-Carbonate	1%
-Pyrite	1%
-Sphalerite	<1%



TS ID: 18-02
DDH: **CMR08-18, 220.7m**
Sample: none

Lithology: Barite Ore
Alteration:

Hand Sample Observations:

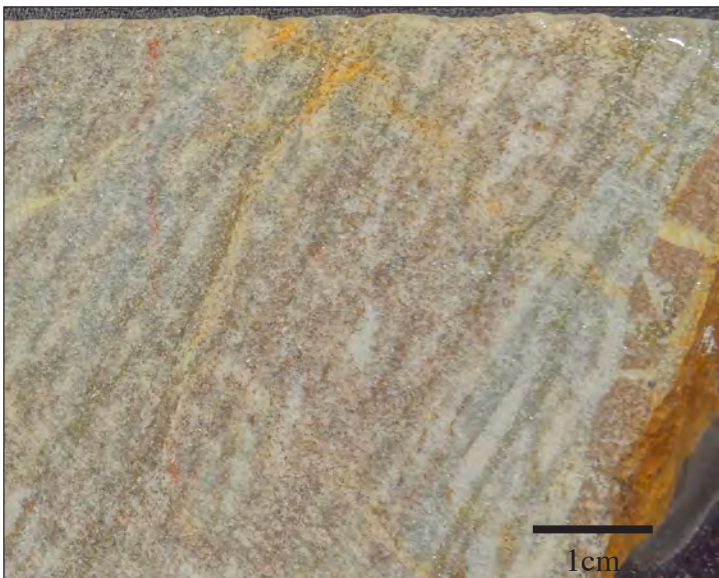
Massive baryte, weakly foliated, mg and crystalline, and cut by both purplish Sphalerite stringers (5-20mm) and Cpy-Sph stringers (where sph is pale tan). Stringers are parallel foliation. Very thin fracture cuts foliation, and is folded into it. Frac is late(?) and cuts stringers, and contain qz? Only Sph stringer shown below. Sph stringer expands to 2cm on backside of core. Appears to cut banding in baryte. Thin Py stringers also observed locally.

Thin Section Observations:

Massive barite, with minor interstitial sphalerite (and lesser cpy-galena) and trace carbonate. A few thin veinlets of fg equant quartz. Barite has been recrystallized/annealed, to coarse, equigranular crystals. foliation in hand sample from the preferential layering of interstitial sphalerite/Cpy/Galena. Minor Pyrite locally as euhedral crystals. All sulfides appear to be interstitial to barite. Chalcopyrite disease in sphalerites. Cpy appears to surround Sph grains (later?)

Mineralogy:

-Barite	95%
-Carbonate	trace
-Quartz	1%
-Sphalerite	3%
-Chalcopyrite	1%
-Galena	trace
-Pyrite	trace



TS ID: 18-03
DDH: **CMR08-18, 227.3m**
Sample: none

Lithology: Mafic volcanoclastic (hyaloclastite?)
Alteration: Strong Carb/Chl, trace quartz

Hand Sample Observations:

Strongly altered, mafic volcanoclastic, with large curvilinear clasts, lapilli to agglomerate sized clasts (1-10cm long). Clasts are selectively Chl altered, and matrix is selectively Calcite altered. Trace vfg Pyrrhotite diss in clasts and matrix.

Thin Section Observations:

Fine grained chlorite clasts in a coarse carbonate matrix. Minor quartz with carbonate. Chlorite is strongly foliated, and contains stretched, elongate chlorite phenos (pseudomorphs of pyx? amph?). Abundant leucoxene in chloritic clasts. Pyrrhotite disseminated as elongate grains, and as discontinuous veinlets through chloritic clasts, locally protruding into carb matrix?
Carb matrix is of coarse grained carbonate aggregates, usually surrounded by chlorite.

Mineralogy:

-Chlorite	60%
-Carbonate	40%
-Quartz	1%
-Pyrrhotite	1%
-Sphalerite	trace
-Leucoxene	1%



TS ID: 18-04

DDH: **CMR08-18, 235.9m**

Sample: none

Lithology: Chert

Alteration: intense quartz, weak sericite, weak-mod carb

Hand Sample Observations:

Pale grey, massive rock. Mod, pervasive Qz alteration throughout, with slightly stronger qz as thin stringers (alt conduits). Vfg diss Py throughout (1%). Rock is very fine grained. Trave Ser along fracs(?). On the log, this unit is ambiguous, and located between two distinctly volcanoclastic intervals. May be altered syn-volcanic sill or dyke?

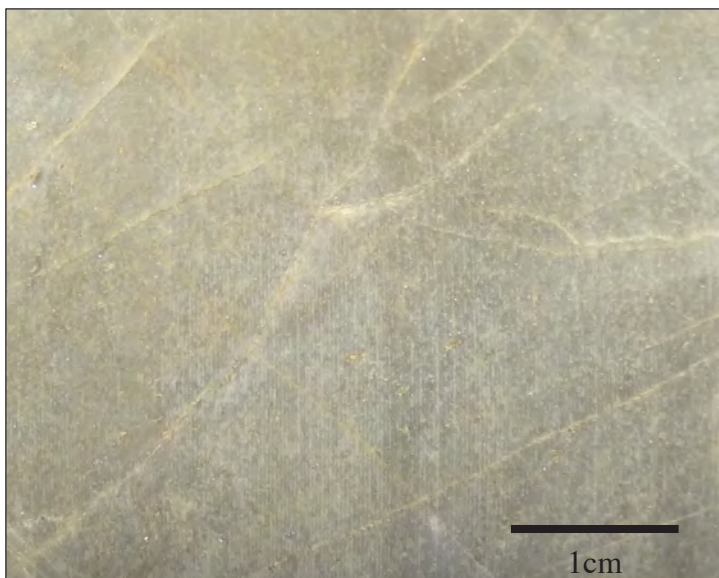
Possibly altered tuff or Chert?

Thin Section Observations:

Groundmass if vfg equant quartz and trace interstitial muscovite and anhedral carbonate. May be altered tuff? Cut by numerous thin fractures/veinlets of carbonate. These are in turn cut by thinner muscovite/carb/sulfide veinlets. Groundmass is very homogeneous. Sulfides are mainly pyrite, as anhedral aggregate brecciated masses to euhedral grains. Trace Sph and Chpy as well interstitial to Py or to qtz-carb.

Mineralogy:

-Quartz	85%
-Muscovite	3%
-Carbonate	3%
-Pyrite	1%
-Sphalerite	trace
-Chalcopyrite	trace



TS ID: 18-05
DDH: **CMR08-18, 245.4m**

Lithology: Tuff and volcaniclastic
Alteration: Strong Qz, Strong Carb, Mod Chl

Hand Sample Observations:

Pale green is Qz and Calcite alteration (strong). Dark green is chl. Lesser Ser alteration also present pervasively. Chl is selective to local clasts (?). Rock was volcaniclastic, and has been selectively, variably altered. Local patches of fg Py and trace pale-tan Sph as well - may be replaced clasts?.

Thin Section Observations:

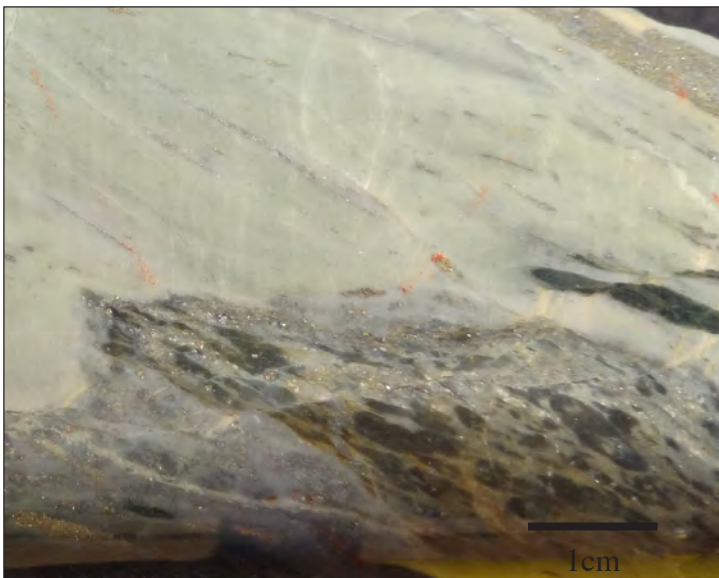
Two distinct units? Or more? 1st unit is vfg groundmass of quartz with minor muscovite, likely an altered Tuff. Resembles 18-04 - cut by thin carb-sx veinlets.

Contact with other unit is cut(?) by muscovite vein. 2nd unit is coarse grained breccia of barite, quartz, sericite and carbonate within a fg matrix. Appears to be clasts of barite-Carbonate in quartz-carb matrix, and qtz-sulfide clasts in a chlorite-quartz matrix. Two distinct units? Chlorite veinlets cut and flood through matrix. Drawing in notes of relationship.

Vfg chlorite unit on edge of sample. Disseminated leucoxene here, but nowhere else. Altered volcanic fragment.

Mineralogy:

-Quartz	70%
-Muscovite	5%
-Carbonate	10%
-Barite	2%
-Chlorite	5%
-Pyrite	3%
-Galena	trace
-Sphalerite	rare trace
-leucoxene	trace



TS ID: 18-06
DDH: **CMR08-18, 255.4m**
Sample: none

Lithology: Barite Ore (sediment) Debris flow?
Alteration:

Hand Sample Observations:

White, fg-mg, fragmental unit/breccia of Baryte, Calcite, Sulfide clasts. Py mostly in Matrix as fg diss. Possible Qz-alt too? Check Thin Section. Chl chunk could be from Dyke?
Trace amnts of purple mineral - may just be qz?

Thin Section Observations:

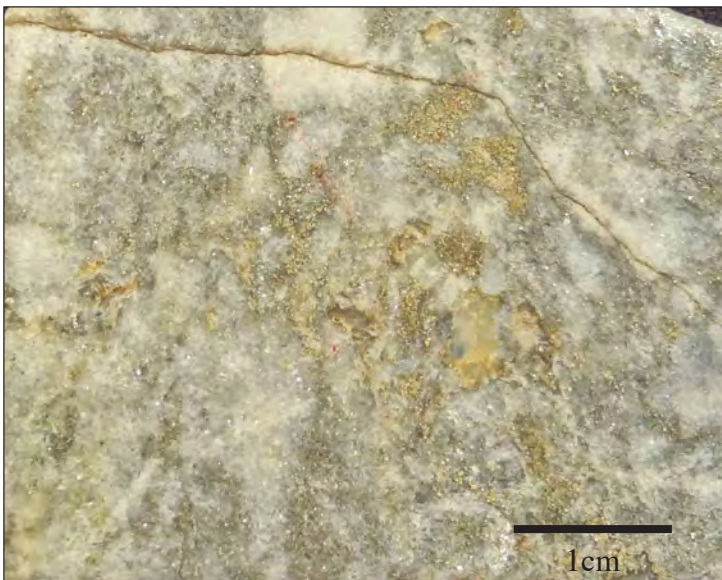
Unit of brecciated barite, with lesser sulfide and carbonate clasts. Debris flow? Carbonate crystals are rounded, and altered? (fuzzy appearance). Sulfide also interstitial to barite. Trace muscovite locally interstitial to clasts.

Sulfides are interstitial, filling space between clasts, and as sulfide clasts. Sx clasts are typically Py as mg aggregates of brecciated sub-euhedral crystals. Pyrite in clasts have interstitial Cpy and Sph.

Barite has been recrystallized/annealed. Pyrite has not? All sub-anhedral.

Mineralogy:

-Barite	90%
-Carbonate	7%
-Chlorite	trace
-Muscovite	trace
-Pyrite	2%
-Sphalerite	1%
-Chalcopyrite	0.5%



TS ID: 18-07 (labelled 18-08)

DDH: **CMR08-18, 258.8m**

Sample: none

Lithology: Barite Ore

Alteration:

Hand Sample Observations:

Massive Sph-Py. ~40% Sph, 20% Py, and 40% Bar ($\pm$ qz?).

Thin Section Observations:

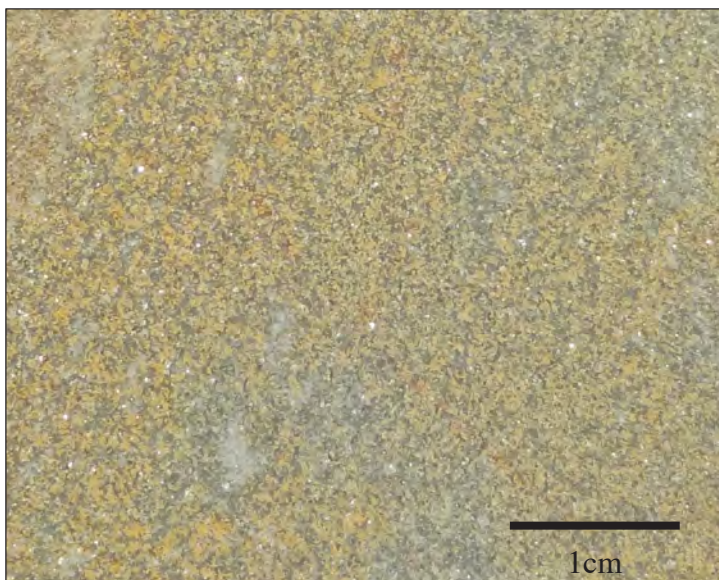
Massive sulfide - Pale honey-brown sphalerite and barite (? - along with albite/quartz??). Local cg carbonate with Barite. Barite Grains are coarse, and possibly annealed? - likely occurred with Sph, although recrystallized and difficult to tell.

Pyrites are sub-euhedral single grains, within massive sphalerite. Boundaries of sphalerite with barite all look ragged, and typically rimmed by chalcopyrite. Sph also exhibits Chalcopyrite disease.

Locally, Pyrite and or sphalerite grains replaced by tetrahedrite with Arsenopyrite and Chalcopyrite inclusions?? Galena as anhedral grains, within sphalerite, typically adjacent Py grains. Py replaced by Sph, with Galena forming at contact? See pic. Arsenopyrite is euhedral, and vfg, locally cg (rare).

Mineralogy:

-Barite	30%
-Chlorite	1%
-Carbonate	trace
-Sphalerite	50%
-Pyrite	15%
-Galena	trace
-Chalcopyrite	trace
-Tetrahedrite	trace
-Arsenopyrite	trace



TS ID: 18-08 (labelled 18-07)

DDH: **CMR08-18, 259.2m**

Sample: none

Lithology: Massive Sulfide (Py/Cpy)

Alteration: strong Chl-albite (+quartz?)

Hand Sample Observations:

Sulfide, fg, massive. Under lens, get clots of Py with surrounding Cpy?. Trace qz locally.

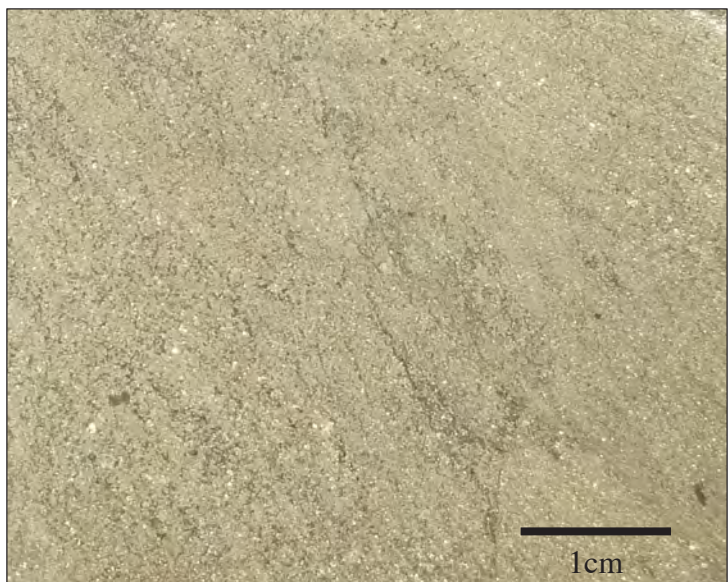
Thin Section Observations:

Massive sulfide with Chl and Albite (+Qtz?) gangue is interstitial to sulfides. Sample is mainly pyrite, as sub-euhedral fractured and brecciated grains, with interstitial sphalerite and chalcopyrite.

Pyrite has been annealed/recrystallized?

Mineralogy:

-Chlorite	5%
-Albite	1%
-Pyrite	85%
-Sphalerite	3%
-Chalcopyrite	5%



TS ID: 18-09
DDH: **CMR08-18, 259.9m**
Sample: none

Lithology: Altered Volcaniclastic
Alteration: Strong Qz-Ser

Hand Sample Observations:

Selectively, strongly Qz-Ser-Py altered volcaniclastic. Lapilli to agglomerate sized clasts from 5-30mm long. Clasts are sub-angular, elongate // a foliation, highly irregularly shaped, and selectively Qz altered. Matrix is Qz-Ser and Py. Py is fg, granular. Qz alt is either white and creamy in clasts, or grey and translucent in matrix.

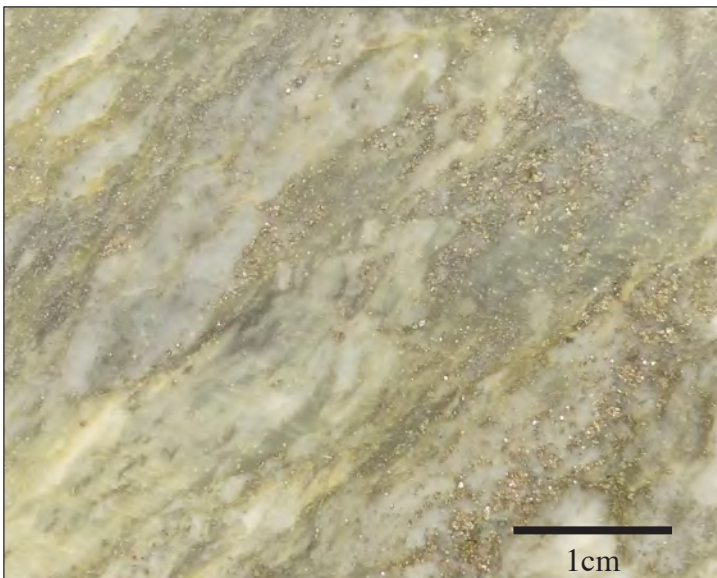
Thin Section Observations:

Volcaniclastic, lapilli to agglomerate size clasts. Large clasts are brecciated (hydrothermally?). Clasts are quartz, within a muscovite matrix. Matrix is crenulated. Large clasts are equant quartz with interstitial muscovite. Clasts range from 0.2mm to >8mm, rounded to angular.

Pyrite is subhedral, disseminated grains. Cpy and Sph are interstitial to Py, and Qtz. Pyrite is fg to cg.

Mineralogy:

-Quartz	30%
-Muscovite	60%
-Pyrite	7%
-Chalcopyrite	1%
-Sphalerite	trace



TS ID: 18-10
DDH: **CMR08-18, 266.0m**
Sample: none

Lithology: Altered Volcaniclastic
Alteration: Intense quartz, weak ser.

Hand Sample Observations:

Mostly clotty aggregates of fg Py, with Mottled-looking quart. Protolith unknown. Py-clots are up to 7mm across, and round. Minor Ser pervasively, but mostly pervasive qz-alteration. Local clots of red Sph (trace). up to 50% Py.

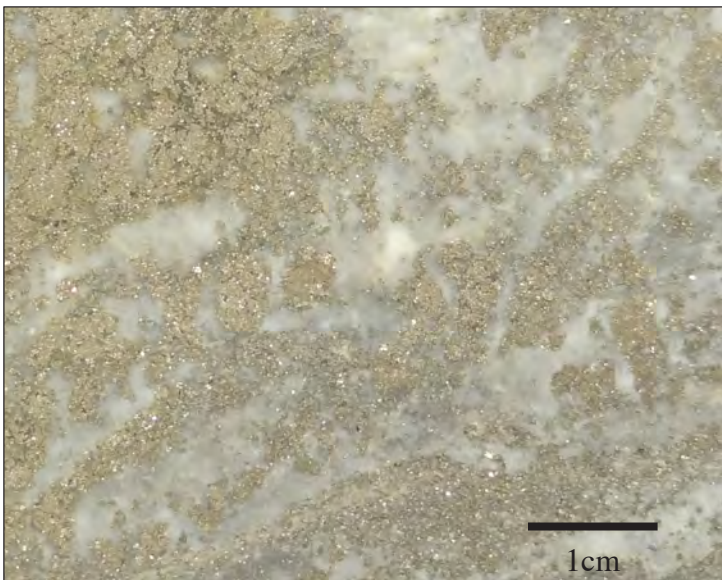
Thin Section Observations:

Pyrite clasts(?) in a quartz-flooded matrix. Quartz matrix is variable grain size. Stylolites throughout of muscovite vnlets randomly. Pyrites are sub-anhedral and brecciated (friable).

Trace Sph and Cpy. Sph is pale yellow/brown. Cpy and Sph are within pyrites, along fractures. Sample is mostly Quartz and Pyrite.

Mineralogy:

-Quartz	72%
-Muscovite	3%
-Pyrite	25%
-Sphalerite	trace
-Chalcopyrite	trace



TS ID: 18-11
DDH: **CMR08-18, 272.1m**
Sample: none

Lithology: Volcaniclastic Qz-Ser-Py
Alteration: Strong Quartz, Mod-strong Ser

Hand Sample Observations:

Strongly to intensely altered volcaniclastic? Small, sub-angular grey qz-ser-py clasts within a more ser-rich white matrix. Clasts in this sample are mostly <1cm, although on the left is a possible large >5cm clasts(?). On the right are round, qz-filled amygs(?) - or possible qz-phenos depending on composition. Likely amygs.

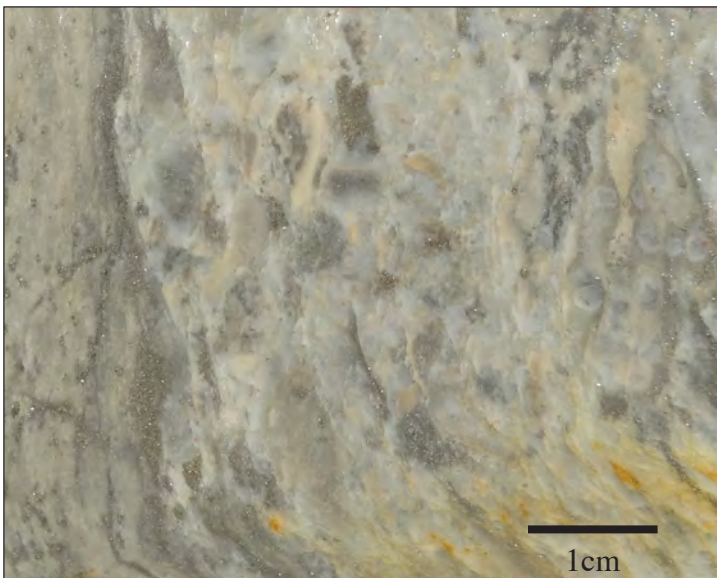
Thin Section Observations:

Large, lenticular clasts within a quartz-muscovite matrix. Clasts are variably altered, leading me to believe they may have been polymictic? Large, vfg lenticular clasts of quartz-musc-py, and large blocky cg clasts of qtz-py, and elongate clasts of mostly sulfide.

Sulfide mostly localized to clasts, and variable from clast to clast. Mostly pyrite, as vfg to mg friable sub-anhedral grains and masses. Trace Sph locally very pale.

Mineralogy:

-Quartz	60%
-Muscovite	30%
-Pyrite	10%
-Sphalerite	trace



TS ID: 18-12
DDH: **CMR08-18, 281.3m**
Sample: none

Lithology: Carb-Sph Ore (cut by qz-cpy-sph stringers)
Alteration: Intense Calcite, mod Qz-Chl

Hand Sample Observations:

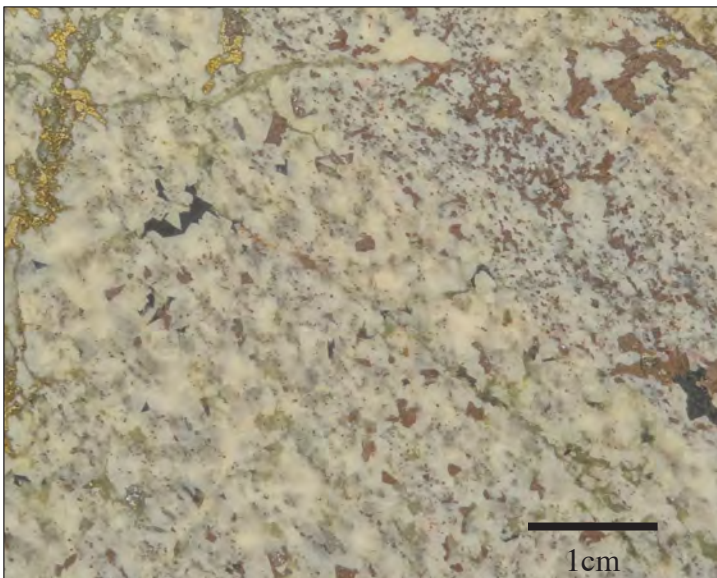
Mottled quartz and calcite alteration of rock, then cut(?) by Cpy, Sph and Chl stringers, but discontinuously(?) giving rock a brecciated look. Paragenesis ambiguous? Sph and Chl are angular and locally euhedral (sph anyhow). Possibly some type of vein?

Thin Section Observations:

More like carb-sph ore? Mostly vcg equant/interlocking carbonate crystals, with minor chl quartz and sulfide interstitially. Cut by quartz-chl-sulfide vein across section. Also cut by brittle, late carbonate veins. Quartz in vein is partially replaced by carbonate along fractures (pic). Cpy and Sph (coarse) within qtz-chl veins, and as large clots filling space between angular carb crystals. Mg Sph and Py also as inclusions to Carbonate. Cpy and Sph in vein fills space b/w quartz grains and within fractures.

Mineralogy:

-Carbonate	75%
-Quartz	7%
-Chlorite	5%
-Sphalerite	10%
-Pyrite	1%
-Chalcopyrite	5%



TS ID: 18-13
DDH: **CMR08-18, 281.8m**
Sample: none

Lithology: Po-Cpy stringer Ore (thru a Volcaniclastic)
Alteration: Strong Qz-Musc, lcl Chl

Hand Sample Observations:

Intensely qz-altered fragments in a Po matrix? - Or more likely Qz-Po veins? Stringer zone. Qz fragments are angular to sub-angular. Cpy occurs locally around large qz-'clasts'. A thin red Sph? veinlet cuts across core, with minor Chl surrounding it. Approx 35-40% Po, 1% Cpy (or py? - see thin section).

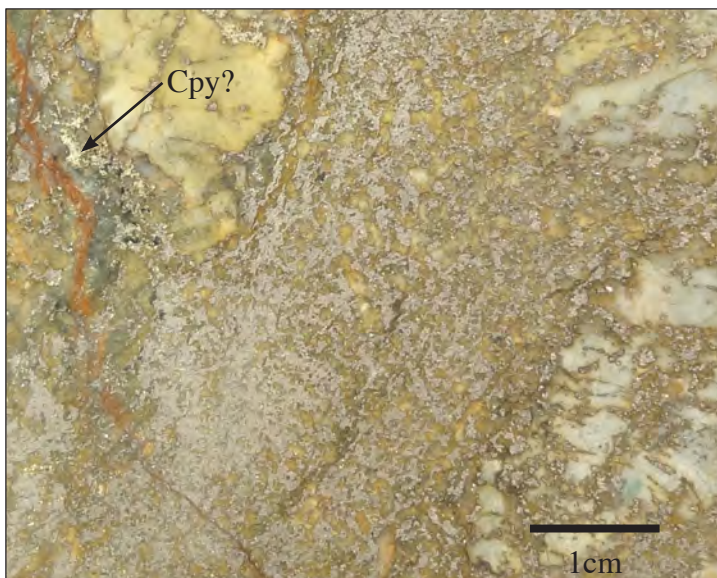
Thin Section Observations:

Coarse grained quartz clasts(?) in a sulfide matrix. Several large vfg quartz clast on outsides of section are distinctly clasts. Rest of sample is intergrown aggregates (or clasts?) of quartz+muscovite with Sulfides (pic). Likely the qtz-musc-sulfide section is a large stringer, or alteration pathway cutting a volcaniclastic, flooding around large cm-scale vfg quartz-altered clasts.

Po is skeletal, filling space between qz and musc. Minor Cpy with Po, with local concentrations. Py locally replacing Po around edges and fractures. Chl only locally, however strong spatial relationship between chl and Cpy. Trace Sph locally, mostly with Cpy-Chl concentrations.

Mineralogy:

-Quartz	40%
-Muscovite	20%
-Chlorite	2%
-Pyrrhotite	30%
-Chalcopyrite	5%
-Pyrite	3%
-Sphalerite	trace



TS ID: 8-14
DDH: **CMR08-18, 289.7m**
Sample: none

Lithology: Volcaniclastic (Qz-Ser-Py)
Alteration: Intense Qz, Mod Ser

Hand Sample Observations:

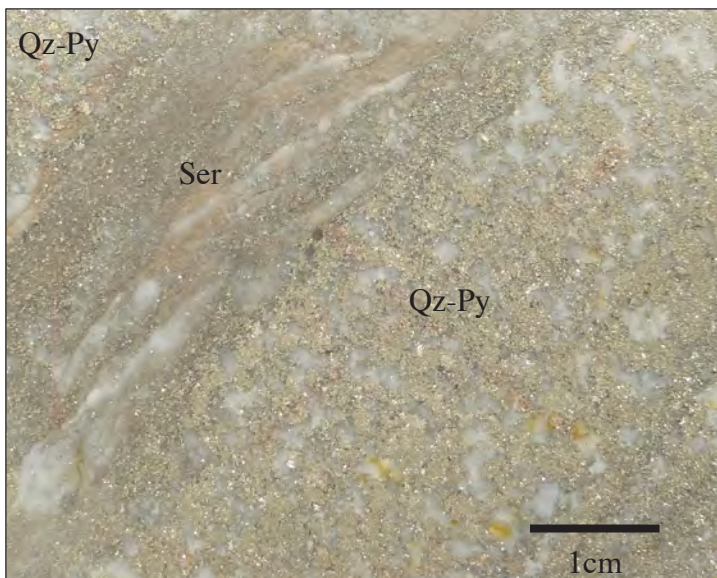
Mottled Qz-Py, equigranular-looking rock, cut by a more sericitic qz-ser-py stringer. 35-40% Py as round clots or aggregates of fg Py, interspersed with Qz. Clots are up to 5mm across. Ser stringer is about 2cm across and foliated. Rest of rock is unfoliated (not to the naked eye anyhow). Seems to be a transition zone from only Qz and Sx to More Sericitic zone.

Thin Section Observations:

May be volcaniclastic completely flooded by quartz-musc and abundant pyrite. Little to no other sulfides (trace sph). Pyrite is sub-euhedral, brecciated and friable. Locally 'clasts' of mostly mg quartz, within matrix of fg quartz-muscovite. May be relicts of volcaniclastic clasts?

Mineralogy:

-Quartz	60%
-Muscovite	10%
-Pyrite	30%
-Sphalerite	trace



TS ID: 8-15
DDH: **CMR08-18, 299.3m**
Sample: none

Lithology: Volcaniclastic (resedimented?) (Ser-Qz-Py)
Alteration: Strong Qz-Ser

Hand Sample Observations:

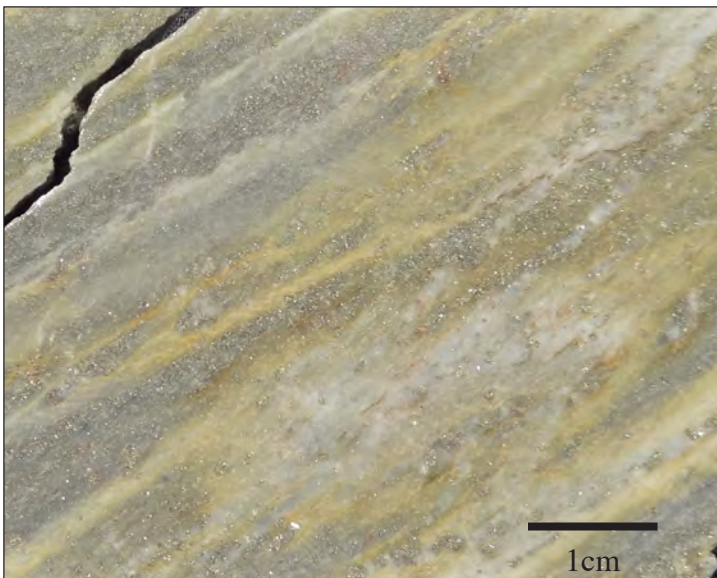
Later Ser alteration? As thin stringers that cut Qz-Py lenses. Py is granular, fg and more localised to qz-sections. Foliation is moderate. May be replaced volcaniclastic? Or resedimented unit, cut by qz-ser-py stringers. No idea of original lithology. See geochem.

Thin Section Observations:

Quartz-Sx 'clasts'? floating in and veins cutting through a fg qz-musc-sx matrix. Matrix is crenulated. Py is cg, sub-euhedral and brecciated/friable aggregates and lone crystals. Rare trace Sph and Cpy (a few grains). All 'clasts' and veins are elongate parallel the primary foliation. Foliation is crenulated.

Mineralogy:

-Quartz	60%
-Muscovite	30%
-Pyrite	10%
-Sphalerite	rare trace
-Chalcopyrite	rare trace



TS ID: 8-16
DDH: **CMR08-18, 306.0m**
Sample: none

Lithology: Volcaniclastic (resedimented?) (qz-musc-py)
Alteration: mod Qz-Ser, wk sel. carb-chl.

Hand Sample Observations:

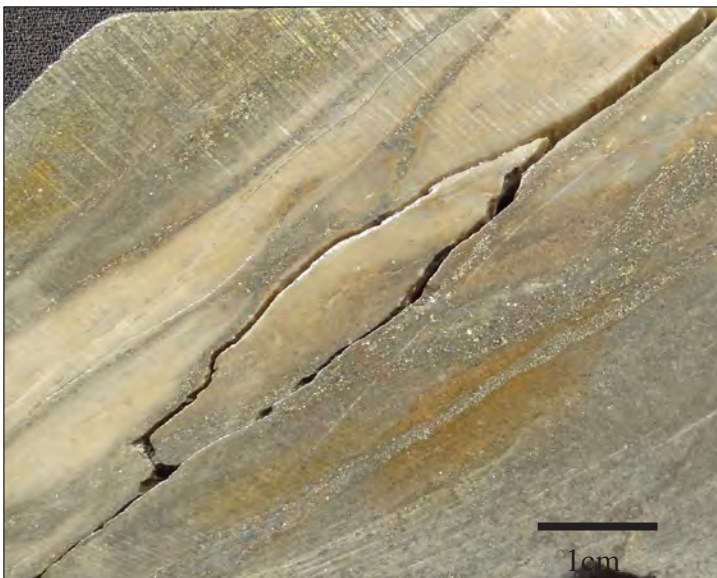
Selectively altered lenses in a vfg volcaniclastic? Possibly a resedimented tuff or ash? with selectively altered beds/lenses, or possibly the lenses are large altered deofred clasts? Can't tell in core. Diss Py in darker grey layers. Ser is strongest alteration, with subordinate qz and py.

Thin Section Observations:

Vfg quartz-muscovite matrix, locally matrix is greenish zeolites? Prehn/Pump? Chl?, with numerous augen-shaped quartz-pyrite filled amygdules. Quartz-Carb-Sulfide-Chl veinlets cut sample (1mm). Vfg Leucoxene throughout sample. Pyrite and Po occurring together in nearly equal parts. Appears to be Py replacing Po? Or in equilibrium? Py concave, and often euhedral, Po convex and anhedral. Minor Cpy and Sph locally with Po.

Mineralogy:

-Quartz	40%
-Muscovite	30%
-Chlorite?	15%
-Carbonate	1%
-Pyrite	6%
-Pyrrhotite	4%
-Chalcopyrite	<0.5%
-Sphalerite	trace
-Leucoxene	1%



TS ID: 19-01
DDH: **CMR08-19, 194.2m**
Sample: none

Lithology: Altered Mafic Volcanic (pseudobreccia?)
Alteration: Mod perv Ser, weak perv/sel quartz, weak sel chl

Hand Sample Observations:

Appears to be a medium green massive mafic volcanic, subtly brecciated by faint stringers of mostly Ser-Py.) Clasts are mostly cm-scale, separated by up to 5mm wide stringers of py-ser.

Thin Section Observations:

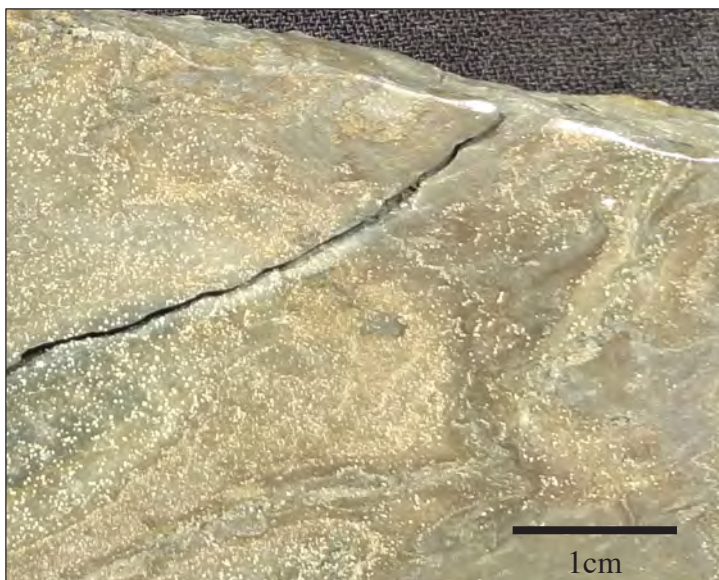
Vfg groundmass of quartz and muscovite, with slightly larger quartz grains, and rounded amygs(?) filled with quartz-sulfide(Py-Sph)-chl. Unit cut by sharp brittle, thin veins (0.3mm) of quartz with lesser sulfide and chl. This same sequence that fills straight brittle veins and amygs also locally alters domains(?) at contacts between 'clasts' and matrix with very coarse chl-quartz and sulfide (Py-Sph).

Clasts or pseudoclasts outlined by stronger alteration and mineralization. Clasts are irregularly shaped, and mostly vfg and sericite altered within. Abundant ilmenite/leucoxene throughout, although variably distributed and with variable crystal size from alteration.

Late carbonate veins cross-cut everything. Most sulfide is diffuse, 'sprays' of fg pyrite, along with leucoxene (altering to pyrite?). Sphalerite is pale honey brown. Trace Cpy locally in veins and with Lx. Py in veins is sub-euhedral.

Mineralogy:

-Quartz	15%
-Muscovite	50%
-Chlorite	3%
-Leucoxene	7%
-Pyrite	10%
-Sphalerite	<1%
-Chalcopyrite	trace



TS ID: 19-03
DDH: **CMR08-19, 203.9m**
Sample: none

Lithology: Barite Ore
Alteration: weak ser

Hand Sample Observations:

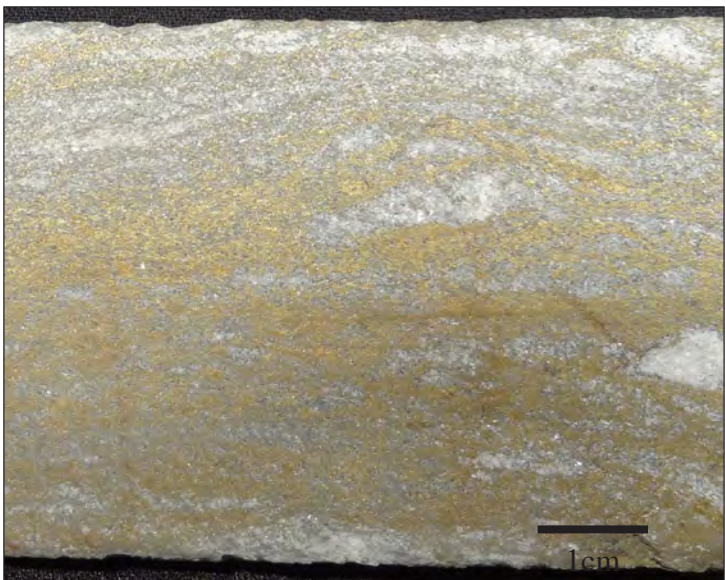
Massive foliated baryte and Cpy with subordinate Py. Cpy stringers cutting layered baryte? Cpy is msv. About 25% Cpy?

Thin Section Observations:

Mostly barite, Cpy and Sph as domains stretched out parallel a weak foliation. Barite is coarse grained, annealed, recrystallized with nice 120° triple junctions, with minor interstitial muscovite needles throughout, up to 0.2mm long. Cpy and Sph are massive and interstitial to barite. Cpy appears to replace Sph. Sph exhibits Cpy-disease. Sub-anhedral, fg pyrite aggregates occur throughout Sph/Cpy. Sph is yellow-brown. Local coarse-grained albite is weakly altered, twinned and contains numerous round sulfide inclusions (Py). Muscovite also within the sulfide as distinct needles - came with sulfide fluid?.

Mineralogy:

-Barite	50%
-Plagioclase	trace
-Muscovite	1%
-Sphalerite	20%
-Chalcopyrite	25%
-Pyrite	5%



TS ID: 19-04
DDH: **CMR08-19, 213.0m**
Sample: none

Lithology: Barite Ore
Alteration: weak quartz-musc

Hand Sample Observations:

Layered Baryte and Quartz(?) replaced(?) by Py and yellow-brown Sphalerite. Approx 25% Sph, 10%Py. Fg-mg, equigranular.

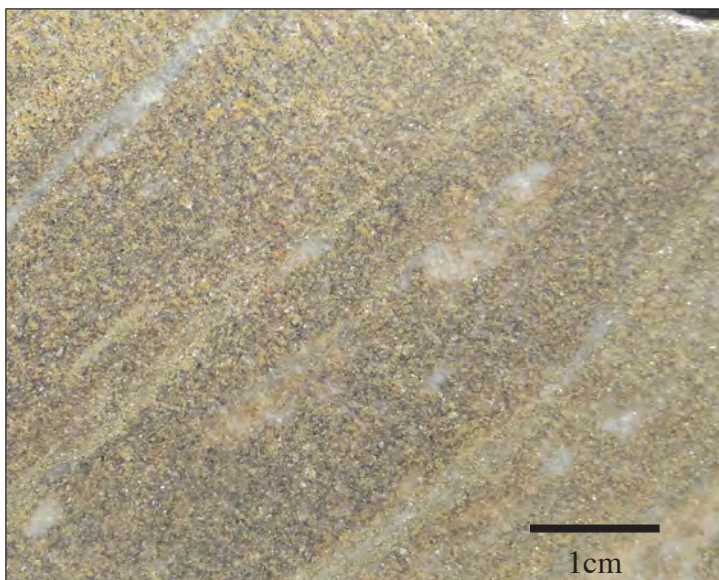
Thin Section Observations:

Sample is mostly barite and honey-brown sphalerite with a few 3mm conduits/layers of quartz-barite-pyrite. Only minor Pyrite disseminated throughout the rest of sample. Minor galena spatially associated with these layers, interstitial to quartz, barite or sphalerite. Pyrite is sub to euhedral and mg. Sph and barite are vcg. Barite and quartz have been recrystallized/annealed, forming polygonal equant grains. Trace vfg Cpy around edges of Sph xtals.

No Cpy-disease in sph, but trace inclusions of vfg pyrite in Sph. Sph within triple junctions of barite - suggesting barite annealed and recrystallized with sph. Minor muscovite interstitial to barite.

Mineralogy:

-Barite	50%
-Quartz	5%
-Muscovite	1%
-Sphalerite	30%
-Pyrite	5%
-Galena	<1%
-Chalcopyrite	rare trace



TS ID: 19-05
DDH: **CMR08-19, 214.4m**
Sample: none

Lithology: Chert (+Barite)
Alteration: Weak quartz-ser?

Hand Sample Observations:

Light grey chert cut by thin Py-Sph stringers up to 1mm). Concentration of stringers on left (photo), forming a band of Py-sph. Possible Galena? See thin section. Sph is honey-brown to grey.

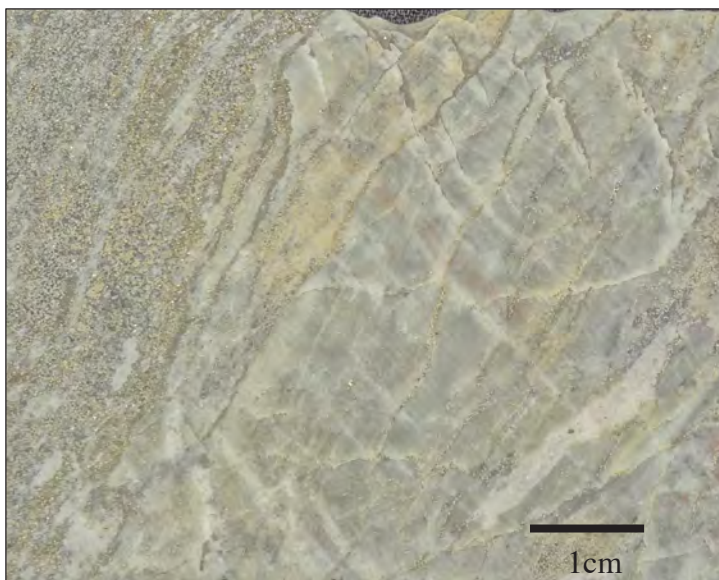
Thin Section Observations:

Interlayered barite and chert with sulfides. Fragments and xtals of barite in chert. Sample grades from vfg barite-quartz-sulfide layers, to vfg quartz with local fragments (can be very large 1cm) of barite and sulfide. Chert is vfg equant quartz with interstitial muscovite. Possible 'veins' of barite as well? oblique to layering. Seams of muscovite locally oblique to layering. Brittle veins of quartz-sulfide cut layering at high angles.

Sulfide at bottom with cg barite is also vfg, and dominantly Sph, with Cpy-disease and minor Cpy replacing Sph along edges and fractures. Minor (upto 1% within coarse qtz/barite layer) tetrahedrite and Galena with sphalerite. Galena mostly remobilized to triple junctions within gangue. Trace euhedral mg, tabular Arsenopyrite here as well. Grading up, to finer chert, sulfide becomes mostly sphalerite and pyrite, as other sulfides fade out. Sph up-section does not exhibit Cpy-disease.

Mineralogy:

-Barite	7%
-Quartz	70%
-Muscovite	3%
-Sphalerite	10%
-Pyrite	5%
-Tertrahedrite	0.5%
-Galena	0.5%
-Chalcopyrite	<0.5%
-Arsenopyrite	trace



TS ID: 19-06
DDH: **CMR08-19, 217.6m**
Sample: none

Lithology: Volcaniclastic? (resedimented?) (Tuff?)
Alteration: strong perv Ser, mod quartz

Hand Sample Observations:

Strongly, pervasively Sericite altered volcaniclastic? Lapilli and tuff sized fragments. May be resedimented volcaniclastic? Local stringers of white vfg quartz alteration, and fg-cg diss Py, concentrated parallel a strong foliation.

Thin Section Observations:

Quartz, sulfide and Plagioclase? clasts and veinlets (0.5cm) within a dominantly muscovite groundmass. May be resedimented clasts of qtz-sulf and plag that have been recrystallized? Trace strongly deteriorated orthopyroxenes locally in groundmass. Pyrites are all sub-anhedral aggregates or clasts, strongly brecciated/ friable, and single rounded grains within matrix. Muscovite-rich groundmass is strongly crenulated. Abundant ilmenite throughout, containing abundant rounded Pyrite inclusions (py replacing ilmenite?). Minor sphalerite with pyrite.

Ilmenite could be pyroxene, or vice versa? I can't tell.....

Looks to be a weakly annealed, deformed resedimented(?) volcaniclastic

Mineralogy:

-Quartz	25%
-Muscovite	40%
-Plagioclase?	
-Pyrite	30%
-Sphalerite	1%
-Ilmenite	3%
-Orthopyroxene	trace



TS ID: 19-07
DDH: **CMR08-19, 223.2m**
Sample: none

Lithology: Barite Sand
Alteration: Strong carb

Hand Sample Observations:

QSP altered(?) Baryte, containing Py clasts? Large clasts of Py, that appear rounded. Rock is crystal rich, with cg Calcite(?) and barite crystals throughout. Matrix is barite/calcite $\pm$ qz-ser?. Some large calcite clasts? See thin section to better explain textures. Minor Cpy clasts as well. Sx clasts range from 2mm-1cm.

Thin Section Observations:

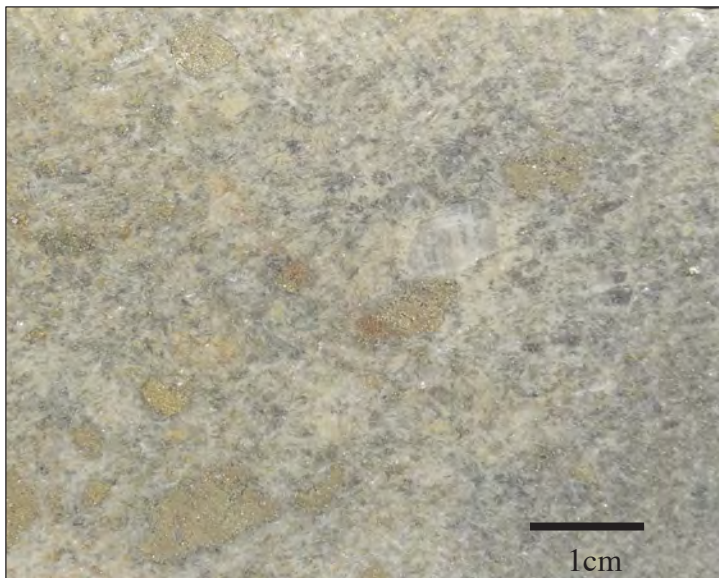
Abundant sub-euhedral barite crystals/phenocrysts within a vfg massive carbonate matrix. Rounded clasts of sulfide also in carb matrix. This resembles Barite sand from Kuroko.

Barite crystals range from $<0.01\text{mm}$ to 1cm across. Sulfide clasts are Sphalerite/Chalcopyrite/Pyrite $\pm$ galena/tetrahedrite, and contain coarse crystals of carbonate (+ bar?) gangue. Sulfide clasts range from interstitial blebs to 1cm, and have irregular shapes. They are either pyrite, cpy or sph dominated. Typically sub-anhedral, brecciated/friable pyrite grains within Sph, or Cpy, or both. Tetrahedrite and galena occur with others.

Barite blades are aligned preferentially, possibly as initial layering?

Mineralogy:

-Barite	50%
-Carbonate	40%
-Pyrite	5%
-Sphalerite	5%
-Chalcopyrite	2%
-Galena	$<0.5\%$
-Tetrahedrite	trace



TS ID: 19-08
DDH: **CMR08-19, 228.4m**
Sample: none

Lithology: Barite-Carbonate Ore
Alteration: Strong Carb

Hand Sample Observations:

Thin Section Observations:

Interlocking crystals of barite and carbonate, with domains of more carbonate locally. Abundant massive sulfide as pale honey-brown sphalerite, with cg-vcg sub-euhedral to massive (rextalized msv py?), brecciated/friable pyrites, locally abundant tetrahedrite. May be a layered unit, with varying sulfide and gangue contents (dominated by py vs sph, and layers with much less Sx). Layers are >2mm.

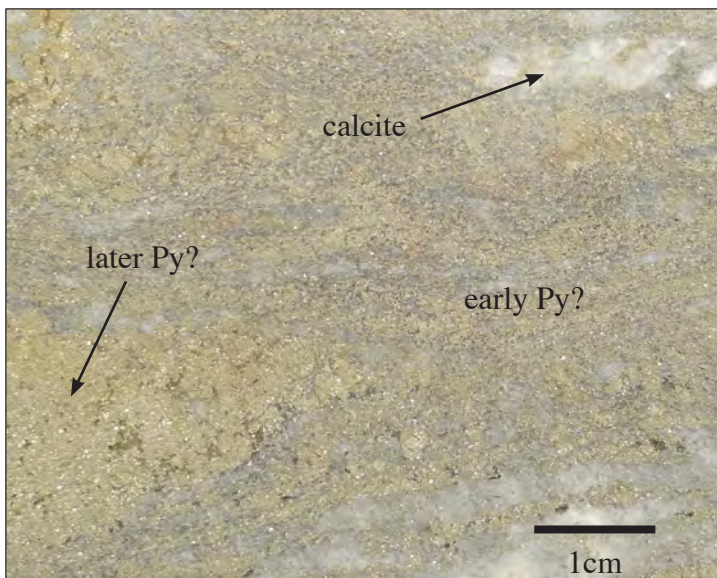
An array of fractures at high-angle to layering fractures sulfides, but not gangue. Minor muscovite locally throughout defining a foliation parallel to layering, interstitial to barite and carb.

Sulfides are very brittly fractured and blasted.

**Similar to 13-10, with more base metals.

Mineralogy:

-Barite	30%
-Carbonate	7%
-Muscovite	trace
-Pyrite	40%
-Sphalerite	20%
-Chalcopyrite	3%
-Tetrahedrite	2%
-Galena	



TS ID: 19-09
DDH: **CMR08-19, 231.0m**
Sample: none

Lithology: Layered barite + musc/albite/carb/sulfide
Alteration: Intense Qz-Ser-Py/(Gal?)-Carb $\pm$ Bar?

Hand Sample Observations:

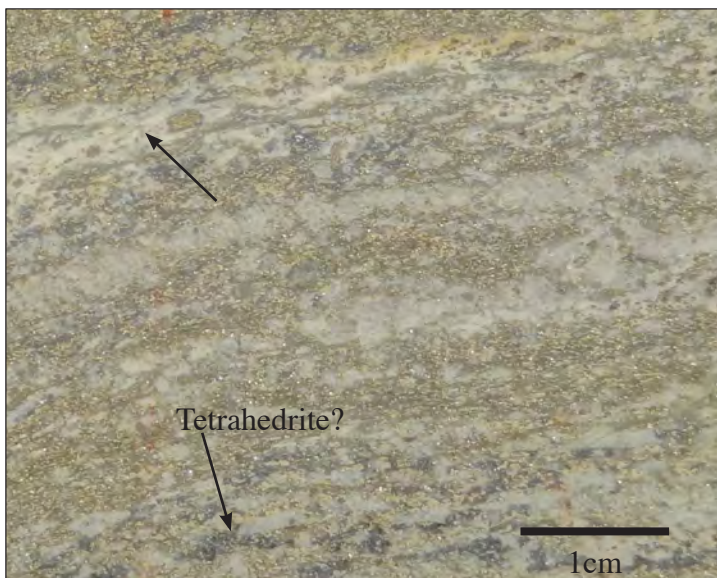
Completely replaced rock - now Qz, Ser and Py (30%) $\pm$ baryte?. Minor Galena(?) with Py (~1%?). Check thin section. Minor, local/selective carbonate(calcite) alteration

Thin Section Observations:

Layers of barite intercalated with complex, convoluted layers of albite/carb/sulfide, and thin layers of muscovite/sulfide that contain crystals of barite, and albite/carbonate? Likely a layered sediment, similar to 19-07. Another possibility is massive barite-sulfide blasted by Qz-Ser-Albite? Layers are up to 5mm across

Mineralogy:

-Barite	25%
-Albite	15%
-Muscovite	20%
-Quartz	3%
-Carbonate	3%
-Pyrite	20%
-Sphalerite	10%
-Tetrahedrite	5%
-Chalcopyrite	trace



TS ID: 19-10
DDH: **CMR08-19, 234.1m**
Sample: none

Lithology: Barite Ore (+carb)
Alteration: Weak carb, weak quartz, weak ser

Hand Sample Observations:

Massive baryte, replaced by 35% Py. Weak calcite alteration as clots and thin vnlets, and within matrix. Minor Sph? - check thin section.

Thin Section Observations:

Massive barite and sulfide, with local “clasts?” of quartz, and possibly clasts of muscovite/sulfide. Possible bedding contact in thin section (see pic), runs almost the length of the sample. Contact has a thin layer of muscovite on one side, that could mark a thin layer of ash? Sulfide is mainly brecciated pyrite with sphalerite. Sph fill fractures and surrounds py. Minor Cpy locally with Sph. Cpy replacing Sph. Py is heavily fractured and brecciated.

Minor carbonate crystals disseminated throughout barite. Strange twinning or exsolution texture in many barite(?) xtals throughout (pic). May be fractures like in sulfides? Trace albite xtals (mg) within sulfide ‘clasts’ or aggregates. Trace Galena associated with quartz ‘clasts’. Tetrahedrite, Aspy and Galena are spatially associated? Large chunk of Tetra and galena within quartz-clast. Tetra locally around Sph throughout.

Mineralogy:

-Barite	45%
-Quartz	3%
-Muscovite	1%
-Carbonate	trace
-Albite	trace
-Pyrite	25%
-Sphalerite	15%
-Chalcopyrite	trace
-Galena	trace
-Tetrahedrite	trace
-Arsenopyrite	trace



TS ID: 19-11
DDH: **CMR08-19, 267m**
Sample: none

Lithology: Volcaniclastic
Alteration: strong Qz/Ser/Carb

Hand Sample Observations:

Volcaniclastic, likely resedimented? rock, containing selectively qz-altered, ser-alt'd and carbonate altered clasts of up to 2-3cm in size, strongly elongate parallel a strong foliation. Matrix is Qz-Ser-Po. Also calcite within tension fracs at high angles to foliation within larger, qz-altered clasts. Several large clasts exhibit amygs(?). Trace Py observed locally. Locally clasts exhibit shearing - rotation. Are these variably altered clasts? Or a sheared, altered, heterolithic conglomerate? Tension gashes also show sigmoidal rotation.

Thin Section Observations:

Layered volcaniclastic. Variably altered to quartz, sericite, carbonate. Crenulated. Quartz-muscovite-sulfide clasts in a muscovite-sulfide matrix. Minor epidote, subhedral, disseminated throughout. Several clasts are quartz-carb-musc-sulfide. Clasts range from 0.4mm to >1cm.

Qtz-carb is fg to vcg, variably in different layers and clasts.

Leucoxene throughout matrix, fg. Po does NOT exhibit birds eye texture with pyrite.

Mineralogy:

-Muscovite	45%
-Quartz	30%
-Carbonate	10%
-Epidote	<1%
-Pyrrhotite	15%
-Chalcopyrite	trace
-Leucoxene	2%
-Sphalerite	trace



TS ID: 19-12
DDH: **CMR08-19, 275.5m**
Sample: none

Lithology: Volcaniclastic
Alteration: Strong Qz-Ser, weak Carb (sel.)

Hand Sample Observations:

Altered volcaniclastic (hyaloclastic clasts?). Clasts are large, locally curvilinear, qz-altered, and cut by Fe-Carb(?) filled tension gashes. Matrix is Qz-Ser-Py rich. Possibly minor Chl locally? Clasts up to 5cm long, and elongate // a moderate foliation. Locally qz-altered clasts have a thin pyrite margin.

Thin Section Observations:

Clasts altered with zonation, sulfide-muscovite rims, with vfg quartz-muscovite interior, and local domains of megacrysts and zones of carbonate, and coarse grained zones of polygonal quartz. Sulfides are disseminated variably, and fg-cg within clasts, fg within matrix, and concentrated as fg around rims of clasts. Sulfide is dominantly pyrite, as vfg to cg **framboids or rosettes**. Framboids have been somewhat recrystallized/annealed, but retain shape (pic). Very coarse carbonate filling fractures locally, tension gashes?.

Mineralogy:

-Quartz	50%
-Muscovite	35%
-Carbonate	10%
-Pyrite	5%
-Sphalerite	trace
-Chalcopyrite	trace
-Leucoxene	trace



TS ID: 19-13
DDH: **CMR08-19, 289.9m**
Sample: none

Lithology: Mafic Volcanic - Feldsphyric and amygdaloidal.
Alteration: Moderate perv Epidote, weak Ser, subtle Qtz

Hand Sample Observations:

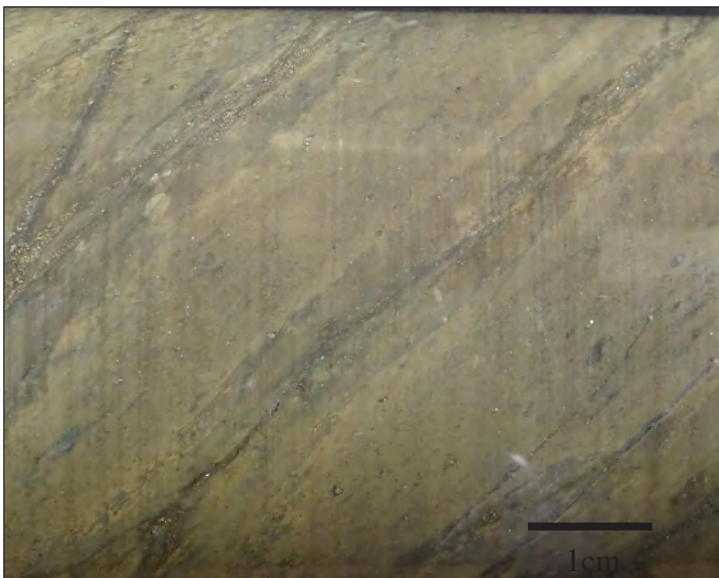
Moderately altered massive mafic volcanic, with small round amygdules (<1%). Weakly, faintly brecciated by Ser-py alteration stringers, and pervasively altered by Ser. Approx 3%Py.

Thin Section Observations:

Groundmass has been mostly replaced by vfg epidote, with lesser muscovite? So Mod pervasive epidote and weak pervasive sericite alteration. Amygs of Qz-Musc-Sulfide throughout, rounded and well distributed. Flattened, lenticular feldspar phenos also throughout, completely altered to mg epidote fans and locally to muscovite. Pervasive alteration is domainal, with 'stringers' of stronger muscovite alteration. Sulfide is both Po and Py, with what appears to be Po replacing Py locally. Trace Cpy with Po locally. Minor Leucoxene(?) or magnetite disseminated throughout.

Mineralogy:

-Epidote	75%
-Muscovite	15%
-Quartz	2%
-Pyrite	5%
-Pyrrhotite	3%
-Chalcopyrite	trace



TS ID: 19-14
DDH: **CMR08-19, 321.9m**
Sample: none

Lithology: Mafic Volcanic - Amygdaloidal, aphyric
Alteration: Mod pervasive Ep-Ser, weak sel. Qz

Hand Sample Observations:

Massive mafic volcanic, with very large round amygs (up to 1cm), qz-Po filled. Rock is weakly pervasively silicified. Thin Po (+Qz) stringers cut randomly, approx 3%.

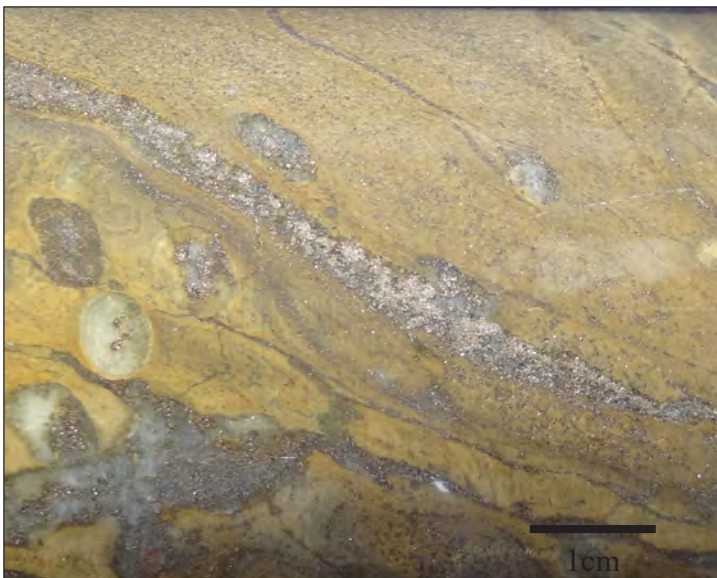
Thin Section Observations:

Groundmass is mod-strongly muscovite-epidote altered, with lesser quartz. Unit contains numerous very large amygdules, filled with quartz and sulfide. Quartz has been recrystallized. Several <1cm quartz-sulfide and quartz-epidote-muscovite-sulfide veins cut unit. Mg Sulfides are disseminated throughout the groundmass, and occur as phenocrysts together with cg epidote and muscovite crystals (fans). Amygs are very large, at up to 1cm diameter.

Sulfide is mainly Po, with colloform pyrite replacing around local edges and fractures exhibiting Bird's eye texture. Restricted to local cg veins? Trace Cpy and Sph locally with Po. Minor local leucoxene (or Magnetite?) locally.

Mineralogy:

-Quartz	15%
-Muscovite	35%
-Epidote	40%
-Pyrrhotite	10%
-Sphalerite	trace
-Chalcopyrite	trace
-Leucoxene	trace



TS ID: 19-15
DDH: **CMR08-19, 337.7m**
Sample: none

Lithology: Cpy-Po Stringer Ore
Alteration: Intense Qz, mod Ser-Epidote

Hand Sample Observations:

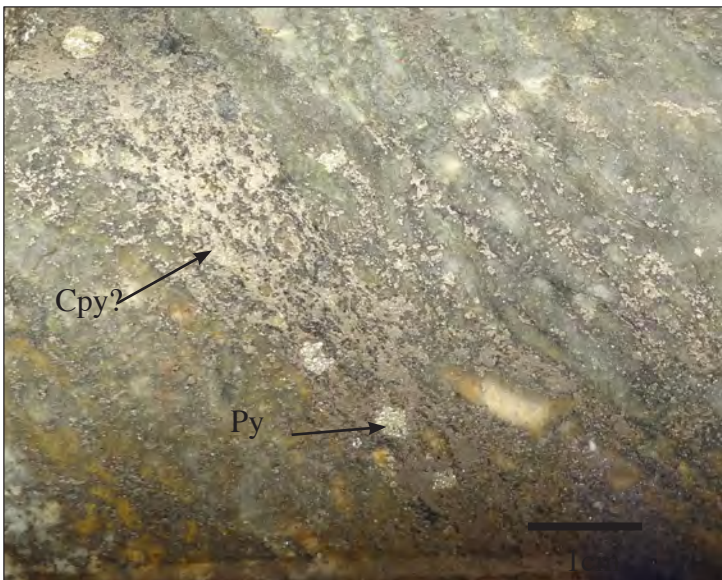
Strong stringer zone of cm-scale Po stringers with trace Cpy?, and later (?) cg Py xtals overprinting. Stringers cut intensely qz-altered rock. Trace local Carbonate clots, and minor sericite locally. Apprx 30%Po, 3%Py.

Thin Section Observations:

Possibly coherent, and possibly volcanoclastic, mafic volcanic rock, strongly quartz-ser-Po altered, moderately, locally epidote altered, and cut by Quartz-epidote(chl?)-muscovite-Po stringers. Minor Cpy locally within Po-stringers. Abundant large 'clasts' of quartz may be amygs? Or brecciated earlier veins? Several megacrysts of sub-euhedral pyrite disseminated throughout
Host rock that remains between large stringers resembles a volcanoclastic, but is heavily altered and brecciated.

Mineralogy:

-Quartz	30%
-Muscovite	15%
-Epidote(chl?)	25%
-Pyrrhotite	20%
-Chalcopyrite	trace
-Pyrite	1%



TS ID: 19-16
DDH: **CMR08-19, 355.2m**

Lithology: Mafic Volcanic
Alteration: Strong Ser-Epidote, weak quartz

Hand Sample Observations:

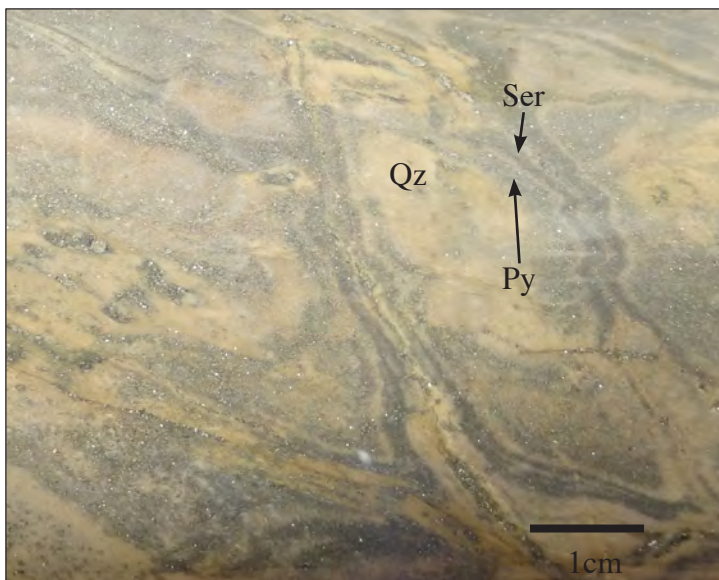
Pervasive and disseminated Qz-Ser-Py alteration (about equal), and thin qz-ser-py stringers cut what may have been a massive mafic volcanic? Py is vfg, diss and approx 3% overall. Py in stringers is mg (coarser). Stringers are 1-5mm, and brecciate rock, forming clasts that exhibit alteration zonation, with more qz-altered centers, and Py-Ser zoning outwards. Then more Qz-Py at center of stringer? Check this in Thin Section.

Thin Section Observations:

Quartz-Epidote and Muscovite altered groundmass (mostly Musc-Ep), cut by thin (<1mm) Quartz-epidote-muscovite sulfide veins. Areas between veins are zoned, forming pseudo-clasts(?), with varying quartz-epidote-muscovite alteration. Abundant euhedral pyrite disseminated throughout, and also zoned with alteration. Pyrite is fg to vg, and vcg in veins. Vfg leucoxene disseminated evenly throughout suggesting that this was a coherent massive unit before alteration.

Mineralogy:

-Epidote	40%
-Muscovite	35%
-Quartz	10%
-Pyrite	15%
-Leucoxene	1%



Sample 19-17
DDH: **CMR08-19, 358.4m**
Sample: none

Lithology: Mafic Volcanic - Amygdaloidal
Alteration: Strong Ep-Ser, mod-strong Quartz

Hand Sample Observations:

Moderately qz-po altered massive mafic, amygdaloidal volcanic. Large round amygs are qz-po filled. Qz-Po stringers (1-5mm) cut through rock (3%). Po also disseminated throughout rock, with total Po approximately 5-7% overall. Rock is hard, likely weakly silicified pervasively. Amygs range from 2mm-10mm.

Thin Section Observations:

Groundmass is muscovite and epidote, with lesser quartz. Veins and amygs are very coarse quartz, sulfide and epidote, with lesser coarse muscovite. Abundant disseminated sulfide within groundmass. Quartz alteration is domainal in groundmass, whereas musc and ep are pervasive. Sulfide is massive clots of Po, with trace Sph and Cpy. Po often replaced as bird's eye texture by colloform Pyrite. Minor coarse, but deteriorated ilmenite/magnetite/leucoxene?

Sample is coarser grained than 19-16 and 19-15, meaning more recrystallization?

Mineralogy:

-Muscovite	30%
-Epidote	25%
-Quartz	20%
-Pyrrhotite	20%
-Pyrite	5%
-Sphalerite	trace
-Chalcopyrite	trace
-Leucoxene	trace

