STRATIGRAPHY, MINERALOGY, GEOCHEMISTRY, AND GENESIS OF THE AU–RICH VOLCANOGENIC MASSIVE SULFIDE (VMS) SYSTEM FROM THE BAIE VERTE PENINSULA, NW NEWFOUNDLAND, CANADA: THE 1806 ZONE AS AN EXAMPLE FROM THE MING MINE, RAMBLER CAMP

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ABSTRACT

The 1806 zone is part of a Au-rich volcanogenic massive sulfide deposit at the Rambler Camp on the Baie Verte Peninsula, northwestern Newfoundland, and is characterized by high Au grades (3.97 g/t), relatively low Cu and Zn grades (0.60 wt% Cu, 1.17 wt% Zn), and moderate Ag grades (27.83 g/t) at ca. 0.37 Mt ore. Gold and Ag occur as electrum and different Ag varieties including Ag–Hg ± Au alloys, miargyrite, and pyrargyrite that occur often in close proximity to electrum. Additionally, Ag–, As–, Sb–, and Sn–bearing sulfosalts are frequently observed and usually close to electrum. These textural relations strongly favor a syngenetic/magmatic origin for the 1806 zone, despite having a metamorphic overprint.

Keywords   Au-rich VMS, syngenetic, magmatic volatiles, electrum, Ag–phases, sulfosalts, Rambler Camp, Newfoundland Appalachians

INTRODUCTION

The 1806 zone is one of four Cu–Au and minor Zn horizons at the formerly active Ming Mine, Rambler Camp, Newfoundland Appalachians. Measured and indicated resource for all four zones is 3.65 Mt ores at 2.26 wt% Cu, 1.13 g/t Au, 6.78 g/t Ag, and 0.32 wt% Zn, where the 1806 zone is most enriched in Au and Ag with 3.97 g/t and 27.83 g/t, respectively [1]. These data underline the status of the Rambler Camp as a world class Au–rich volcanogenic massive sulfide (VMS) deposit.

The Ming Mine, including the newly discovered Au-rich horizons, are classified as a bimodal–mafic VMS deposit affected by upper greenschist metamorphism and deformation [2]. Despite the long mining history, the genesis of this deposit and its Au–Ag–rich VMS deposits, in general, is still unresolved. Most controversial in literature are the timing of the precious metal enrichment and the influence of magmatic volatiles, and some workers favor an epigenetic origin with Au-Ag-enrichment due to later orogenic Au-Ag upgrading. This paper provides detailed stratigraphic, petrographic, mineralogical and geochemical data on the 1806 zone and preliminary data strongly favor a syngenetic/magmatic genesis of the 1806 zone and the Rambler Camp.

TECTONIC SETTING

The Rambler Camp is located ca. 7.5 km SE of the town Baie Verte on the Baie Verte Peninsula in northwestern Newfoundland. It comprises the formerly active Ming Main and Ming West Cu–Au mines and newly discovered Cu–Au and minor Zn mineralized horizons. These new horizons occur along strike and up and down plunge of Ming Main and are namely the 1806 zone, 1807 zone, Ming S up and down plunge of the Ming Mine (Fig. 1; [1]). Geologically, Rambler is located in the Pacquet Harbour Group (PHG) in the Notre Dame Subzone of the Dunnage Zone in the Newfoundland Appalachians [2–5]. The PHG is characterized by deformed and metamorphosed mafic to felsic volcanic and volcaniclastic rocks, and sedimentary rocks and is divided into the lower and upper portions [3, 5]. The lower PHG contains boninite, pillowed basalt, tuff, lapilli tuff and tuff breccia, and a sequence that is commonly referred to as Rambler rhyolite. The Rambler rhyolite sequence consists of boninitic, quartz–phyric rhyodacite and felsic tuff and tuff breccia and is host to the VMS deposits of the group [2–5]. Gabbroic dykes cut the lower PHG [3–5]. Uranium/Pb dating on zircons from the Rambler rhyolite revealed an early Ordovician age of 487 Ma (unpublished data, V. McNicoll, 2008 in [3, 5]). The upper PHG is mainly located NE of the Rambler deposit and consists of boninite, tholeiitic pillow basalt, felsic tuff, black chert and iron formation, and locally polymict conglomerate and breccia [3, 5]. The age for the upper PHG is assumed to be younger than the lower PHG, but still of Ordovician age [3, 5]. Several authors [3–5] suggest a stratigraphic correlation between the rocks of the PHG and Ordovician volcanic and sedimentary rocks in the N and E of the Baie Verte Peninsula. However, sparse outcrops and Silurian intrusions make correlations between the rocks of the PHG in the center of the Baie Verte Peninsula with rocks in the N and E difficult. The Silurian intrusions occurring in the W and S of the PHG includes the Burlington Granodiorite (ca. 434 – 430 Ma), and in the E of the PHG includes the Cape Brulé Porphyry (ca. 430 Ma) and the early Silurian Cape St. John Group [6].

The Baie Verte Peninsula is tectonically complex with four deformation events recognized [2–4], with the most intense even being D_2 [3]. This deformation event is also observed in the PHG and the Rambler rhyolite as an L > S fabric and N to NE dipping folds [2–4]. The same dipping direction is observed in the Rambler Brook Fault occurring S of the Rambler rhyolite and affecting the position of the stratigraphic units of the PHG including the sulfide mineralization horizons at the Rambler Camp that dip ca. 32 – 35° to the NE [1, 2]. Deformation and metamorphism on the Baie Verte Peninsula generally increases from S to N, and the metamorphic grade changes from upper greenschist to lower amphibolite facies [3, 7].

56° 08' 23" W   **56° 01' 18" W**

5531388 N   49° 55' 54" N

N

Rocky Pond

To Ming's Bight

Ming North Zone

1807 Zone

1806 Zone

Ming South Zone

1806 Zone

418

Ming West Mine

414

To La Scie

South Brook

Ming Main Mine

To Baie Verte

Little Rambler Pond

Rambler Mine

Rambler

England's Brook

Brook

Fault

Big Rambler Pond Mine

2 km

5524173 N   49° 51' 57" N

561741 E   **570213 E**

Silurian Intrusions

Cape Brulé Porphyry (430 Ma)
Porphyritic granodiorite, quartz-feldspar porphyry

Burlington Granodiorite (434 - 430 Ma)
Granodiorite

Cape St. John Group (early Silurian)
Rhyolitic and trachytic flows and tuffs, intrusives, locally mafic and intermediate tuffs and flows

414   **Highway and highway number**

○ Ming Main Mine   **Mine location**

1806 zone   **Mineralization horizon**

Underground shaft

Fault

Ordovician rocks - Pacquet Harbour Group (PHG)
Upper PHG (Mid- to early Ordovician)

Balsam Bud Cove Formation
Mafic epiclastic rocks, black shale

Balsam Bud Cove Formation
Rhyolite (467 Ma), and felsic tuff (470 Ma)

Venam's Bight Formation
Pillow basalt

Bobby Cove Formation
Mafic tuff, epiclastic rocks, turbidites

Scrape Point Formation
Pillow basalt, gabbro (483 Ma)

Lower PHG (Early Ordovician)

Mt. Misery Formation
Rhyodacite, rhyolite massive flows, tuff breccia ('Rambler rhyolite'; 487 Ma)

Mt. Misery Formation
Intermediate Ti-boninite, island arc tholeiitic pillow basalt, pillow breccia

Betts Head Formation
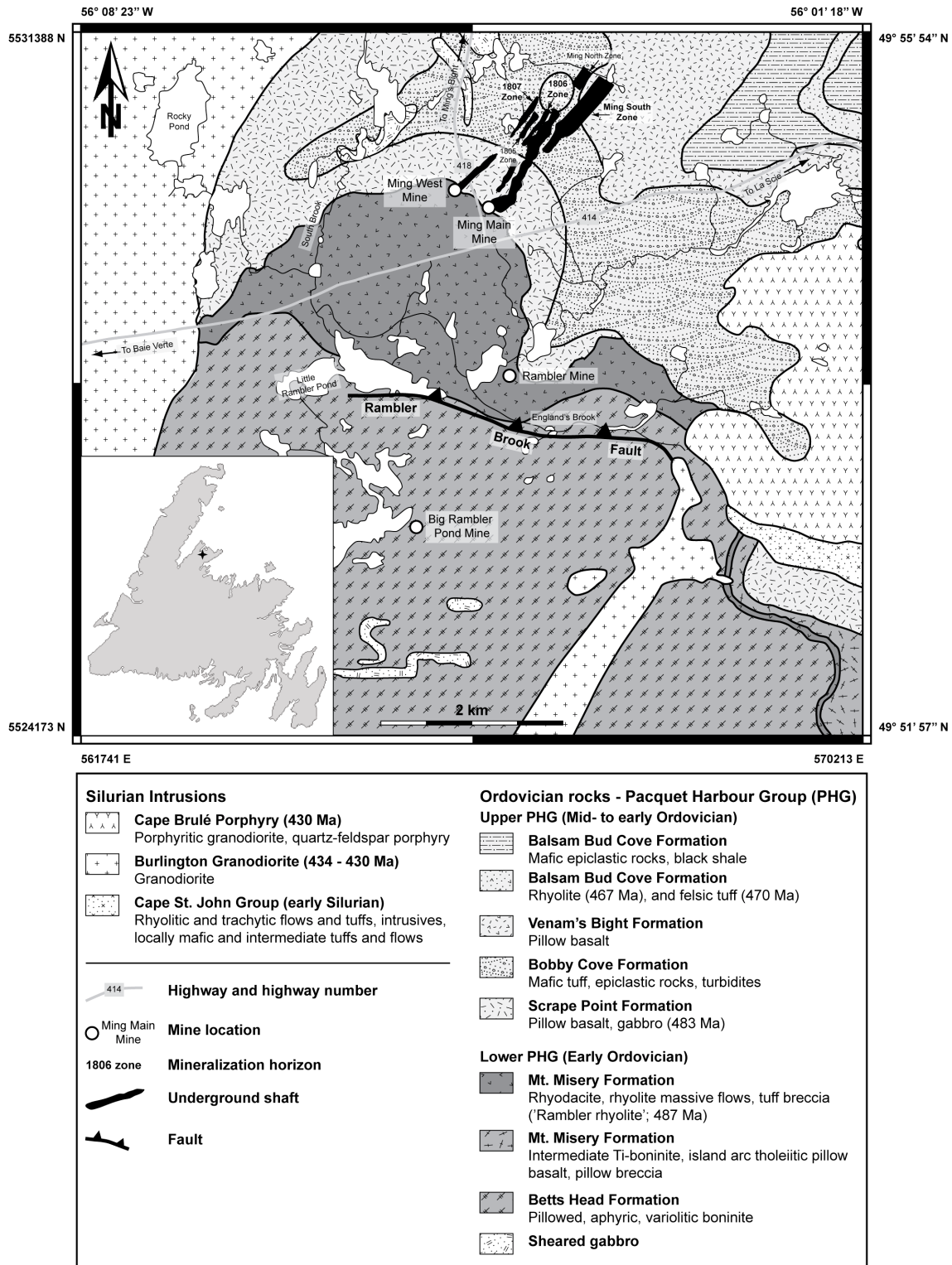Pillowed, aphyric, variolitic boninite

Sheared gabbro

Figure 1 – Geologic map of the studied area. Inlay in the lower right corner shows Newfoundland and the location of the map (star). The 1806 zone of the Ming Mine is encircled. Coordinates are in WGS 84 (top and right) and UTM Zone 21N (83 NAD) (bottom and left)
Modified after [1–4], age data after [3, 6]

METHODS

From each drill core samples were taken usually at each meter for assay data with focus on the mineralized rhyolite. Analyses were undertaken initially at Eastern Analytical Ltd., Springdale, NL, with check and final assays undertaken at Activation Laboratories (ActLabs), Ancaster, ON. Assay data were obtained for Cu, Au, Zn, Pb, and in some cases for Ag. Gold and Ag were obtained using fire assay fusion, followed by acid digestion and finally atomic absorption spectrometry (AAS) for samples with Au contents < 3 g/t and Ag < 0.1 g/t., whereas higher grade samples had a gravimetric finish. Copper, Zn, and Pb were measured by acid digestion pre-preparation and an inductively couple plasma optical emission spectrometry (ICP–OES) finish. Data quality was checked by external reference materials and is outlined in detail in Pilgrim [1].

Polished thick sections (~ 200 µm) were obtained on the ore and analyzed via scanned electron microscopy (SEM) at the INCO Innovation Center, St. John's, NL, for back scattered electron (BSE) images. Moreover, SEM was combined with semi–quantitative, energy discriminated X–ray (EDX) to detect concentration changes within ore phases. Therefore, an EDX scan was applied to a linear profile (i.e., line scan) within the thick section for 5 min at 25 kV detecting the intensity of the emission lines in percent for each analyzed element. Detection limits for the EDX system are nearly 1,000 g/t and correlate with 4 – 5 % intensity for the line scans.

STRATIGRAPHY, PETROGRAPHY, AND MINERALOGY

Stratigraphy

The sulfide mineralization in the Rambler Camp, including the four newly discovered Cu–Au–minor Zn mineralization horizons, is associated with felsic volcanic and volcaniclastic rocks of rhyodacitic to rhyolitic composition (Fig. 2; [1, 2]). This felsic unit is commonly referred as Rambler rhyolite of the Mt. Misery Formation of the lower PHG. The mineralized rhyolite is often capped by a dm-thick silicified horizon, which also contains sulfide mineralization. This horizon is assumed to belong to the Mt. Misery Formation but has been affected by very strong silicification. The hanging wall is characterized by felsic and mafic tuffs and sedimentary rocks, which form together very often a turbidite sequence. These volcanic and sedimentary rocks including the turbidite are assumed to belong to the Bobby Cove Formation of the upper PHG. Pillowed basalts of the Scrape Point Formation are not observed in the drill core from the 1806 zone and are probably diked out by fine and coarse–grained gabbroic dykes that cross-cut the stratigraphy, including the mineralized rhyolite. Moreover, thin light grey dykes of probably felsic composition occur within the rhyolite, but are not nearly as frequent as the much thicker mafic dykes.

Petrography

'Rambler Rhyolite' with Sulfide Stringer and Semi–Massive to Massive Sulfide Horizon

Sulfide mineralization occurs as fine, mm– to several cm–thick stringers in rhyolitic volcanic and volcaniclastic rocks that range in color from bluish-grey, grey to greenish-grey. Massive flows are the dominant hosts to mineralization and are partly foliated and quartz–eye bearing and the rhyolites are variably deformed. The rhyolite flows often grade into jigsaw-fit breccias that further grade into lapilli tuff, but these transitions are very difficult to recognize due to hydrothermal alteration; tuff breccia is present in rare cases. Where sulfide stringers are developed within clast-rich sections they occur around these clasts in an almost jigsaw-fit texture.

A 20 to 30 cm think, extremely silicified horizon very often caps the Rambler rhyolite. This unit is dominated by dirty, white to light grey quartz that contains sulfide that decreases in abundance with increasing distance from the contact with rhyolite. Often remnants of clasts can be found in this horizon, and it is assumed that this is strongly quartz altered rhyolite flow or lapilli tuff.

Sulfide phases occur most abundantly as stringers of various thickness (mm to cm) in massive rhyolitic flows or fine–grained rhyolitic tuffs to lapilli tuffs. Disseminated sulfides are rare in the sulfides but often developed within the mafic dykes. Semi–massive to massive sulfide horizons varying in thickness between a few cm and several dm are developed in the upper parts of the 'Rambler rhyolite' and often capped by a mineralized, silicified horizon. In some cases, mafic dykes cut through the semi–massive and massive sulfide horizons. Macroscopically, pyrite, and lesser chalcopyrite and sphalerite are developed in the stringer and disseminated sulfides. The semi–massive and massive sulfide horizon is dominated by pyrite, chalcopyrite, sphalerite, pyrrhotite, galena, arsenopyrite, tetrahedrite–tennantite and in rare cases by electrum. Stringer and semi–massive to massive sulfide horizons are usually fine–grained, but pyrite porphyroblasts in pyrrhotite (i.e., buckshot texture) is present close to mafic dyke contacts within the semi–massive and massive sulfide horizons. Magnetite is the only observed oxide phase and occurs more often within the semi–massive to massive sulfide horizon in the down plunge of the 1806 zone.

Turbidite Sequence

The hanging wall turbiditic sequence in the Ming Mine is characterized by mafic and felsic tuffs to lapilli tuffs that alternate with fine, partly clast–bearing sedimentary rocks. The grain size changes gradually from coarser to fine–grained tuffs and sediments with increasing distance from the mineralized 'Rambler rhyolite'. The coarser–grained parts are often clast–bearing with rock and mineral clasts that are often weakly elongated and mm-scale. Changes between tuffs and sedimentary rocks are transitional and not sharp. Bedding in the usually dark–colored turbiditic sequences is either weakly preserved or totally overprinted by fine foliation. Most commonly, the turbidites occur directly above the mineralized rhyolitic flows and tuffs in the hanging wall as several m–thick horizons. In more rare cases, fine–grained mafic tuff to lapilli tuff occurs in–between the rhyolite as a less than 5 m thick horizon. The stratigraphic association of the tuff is not clear yet, but its correlation to the Bobby Cove Formation is strongly assumed and folding likely causes the intercalation within the Rambler rhyolite.

Mafic Dykes

Fine– and coarse–grained mafic dykes of diabasic to gabbroic composition are very abundant and cut both the mineralized rhyolite and the hanging wall sequence. These mafic dykes range widely in thickness from only a couple of decimeters to several decameters; thicknesses of < 10 m are most abundant. The dykes have sharp, variably chilled margins and show variations in grain size. Chilled margins with significant mafic mineral phases (e.g., dark mica, amphibole) and pyrite porphyroblasts are common. The mafic dykes are usually dark green in color and contain biotite, amphibole, minor feldspar, chlorite, and rare carbonate. The coarse–grained variety show usually a porphyritic texture of mm–sized, subhedral biotite, amphibole and feldspar in a greenish, very–fine grained matrix. Fine, secondary carbonate and quartz veins often cut the dykes.

Felsic Dykes

Felsic dykes are rather thin (< 20 cm) in comparison to their mafic counterpart, and light grey in color. They are very fine-grained and have sharp contacts to the rhyolites. They are very rare within the deposit and have limited extent.
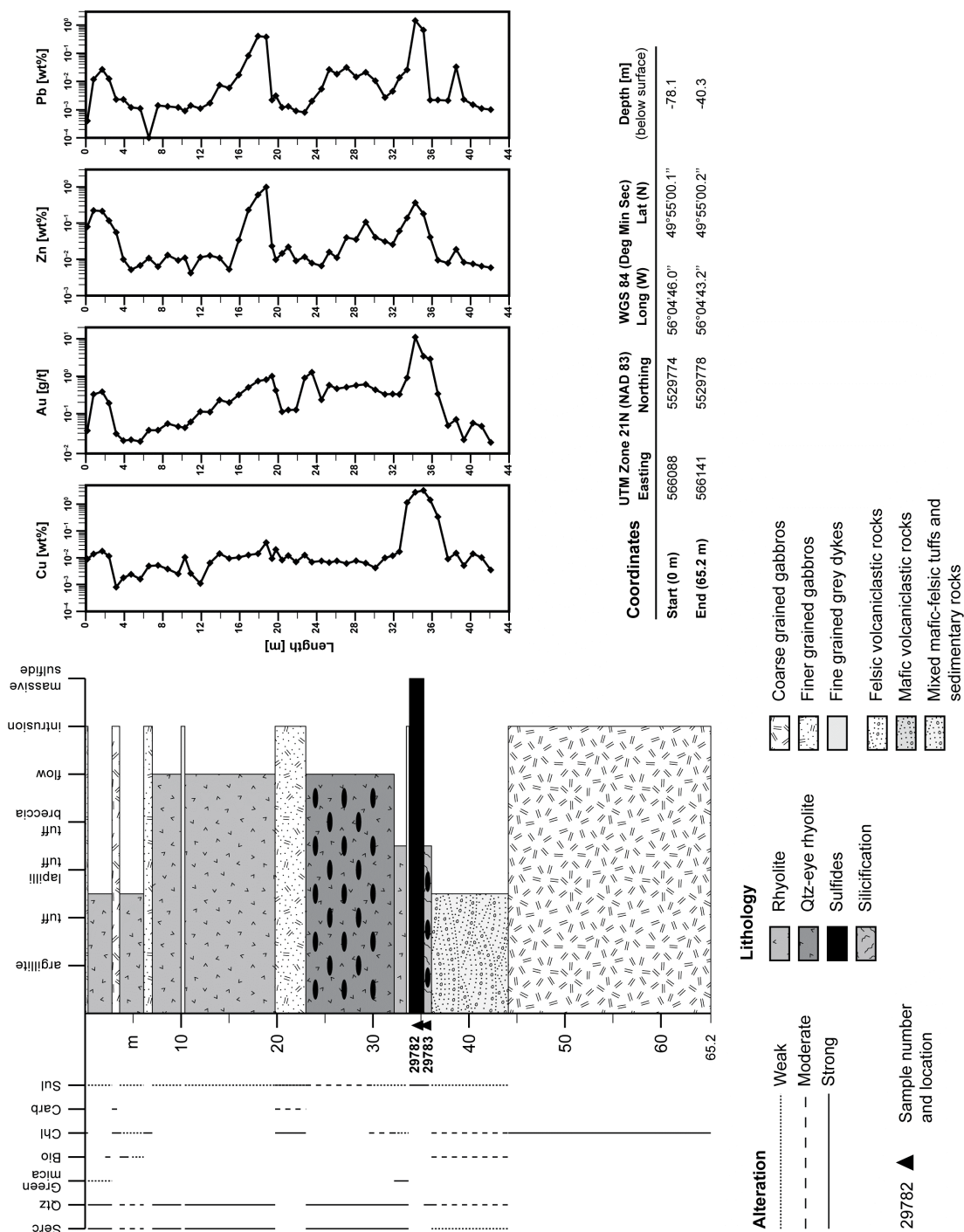
Figure 2 – Stratigraphic section of drill core RMUG08–140, 1806 zone. Rotated core is overturned, and start and end coordinates are given both in UTM zone 21N (NAD 83) and WGS 84. Assay data for Cu, Au, Zn, and Pb are from Rambler Metals & Mining Canada Ltd.

Abbreviations alteration minerals: Serc – sericite, Qtz – quartz, Bio – biotite, Chl – chlorite, Carb – carbonate, Sul – sulfide

Mineralogy

Sulfide and Oxide Mineralogy

Table 1 contains the sulfide mineralogy from the 1806 zone from two key samples from the stratigraphic section in Figure 2. The following description of the observed sulfide and oxide phases is based on their abundance both in the stringer zone and semi–massive to massive horizon within the 1806 zone.

Table 1 – Sulfide and oxide mineralogy representative of the 1806 zone on the example of two samples from drill core RMUG08–140, Section 22 (Fig. 2)

Mineral abundances: +++ major phase (> 10 %), ++ minor phase (10 – 5 %), + accessory phase (< 5 %), – not observed

Sample No.	29782	29783	Sample No.	29782	29783
Depth [m]	34.49 – 34.64	35.43 – 35.48	Depth [m]	34.49 – 34.64	35.43 – 35.48
Description	Massive sulfide	Ccp and Py in massive quartz (high–grade ore)	Description	Massive sulfide	Ccp and Py in massive quartz (high–grade ore)
Py*	+++	+++	Pyr	–	–
Ccp	+++	+++	Ag–Ccp	–	+
Sp	++	++	Ag–Tet–Ten	–	–
Po	++	+++	Stn	–	–
Asp	+	+	Boul	–	–
Tet–Ten	–	–	Loel	–	–
Gn	+	–	Ni–Sb–S	–	+
El	–	+	Mag	–	–
Ag–Hg±Au	–	–	Cass	–	–
Mia	–	+	Chr	–	–

* Mineral abbreviations: Py – pyrite, Ccp – chalcopyrite, Sp – sphalerite, Po – pyrrhotite, Asp – arsenopyrite, Tet–Ten – tetrahedrite–tennantite, Gn – galena, El – electrum, Ag–Hg±Au – Ag–Hg ± Au alloy, Mia – miargyrite, Pyr – pyrargyrite, Ag–Ccp – argento–chalcopyrite, Ag–Tet–Ten – argento–tetrahedrite–tennantite, Stn – stannite, Boul – boulangerite, Loel – loellingite, Ni–Sb–S – unknown Ni–Sb sulfide, Mag – magnetite, Cass – cassiterite, Chr – chromite

Pyrite [FeS_2] is the most abundant sulfide phase in the 1806 zone occurring as a major phase (> 10 %) in both stringer and the massive sulfide horizon. Pyrite is commonly recrystallized often with well–developed triple junctions (± 60°) and bulged grain boundaries. Euhedral to subhedral grains of cubic, triangular or polygonal shape pyrites are the most common form, but weakly anhedral grains or pyrite elongated parallel to foliation are also present. Grain size is highly variable with micron-scale grains in the gangue and coarser crystals, up to several mm, in the massive sulfide. Pyrite typically occurs in groups, often forming polycrystalline aggregates that are tightly packed with inter-grain voids filled with chalcopyrite, sphalerite, galena, pyrrhotite, and/or tetrahedrite–tennantite. Fine needle–like intergrowth between pyrite and arsenopyrite are rare but observed occur usually adjacent to gangue minerals. In other cases, coarse–grained crystals or even porphyroblasts, are found within sheets of chalcopyrite and/or pyrrhotite. Larger pyrite grains often contain inclusions of chalcopyrite, galena and sphalerite. Some larger grains show brittle deformation with fine cracks and veinlets partly filled with galena, Ag–Hg–Au alloys, and pyrrhotite. Buckshot textures of pyrite in a pyrrhotite matrix occur only at close contact to mafic dykes.

Chalcopyrite [$CuFeS_2$] is the second abundant sulfide phase and occurs as major, minor, and, in more rare cases, as an accessory (< 5 %) phase. While less abundant than pyrite, it is an important phase in both the stringer and semi-massive to massive sulfide, and the dominant phase within the silicified cap above the massive sulfide. Anhedral chalcopyrite occurs either as small to moderate grains or as a continuous mass hosting other sulfide phases. Chalcopyrite has close associations with pyrite, arsenopyrite, tetrahedrite–tennantite, sphalerite, galena, pyrrhotite and electrum (Figs. 3a and b). Fine, µm–sized grains of chalcopyrite are developed (1) in–between annealed pyrite aggregates, (2) as inclusions in pyrite and very rarely as inclusions in pyrrhotite and magnetite, (3) as disseminated crystals in gangue, and (4) as fine, wormy–like intergrowth with arsenopyrite + tetrahedrite–tennantite ± sphalerite ± galena ± electrum in tetrahedrite–tennantite (Fig. 3c).

Sphalerite [ZnS] is less abundant than pyrite and chalcopyrite, and occurs as a major, minor or accessory phase, but is most commonly a minor phase in the semi–massive to massive sulfide horizon. In the stringers it occurs distally from the semi–massive and massive horizon. Within semi-massive to massive sulfide horizon, sphalerite occurs as anhedral grains that have bulged or sutured grain boundaries and varies from fine grains to sheets that host pyrite, galena, and to a lesser extent chalcopyrite and tetrahedrite–tennantite. Sphalerite occurs often interstitially in recrystallized pyrite, marginally in pyrrhotite, and as inclusion in pyrite. Very fine intergrowth with arsenopyrite + chalcopyrite + tetrahedrite–tennantite ± galena ± electrum are rarely observed (Fig. 3c). Sphalerite has weak chalcopyrite disease with small rounded inclusions of chalcopyrite present; this is common in the lower parts of the semi–massive and massive sulfide horizon.

Pyrrhotite [$Fe_{(1-x)}S$] occurs close to dyke contacts and is of contact metamorphic origin. The closer to the dyke contacts, the more abundant pyrrhotite is and usually coarse pyrite porphyroblasts occur within pyrrhotite and pyrrhotite veins commonly cross–cut the pyrite porphyroblasts. With more distance to dyke contacts pyrrhotite becomes less abundant and is only a minor or accessory phase. Sub– to anhedral grains of small to moderate size are common and occur usually with marginal sphalerite. Subhedral grains are usually prismatic. Pyrrhotite is associated with pyrite, sphalerite, chalcopyrite, arsenopyrite (Fig. 3b) and electrum. In the down plunge of the 1806 zone magnetite and cassiterite occur close to pyrrhotite or on pyrrhotite margins.

Arsenopyrite [$FeAsS$] occurs as a minor phase in semi–massive to massive sulfides and is euhedral to subhedral varying in size from microns to mm. Fine–grained arsenopyrite often occurs as groups of prismatic to triangular grains that are within gangue but spatially associated with pyrite or chalcopyrite. Fine, euhedral arsenopyrite cubes and prisms are found associated with electrum, pyrrhotite and sphalerite, but this is rather rare. Arsenopyrite has myrmekitic textures with small (< 20 µm), anhedral, wormy–like arsenopyrite grains that are intergrown with chalcopyrite + tetrahedrite–tennantite ± sphalerite ± galena ± electrum (Fig. 3c). On the margin or in the centre of this myrmekitic–like texture there is often a single, euhedral arsenopyrite grain surrounded by chalcopyrite (Fig. 3c) and more rarely by sphalerite. In some cases, acicular arsenopyrite and pyrite are intergrown and occur on the margins of pyrrhotite or sphalerite. Moderately sized arsenopyrite commonly occurs as single grains with recrystallized pyrite and often contains pyrite inclusions, whereas coarser grained, euhedral porphyroblasts (up to 3 mm) are often surrounded by pyrite, chalcopyrite, pyrrhotite (Fig. 3b), sphalerite and/or galena. Arsenopyrite commonly contains rounded inclusions of pyrite (Fig. 3b) or elongated inclusion of electrum that are concentrated on the rim of the arsenopyrite grains.

Tetrahedrite–tennantite [$(Cu, Fe, Ag, Zn)_{12}Sb_4S_{13} – (Cu, Ag, Fe, Zn)_{12}As_4S_{13}$] usually occurs as a minor to accessory phase in the semi–massive to massive sulfides. Tetrahedrite-tennantite occurs as subhedral to anhedral grains that are polygonal, sub–rounded or amoeboid. It occurs most commonly with chalcopyrite, sphalerite and arsenopyrite, but is also present close to galena, pyrite and rarely with electrum. Tetrahedrite–tennantite is also associated with myrmekitic textures as described above (Fig. 3c).
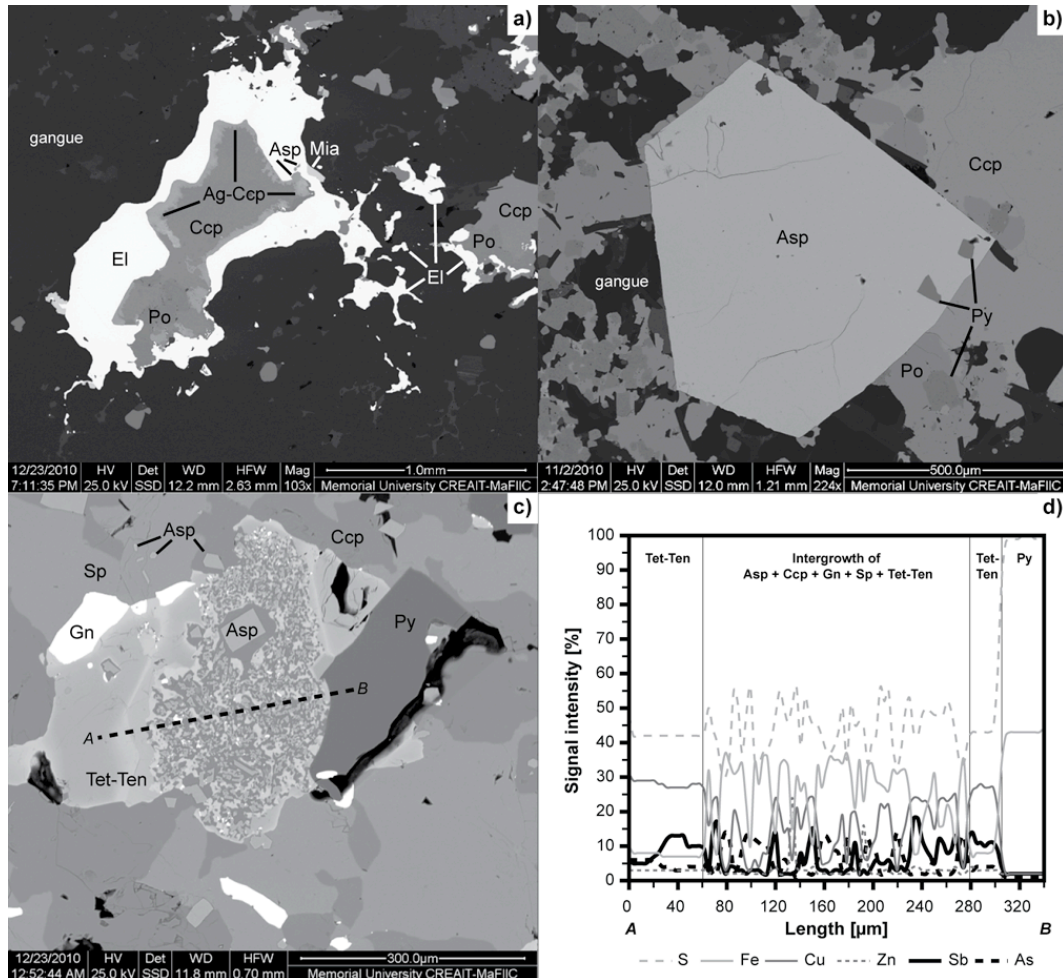
Figure 3 – BSE images and Line scan from samples of the 1806 zone
a) Electrum in gangue (i.e. quartz) associated with other sulfides (sample 29783, RMUG08–140)
b) Recrystallized arsenopyrite blast with marginal pyrite inclusion in chalcopyrite, pyrrhotite, pyrite
(sample 29783 RMUG08–140)
c) Myrmekitic–like intergrowth between arsenopyrite + chalcopyrite + sphalerite + tetrahedrite–tennantite
+ galena in tetrahedrite–tennantite (sample 29781, RMUG08–138)
d) Line scan done with EDX–SEM from A to B of c) showing the elemental zoning especially in
tetrahedrite–tennantite (e.g., inverse behavior of As and Sb)
Mineral abbreviations are the same as in Table 2

Galena [PbS] is a very common accessory phase and occurs as micron-scale, anhedral, roundish grains that occur as interstitial phases between recrystallized pyrite, along pyrite margins, as inclusions in pyrite and sphalerite, and to lesser extent with chalcopyrite, tetrahedrite–tennantite and arsenopyrite (Fig. 3c). Galena is more frequently present in the upper parts of the semi–massive to massive sulfide horizons and almost totally absent in the down plunge extension of the 1806 zone.

Electrum [(Au, Ag)] is an accessory within the semi–massive to massive sulfides and also occurs in the strongly silicified cap to the 'Rambler rhyolite'. The anhedral, partly rounded to ameboid grains range in size of 1 mm to only a couple of μm and occur most commonly with other sulfides, especially chalcopyrite > pyrite > sphalerite >> pyrrhotite > arsenopyrite ≈ tetrahedrite–tennantite > Ag–phases. Electrum occurs in quartz with and without other sulfide phases (Fig. 3a), when it occurs in the silicified cap horizon. It also occurs along pyrite and arsenopyrite grain boundaries, as inclusions in pyrite,

arsenopyrite and pyrrhotite, within the myrmekitic–like pockets in tetrahedrite–tennantite, and with Ag–Hg alloys as fine veinlets in pyrite.

Silver is developed in various forms within the 1806 zone. Most commonly it occurs as Ag–Hg ± Au alloys, which occur either as veinlets in pyrite, as inclusions in pyrite or as up to 20 μm large, rounded grains adjacent to pyrite and chalcopyrite. Miargyrite [$AgSbS_2$] and pyrargyrite [Ag_3SbS_3|] are very rare and occur as μm–scale, anhedral, subrounded crystals. Miargyrite occurs in close proximity to electrum (Fig. 3a), whereas pyrargyrite occurs with electrum, sphalerite, arsenopyrite and/or or pyrite. Silver–rich varieties of chalcopyrite (i.e., argento–chalcopyrite; Fig. 3a) and tetrahedrite–tennantite (i.e., argento–tetrahedrite–tennantite) are also present and found close proximity to Ag–Hg ± Au alloys and/or electrum.

Stannite [$Cu_2(Fe, Zn)SnS_4$] is present in only in a few samples, mostly in the up plunge portion of the 1806 zone. The μm–scale (< 30 μm) crystals are usually anhedral, weakly elongated and occur most commonly adjacent to sphalerite, chalcopyrite and pyrite and in close proximity to galena, pyrargyrite, and electrum. Wormy–like intergrowth between stannite and sphalerite, and stannite enclosing cassiterite occur as well, but are rare.

Boulangerite [$Pb_5Sb_4S_{11}$] is rare and is usually intergrown with galena in the up plunge portion of the 1806 zone or with tetrahedrite–tennantite in the down plunge section of the 1806 zone. The grains are anhedral and up to 50 μm large.

Loellingite [$FeAs_2$] is present in only one sample of the 1806 zone and occurs as ca. 30 μm large, subhedral grain intergrown with triangular arsenopyrite in gangue.

An unknown Ni–Sb sulfide phase is observed in only two samples from the up plunge of the 1806 zone. This phase occurs as ca. 10μm large, round grain on the margin of chalcopyrite.

Magnetite [Fe_3O_4] is the most common oxide phase in the 1806 zone and occurs usually as accessory phase but can be a minor component in the down plunge of the 1806 zone. Crystals range in size from a few μm up to 2 mm and are mostly euhedral cubes. However, fragmental, rounded grains associated with pyrrhotite are present. These fragmental grains have often rounded inclusions of pyrite and chalcopyrite and are intergrown with hematite. Euhedral magnetite occurs either as groups of small to moderate–sized cubes in gangue near pyrrhotite, chalcopyrite, and cassiterite, or as coarse porphyroblasts with inclusions of various sulfide (e.g., chalcopyrite, pyrrhotite) and oxide phases (e.g., chromite). However, these magnetite porphyroblasts are rather rare.

Cassiterite [SnO_2] is only a rare accessory phase in the 1806 zone. In the down plunge of the 1806 zone it occurs as small, rounded grains often in close proximity to magnetite, pyrrhotite, chalcopyrite, and sphalerite, and if developed stannite. In contrast, in the up plunge of the zone cassiterite is present only in two samples and always surrounded by stannite.

Chromite [$FeCr_2O_4$] is observed only in the down plunge of the 1806 zone as cubic inclusion in magnetite.

Alteration Mineralogy

The 'Rambler rhyolite' is characterized by an intense sericite + quartz ± green mica ± chlorite ± biotite alteration (Figs. 2 and 3). Moreover, pyrite is the dominant sulfide alteration phase in the stringer zone accompanied sometimes by chalcopyrite and sphalerite proximal and distal, respectively, to the semi–massive and massive sulfide horizon. Strong silicification and sulfidation is often developed in the dm–strong cap horizon above the rhyolitic flow and tuff. Mafic dykes are usually strongly chloritized and show partly carbonate alteration. Single pyrite porphyroblasts can be observed randomly in the dykes as well.

GEOCHEMISTRY

The assay data for Cu, Au, Zn, Pb (Fig. 2), and Ag show higher maximum and average values in the up plunge than in the down plunge of the 1806 zone. In the semi–massive to massive sulfide horizon in the up plunge maximum values for Cu, Au, Zn, Pb, and Ag are 11.7 wt%, 96 g/t, 34.5 wt%, 2.69 wt%, and 567 g/t, respectively. In contrast, the maximum values for these elements in the semi–massive to massive sulfide horizon in the down plunge are 9.9 wt% Cu, 17.2 g/t Au, 14.5 wt% Zn, and 350 g/t Ag. Due to the almost absence of galena and boulangerite in the down plunge, Pb concentrations are very low. Copper, Au, Zn, Pb, and Ag data in the stringer zone in the up plunge of the 1806 zone are usually much lower than the maximum values reported from the sulfide horizon, but can also reach elevated values with often 0.5 to > 1 wt% Cu, 1 – 5 g/t Au, up to 1 wt% Zn, ca. 10 g/t Ag, and up to 0.5 wt% Pb. However, the stringer zone in the down plunge rarely has economic concentration of base and precious metals. The assay data for the base and precious metals correlate poorly. However, Au and Ag are associated with enrichments in Cu and/or Zn (Fig. 2).

Metal and elemental zoning observed by EDX–SEM is preserved in tetrahedrite–tennantite (Fig. 3d), electrum, and Ag–Hg–Au alloys. Arsenic and Sb have inverse behavior in tetrahedrite–tennantite with increased Sb values on tetrahedrite–tennantite margins or in restricted zones within the grains (e.g., lighter grey in BSE images; Fig. 3c). Electrum is Ag– and Hg–bearing and have rims enriched in Ag and Hg with gold enriched in the cores of grains. The same trend is observed in Ag–Hg–Au alloys with increased Ag–Hg and decreased Au concentrations on the margin and inverse enrichments in alloy cores. Silver–rich varieties of chalcopyrite and tetrahedrite–tennantite are developed adjacent and marginal to their Ag–free counterpart, (Fig. 3a) implying the preferred enrichment of Ag on phase margins.

DISCUSSION

The origin of Au–Ag–rich VMS systems is still highly discussed [8–11] and often made more difficult due to the metamorphic overprint affecting many Au–Ag–rich VMS systems. Hence, a primary syngenetic origin of precious metal enrichment in VMS deposits is often questioned and a synorogenic origin is often favored in many deformed VMS districts [12]. However, evidence supporting an orogenic origin of Au and Ag including limited sulfide mineralogy (e.g., pyrite, chalcopyrite, arsenopyrite), sulfide mineralization associated with quartz veins, and narrow carbonate alteration haloes [13] are not present in the 1806 zone at the Rambler Camp, despite the effect of deformation to the mineral texture. Textural features such as recrystallization, especially in pyrite, replacement of pyrite by metamorphic pyrrhotite and porphyroblasts of pyrite and arsenopyrite indicate that metamorphism and deformation have affected the sulfides at Ming, but it has not completely obscured the primary mineralogy and textures of the sulfides completely. The 1806 zone consists of a complex assemblage of sulfide minerals (e.g., sulfosalts, Au–Ag–Hg–bearing phases) that cannot be explained by a hydrothermal fluid of mid-crustal, orogenic origin, but by primary hydrothermal fluid circulating through the seafloor. Moreover, this odd sulfide mineralogy, especially the occurrence of electrum with sulfosalts containing magmatic suite elements (e.g., Ag, As, Hg, Sb, Sn) as major and minor phases, strongly suggests the potential of a contribution of magmatic volatiles to the primary, base–metal transporting hydrothermal fluid. Furthermore, the sulfosalts represent a high–sulfidation state known from many Au–rich epithermal systems [14] and which was been suggested to be important for the genesis of Au–rich VMS systems [9, 15, 16]. Additionally, electrum and Ag–phases occur predominantly with pyrite and chalcopyrite indicating a metal zoning that has been developed primarily during the waning and waxing stages of the VMS deposit [17, 18]. The metamorphism and deformation had only the effect of zone-refinement and upgrading as seen in the occurrence of electrum and Ag–bearing phases partly along pyrite and arsenopyrite grain boundaries, brittle cracks in pyrite, and as free phase in gangue (e.g., quartz). These data favor a syngenetic origin for precious metal enrichment in the Ming VMS deposit, rather than a later orogenic overprint.

CONCLUSIONS

Recent investigations on the 1806 zone at the Ming Mine, Rambler Camp, NW Newfoundland,

reveal a complex sulfide mineralogy including besides common sulfide phases such as pyrite, chalcopyrite, sphalerite and arsenopyrite, Ag–, As–, Hg–, Sb–, and Sn–bearing sulfosalts, various Ag–phases and electrum. These minerals are mostly concentrated in semi–massive to massive sulfide horizon hosted by rhyolitic massive flows and tuff to lapilli tuff. Fine stringer beneath the semi–massive to massive sulfide horizon is most commonly pyritic and to lesser extend also chalcopyrite– and sphalerite–bearing. Often a strongly silicified and sulfide mineralized horizon caps the mineralize rhyolite. Turbidities are common in the hanging wall and mafic dykes usually cut through the footwall and hanging wall. Base and precious metals are more enriched in the up plunge than in the down plunge of the 1806 zone indicating metal zoning. Textural and investigations by EDX–SEM on the sulfides confirm the deformation (e.g., recrystallization) done by greenschist metamorphism on the 1806 zone. However, EDX–SEM reveals also primary sulfide associations between sulfosalts, Ag–phases, and electrum and elemental zoning in these phases. Based on (1) the observed sulfide assemblage and texture, (2) the sericite + quartz ± green mica ± chlorite ± biotite alteration in the rhyolites, and (3) the metal zoning of electrum preferably occurring with pyrite ± chalcopyrite especially in the up plunge of the 1806 zone a syngenetic origin with magmatic contribution is strongly favored for the genesis of the studied zone. Further microscopic and geochemical work with emphasis on the sulfide and alteration assemblage in the 1806 zone and three other newly discovered Cu–Au mineralization horizons at the Rambler Camp will be continued over the next years to confirm the here presented preliminary genetic results on Au–Ag–rich VMS deposits in the Appalachians.

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