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Critical review

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Abstract: The Ming Cu-Au volcanogenic massive-sulphide deposit (3.65 Mt at 2.26 wt % Cu, 1.13 g/t Au, 6.78 g/t Ag, and 0.32 wt % Zn) located in the Rambler mining camp is hosted by intermediate to felsic volcanic and volcaniclastic rocks of the early Ordovician (ca. 487 Ma) Pacquet Harbour Group, which is part of a regional mafic-dominated rock assemblage of boninitic to tholeiitic affinity. The deposit consists of four parallel, elongated, shallowly plunging 030°N lenses, of which the 1807 zone is currently being mined. The 1807 zone consists of a Cu-Zn-Au-rich massive-sulphide horizon hosted by a sequence of aphanitic to quartz-phyric, dacitic to rhyolitic tuff, lapilli tuff, and tuff breccia. It is structurally to disconformably overlain by a mafic-dominated subaqueous volcanic sequence comprised of mafic to intermediate volcaniclastic to epiclastic rocks. The immediate footwall rocks are hydrothermally altered to chlorite+quartz+sericite±calcite±epidote, with zones of quartz+sericite±green mica, whereas the deeper (~100 m below the massive sulphide) footwall rocks are altered to chlorite+quartz.

The massive-sulphide horizon in the 1807 zone shows evidence of deformation and possible remobilization during a regional compressional deformation. Structural modifications include regional-scale anticlinal and micro- to meso-scale tight folds with a northeast-southwest-trending axial plane with a shallow-plunging 030°N trending mineral lineation. In addition, three generations of mafic to intermediate dykes are recognized with the latest presenting features, indicative of a close temporal relationship with the remobilization of the sulphide horizons.

Résumé : Le gisement de Ming, un gîte de sulfures massifs volcanogènes riches en Cu-Au (3,65 Mt de minerai à 2,26 % en poids de Cu, 1,13 g/t de Au, 6,78 g/t de Ag et 0,32 % en poids de Zn), situé dans le camp minier de Rambler, est encaissé dans des roches volcaniques et volcanoclastiques de composition intermédiaire à felsique de l'Ordovicien précoce (env. 487 Ma) du Groupe de Pacquet Harbour, lequel fait partie d'un assemblage lithologique régional à dominance de roches mafiques aux affinités boninitiques à tholéiitiques. Le gisement se compose de quatre lentilles allongées parallèles et faiblement inclinées (30° N), comprenant la zone 1807 qui est actuellement en exploitation. La zone 1807 se compose d'un horizon de sulfures massifs riches en Cu-Zn-Au encaissé dans une séquence de tuf, de tuf à lapillis et de tuf bréchique aphanitiques ou à phénocristaux de quartz, de composition dacitique à rhyolitique. Cette zone est surmontée en contact structural ou en disconformité par une séquence volcanique à dominance mafique mise en place en milieu subaquatique, qui se compose de roches volcanoclastiques à épiclastiques de composition mafique à intermédiaire. Les roches de l'éponte inférieure les plus proches ont été altérées par des fluides hydrothermaux en une association à chlorite+quartz+séricite±calcite±épidote, avec des zones à quartz+séricite±mica vert, alors que les roches plus profondes de l'éponte inférieure (env. 100 m sous les sulfures massifs) ont été altérées en une association à chlorite+quartz.

L'horizon de sulfures massifs de la zone 1807 montre des signes de déformation et d'une possible remobilisation au cours d'une déformation régionale par compression. Les modifications structurales comprennent des plis anticlinaux d'échelle régionale et des plis serrés d'échelle microscopique à méso-scopique avec un plan axial d'orientation nord-est–sud-ouest et une linéation minérale à faible plongement de 30° N. En outre, trois générations de dykes de composition mafique à intermédiaire ont été identifiées, et les caractéristiques des plus récents indiquent un lien étroit dans le temps avec la remobilisation des horizons de sulfures.

INTRODUCTION

The producing Ming mine is located in the northern central part of the Baie Verte Belt of Newfoundland (Fig. 1). It is one of a number of deposits, some of which are past producers, in the Rambler mining camp. The Ming mine is a bimodal-mafic volcanogenic massive-sulphide (VMS) deposit that contains four ore zones that are hosted within a felsic volcanic/volcaniclastic package, near the contact with the overlying mafic volcanic hanging wall. Combined measured and indicated resource for all four zones is 3.65 Mt at 2.26 wt % Cu, 1.13 g/t Au, 6.78 g/t Ag, and 0.32 wt % Zn, and the 1807 zone is the most Cu- and Au-rich of these with combined measured and indicated resources of 432 000 t grading 3.68 wt % Cu, 1.76 g/t Au, 7.03 g/t Ag, and 0.75 wt % Zn (Pilgrim, 2009).

Detailed mapping was undertaken northwest of the Ming mine in different underground levels along the 1807 zone (i.e. 375, 381, 469, and 481 m levels). This work is part of a larger study evaluating the stratigraphy, alteration mineralogy, and structure of the entire deposit. Because the 1807 zone was actively mined during the time fieldwork was conducted, it was critical to take advantage of the extensive and fresh exposures. The stratigraphy of the Rambler camp is well established at a regional scale, but not so at the deposit scale, mainly because of the lack of outcrop exposures (Tuach and Kennedy, 1978; Hibbard, 1983). Herein we provide detailed stratigraphic, petrographic, and alteration mineralogical information and preliminary structural data for the 1807 zone. Work by others indicates a syngenetic origin for base- and precious-metal mineralization within the 1807 zone with later structural and metamorphic remobilization without significant changes in metal content (e.g. Brueckner et al., 2011).

GEOLOGICAL SETTING

The Baie Verte Peninsula (Fig. 1) is composed of tectonized slivers of ophiolitic sequences ranging in age from 490 to 484 Ma (Dunning and Krogh, 1985; Cawood et al., 1996); for the most part, these show close spatial association with the Baie Verte-Brompton Line (BVBL) (Fig. 1; Skulski et al., 2009, 2010; Zagorevski and van Staal, 2011). These ophiolitic slivers are characterized by harzburgite, ultramafic cumulates, isotropic gabbro, sheeted dykes, pillow basalt, and locally felsic domes (Rambler camp) of boninitic to island-arc tholeiitic affinities (Bédard et al., 1998; Skulski et al., 2009, 2010 and references therein). The slivers are disconformably overlain by a cover sequence comprising the ca. 476–467 Ma Snooks Arm Group and its equivalent in the Pacquet Harbour Group (PHG), Pointe Rousse Complex, and Flatwater Pond Group (Fig. 1; Skulski et al., 2010), ranging from enriched mid-ocean-ridge basalt (E-MORB) (or tholeiitic back-arc basin basalt) to calc-alkaline volcanic rocks (Bédard et al., 1998).

The Ming mine is underlain by the Paquet Harbour Group (PHG, Hibbard 1983; Fig 2), a northeast-dipping sequence dominated by mafic and felsic volcanic rocks. It has been divided into two sequences based on their geochemical affinities and geochronology: the lower and upper PHG (Fig. 3; Skulski et al., 2009, 2010). The upper and lower PHG are in disconformable contact (Skulski et al. 2009, 2010). The lower PHG is believed to represent an incompletely preserved ophiolitic sequence that is located south of the Ming mine (Piercey et al., 1997). Metamorphism in the lower and upper PHG does not exceed upper greenschist facies, except near the intrusive bodies (Fig. 2) (e.g. Cape Brulé porphyry and Dunamagon granite) where contact metamorphism locally reaches amphibolite facies (Tuach and Kennedy, 1978). The lower PHG is divided by the Rambler Brook Fault (Fig. 2), a south-directed, east-west structural feature that contains low-Ti boninites with minor felsic tuff and rhyodacite at its base (Hibbard 1983; Piercey et al., 1997). The hanging wall of the Rambler Brook Fault contains rocks that host the deposits of the Rambler camp, including the Ming mine. These structural hanging-wall (not stratigraphic hanging wall to the deposit) rocks comprise boninitic basalt that is overlain by a 2.5 km thick sequence of quartz-phyric rhyodacite, felsic tuff, and tuff breccia (Rambler Rhyolite formation; Skulski et al., 2010). A felsic volcanic rock sample collected approximately 1 km along strike and south of the Ming mine yielded a U/Pb zircon age of ca. 487 Ma (Hibbard 1983; V. McNicoll, unpub. data, 2008 *in* Castonguay et al., 2009 and Skulski et al., 2009). The age indicates that the lower Paquet Harbour Group is coeval with other ophiolites in the peninsula (i.e. Advocate, Pointe Rousse, and Betts Cove ophiolite complexes; Fig. 1). The upper PHG (Fig. 2) is located northeast of the Ming mine and its base is locally composed of iron-formation and black chert that are overlain by a sequence of epiclastic wacke, siltstone, volcaniclastic rocks, and basalts of tholeiitic to calk-alkaline affinities (Skulski et al., 2009).

The mineralized lenses of the Ming mine are composed of semimassive (<50 vol %) to massive sulphide minerals or narrow (<1 m wide) transposed sulphide veins and veinlets macroscopically composed of pyrite, chalcopyrite, sphalerite, and pyrrhotite. The lenses are spatially associated with several metamorphosed hydrothermal alteration-mineral assemblages developed mainly in the footwall. These lenses are located in the upper sequence of the Rambler Rhyolite formation felsic volcanic rocks. There are four regional deformation events, with the most intense being a D_2 L >S fabric and north- to northeast-dipping folds (Castonguay et al., 2009, and references therein) characterized by a shallowly plunging 030°N-trending mineral lineation (Tuach and Kennedy, 1978; Hibbard, 1983).

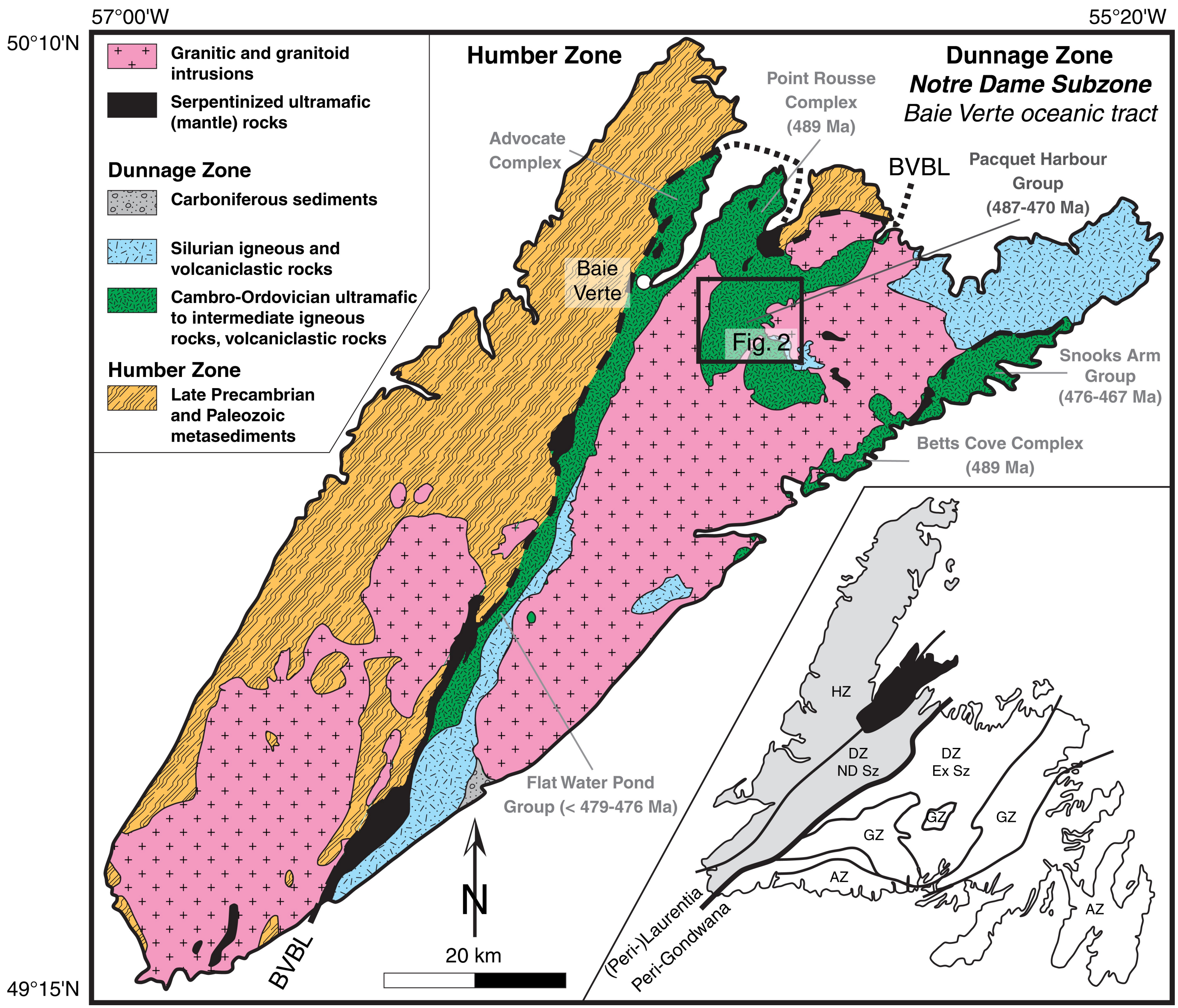

Figure 1. Simplified geological map of the Baie Verte Peninsula (modified after Castonguay et al., 2009 and reference therein). Abbreviations; HZ = Humber zone, DZ = Dunnage zone, ND SZ = Notre-Dame Subzone, Ex SZ = Exploits Subzone, GZ = Gander zone, AZ = Avalon zone, BVBL = Baie Verte-Brompton Line.

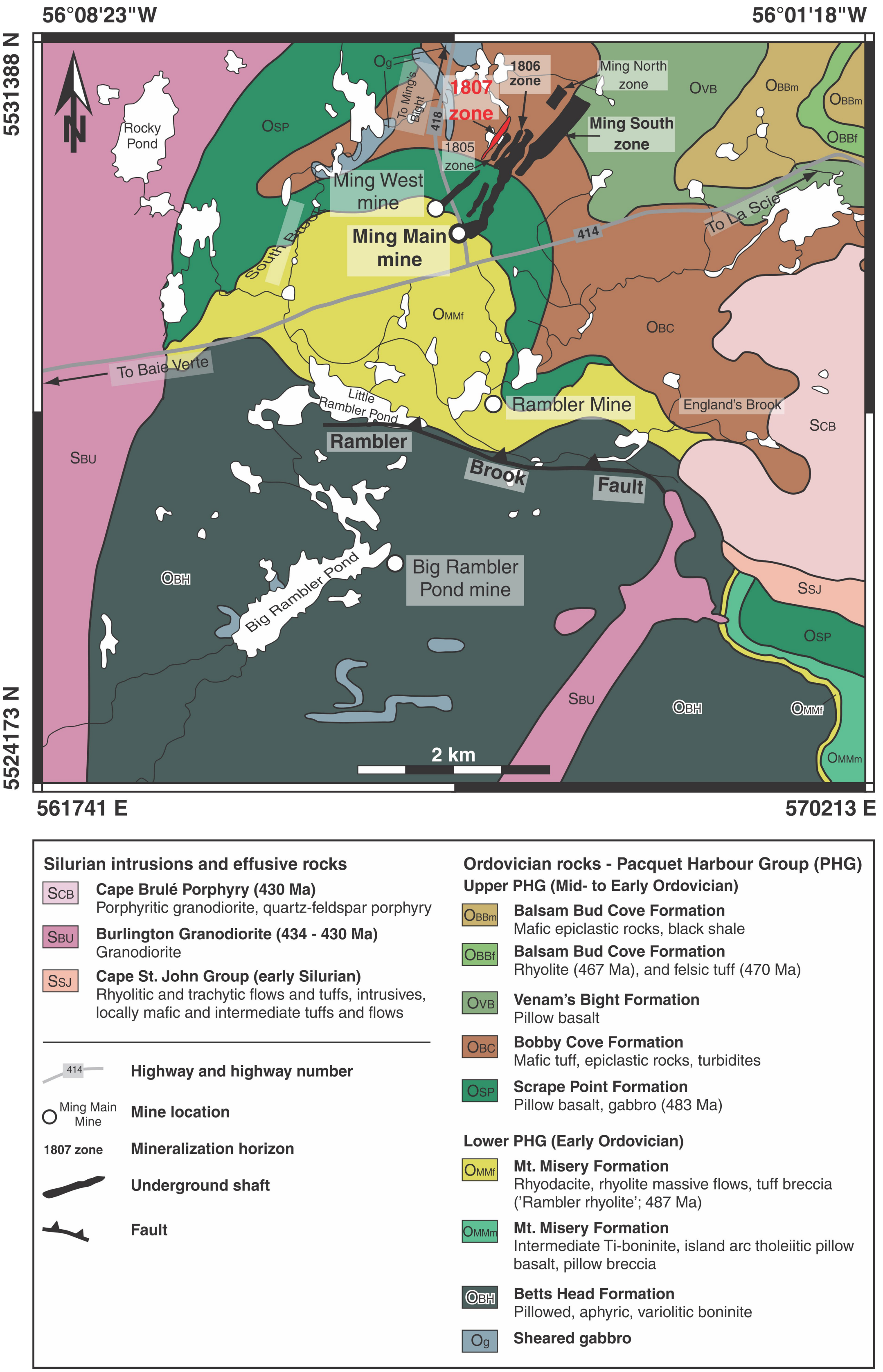

Figure 2. Regional geology map of the study area, Baie Verte Peninsula. Both datums are shown in WGS 84 (top and right) and UTM 21N NAD 83 (bottom and left). Map modified after Pilgrim (2009), Tuach and Kennedy (1978), Castonguay et al. (2009), and Hibbard (1983). Ages are from Castonguay et al. (2009) and Cawood et al. (1996).

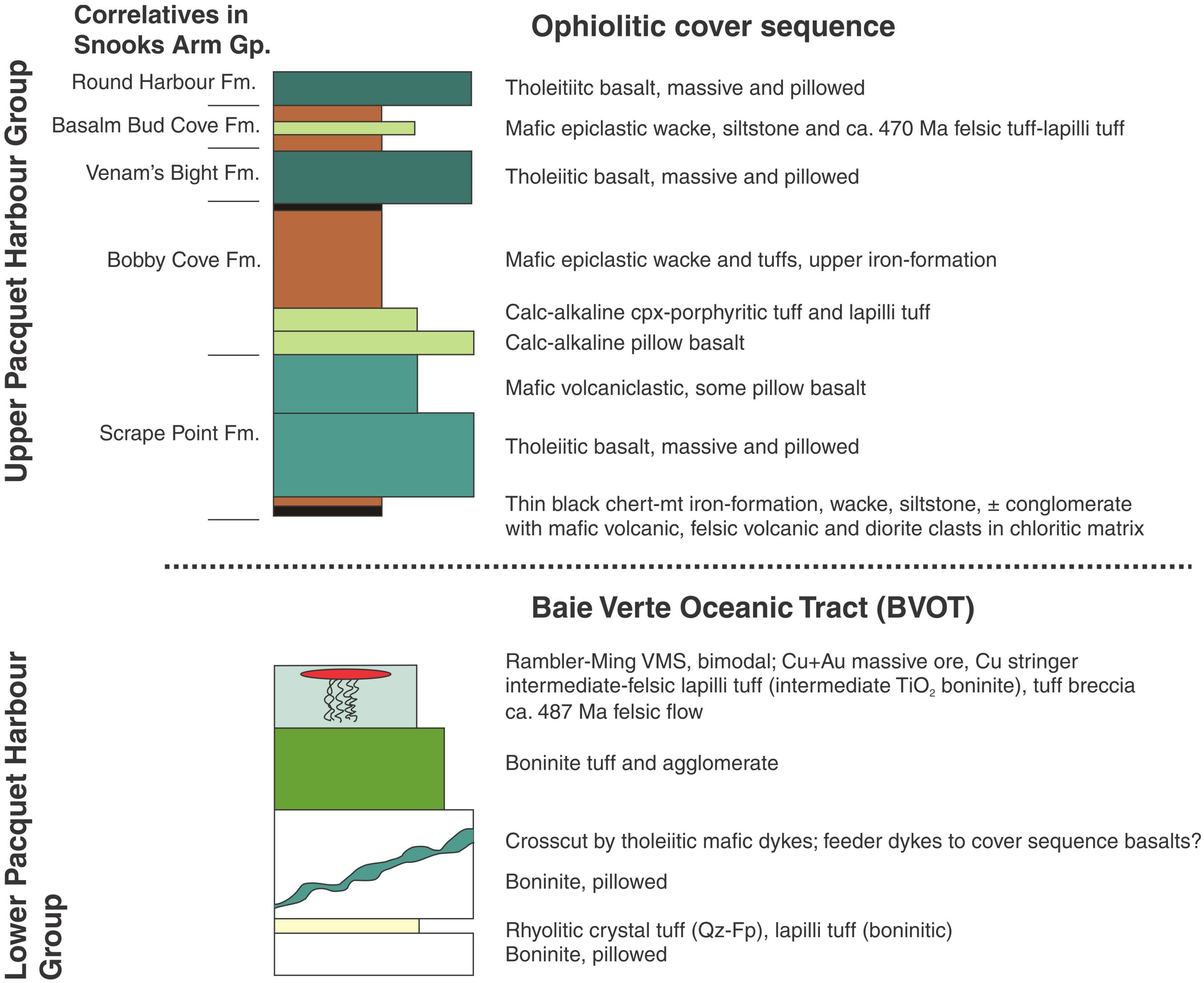

Figure 3. Simplified stratigraphic section of the Pacquet Harbour Group. Correlative formations from the Snooks Arm Group are based on the stratigraphy of Bédard (1999). The U-Pb zircon ages are from G. Dunning (pers. comm.). Abbreviations: cpx, clinopyroxene; mt, magnetite; Qz-Fp, quartz-feldspar; Fm, formation. Diagram modified after Skulski et al. (2009).

STRATIGRAPHY AND PETROGRAPHY OF THE 1807 ZONE

Intermediate to felsic rocks – Upper Rambler Rhyolite formation

Previous workers at the Ming mine separated rock types based on the proportion and abundance of secondary minerals (i.e. chlorite, actinolite, and sericite; Gale, 1971; Tuach, 1976; Tuach and Kennedy, 1978; Bailey, 2002). Although primary minerals and some textures have been obliterated, in many low-strain zones the primary textures and rock types can be discerned. In the 1807 zone the footwall underlying the massive-sulphide zone is composed of coherent aphanitic to porphyritic felsic volcanic and associated irregularly distributed and less abundant felsic volcaniclastic rocks. This latter package is 5 to 10 m thick, and has sharp to gradational contacts with underlying and overlying rocks. The sulphide horizons of the 1807 zone are up to 6 m thick and are locally crosscut by mafic dykes (Fig. 4).

The contact between the felsic rocks and the overlying massive sulphides is sharp and irregular in most levels (Fig. 4 and 5a). Some relict islands of highly silicified rhyolite occur in the massive sulphide, but only at its base. Fragments can be up to 1 m in size. The rhyolite contains abundant disseminated secondary pyrite porphyroblasts and an increase in quartz alteration occurs near the contact with the massive sulphide (Fig. 4). The ubiquitous biotite grains in the rhyolite are interpreted to be metamorphic in origin. On level 481 the footwall contains monolithic volcaniclastic

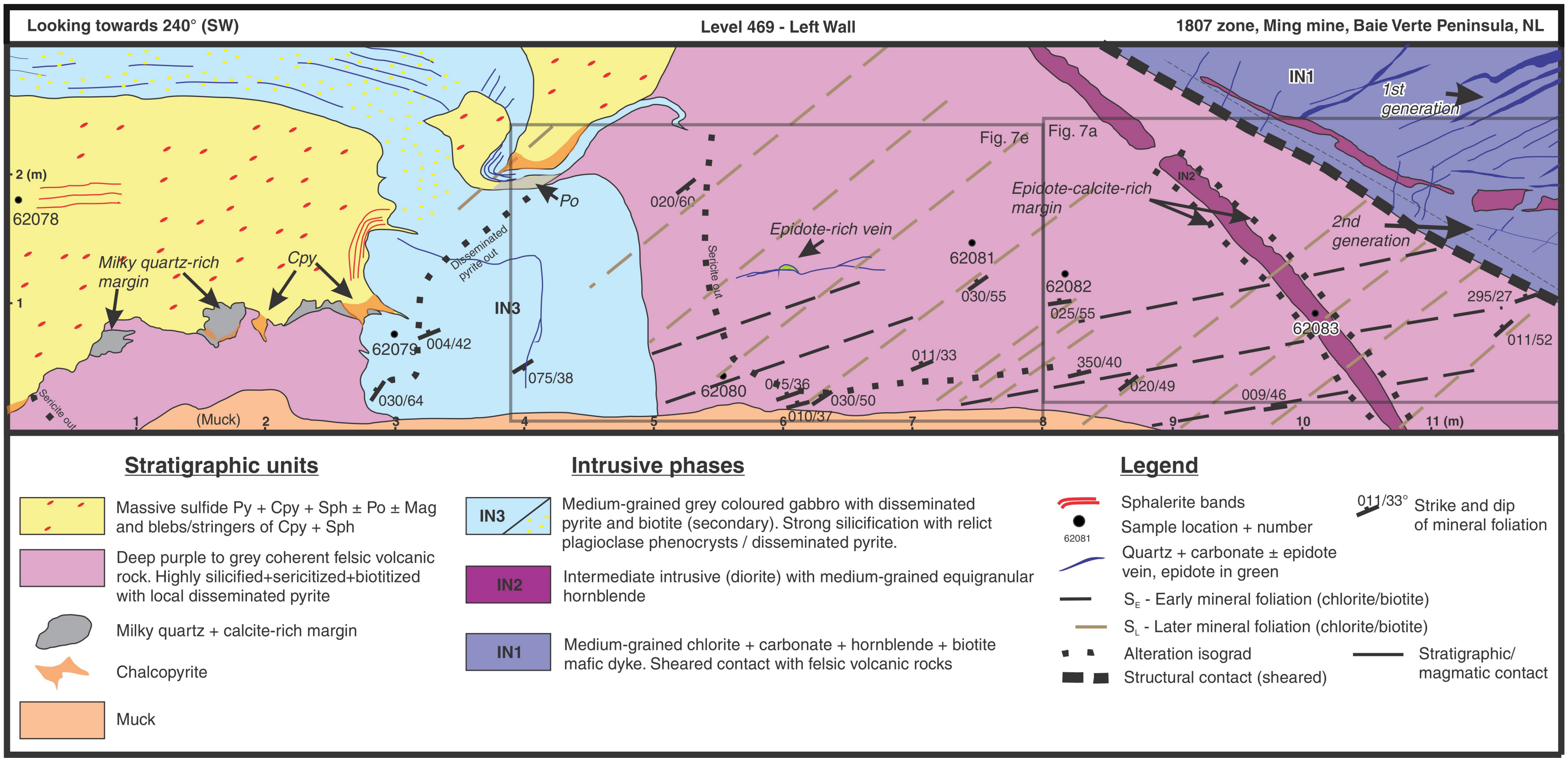

Figure 4. Schematic cross-section of the back wall in level 469, 1807 zone showing the relationship between the different lithological units, including the massive sulphide horizon where it is intruded by IN3. Also shown is the close spatial relationship between the pyrite porphyroblasts in the dyke IN3 and the massive sulphide.

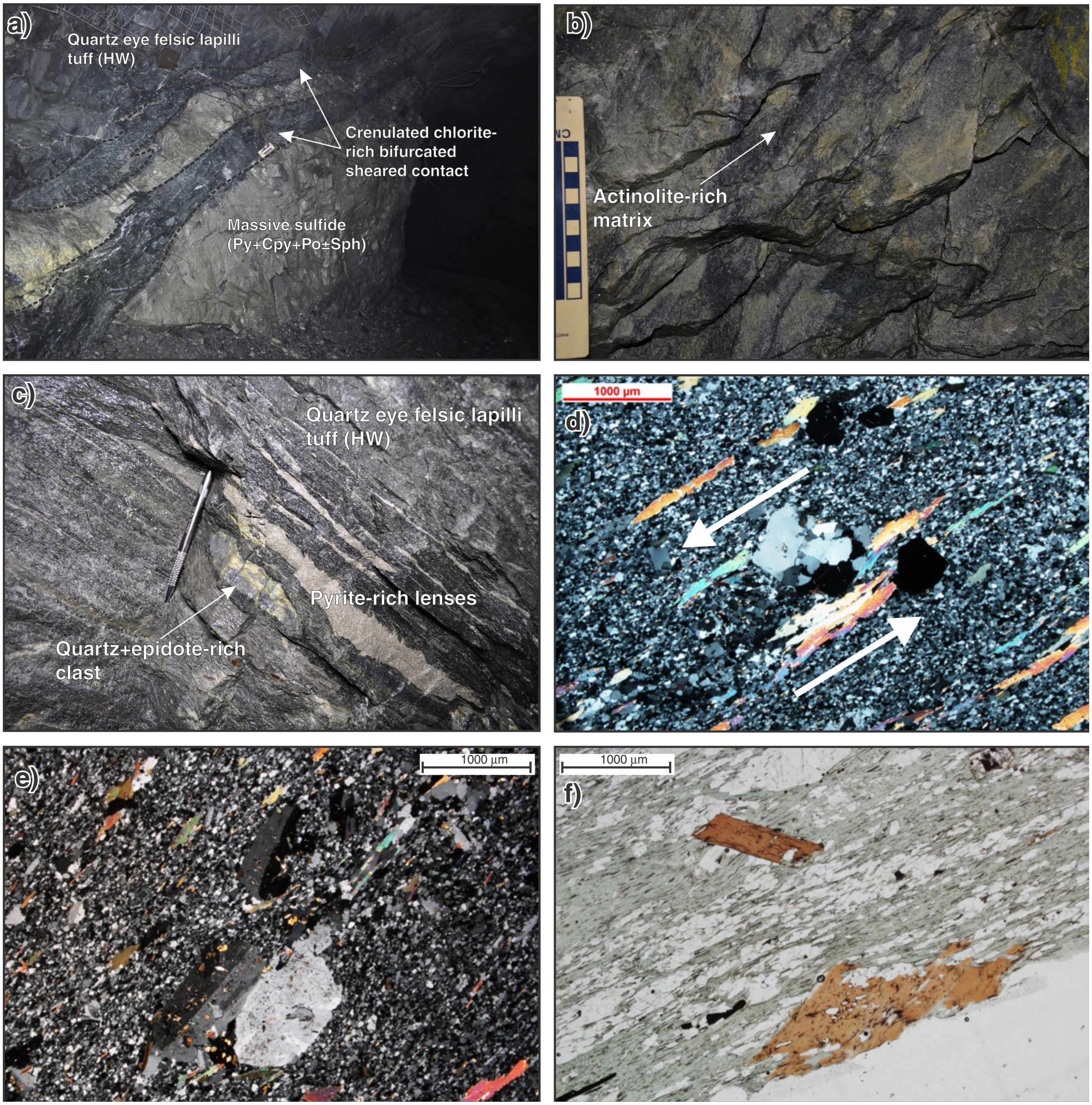

Figure 5. Photographs of underground exposures and photomicrographs of felsic volcanic and volcaniclastic rocks of the 1807 zone, Ming mine. **a)** View looking southwest in level 375 of the sheared contact between the coherent quartz-eye felsic lapilli tuff (HW = hanging wall) and massive sulphide. The scale in the centre is 15 cm long. 2013-297. **b)** View looking southwest in level 481 of the actinolite-rich matrix felsic volcaniclastic rock with epidotized fragments in the footwall zone. 2013-301. **c)** View looking northwest in level 375 of the quartz-eye felsic lapilli tuff with imbricated replacement sulphide lenses and quartz-epidote-rich fragments along the predominant foliation. 2013-305. **d)** Sheared polycrystalline quartz porphyroclasts with biotite along the predominant foliation with shear sense indicated by arrows (cross-polarized; sample 62080a, level 469). 2013-294. **e)** Relict plagioclase phenocrysts showing Carlsbad twinning with internal replacement by epidote and sericite (cross polarized; sample 62081a, level 469). 2013-291. **f)** Chlorite-quartz-biotite-rich showing two phases of biotite grains (sample 62086, lower footwall zone, 100 m below the 1807 zone). 2013-295. Abbreviations: Cpy, chalcopyrite; Po, Pyrrhotite; Py, pyrite; Sph, sphalerite.

rocks that are in gradational contact with the overlying rhyolite flows (Fig. 5b). The clasts are subrounded within a dark grey actinolite-rich matrix (Fig. 5b).

Down-plunge of the 1807 zone (i.e. on the 469 and 481 levels), the magmatic contact between the felsic volcanic rocks and mafic dykes of unknown thickness has been modified by shearing (Fig. 4). The dyke emplacement is interpreted to be coincident with deformation, as evidenced by the presence of sharp, undeformed intrusive contacts with host rocks away from zones of high strain, but folded proximal to zones of high strain and mineralization (Fig. 4). The contacts of the dyke with volcanic rocks proximal to mineralization are typically sheared with a crenulated chlorite-rich matrix.

Overlying the massive sulphides are highly quartz-altered (silicified) intermediate to felsic volcaniclastic rocks, generally less than 3 m in thickness, that are composed of variably altered quartz-eye porphyritic rhyolite (Fig. 5c). Along the base of the hanging-wall rocks on the 375 and 381 levels, there is a foliation demarcated by elongated silica- and epidote-rich clasts up to 10 cm long that occur with, and are imbricated by, elongated sugary pyrite lenses up to 50 cm long. These lenses have an average aspect ratio of 20:1 (Fig. 5c). The sulphides are in irregular contact with the host felsic volcaniclastic rocks suggesting they have a replacement origin, and are not a chemical sedimentary product (Fig. 5c).

The rocks underlying and overlying the ore are light grey to dark purple, porphyritic to aphanitic, felsic tuff, lapilli tuff, and flows. Petrographic analyses of representative samples reveal a predominance of fine-grained heterogranular quartz grains occur together with biotite (Fig. 5d). Two varieties of biotite have been identified; 1) commonly anhedral containing pleochroic haloes, possibly surrounding zircon inclusions, and 2) devoid of zircon inclusions and displaying glomero-porphyroblastic textures to homogenously distributed throughout the rock. The latter has been interpreted to result from the metamorphism of previously K-Fe-Mg-altered rocks. Both varieties, however, are aligned parallel to foliations. In addition, very fine- to fine-grained interstitial muscovite (<30 vol. %) and epidote (<2 vol. %) occur throughout the rock. Some samples show relict fine-grained anhedral plagioclase grains with albite and Carlsbad twinning (Fig. 5e). These latter grains have been variably altered to epidote, zoicite, sericite, and albite.

Near (<5 m) the massive sulphides of the 1807 zone, the felsic rocks are silicified with biotite that appears to be of two generations, along with muscovite (sericite), epidote, and sulphide minerals. Up-plunge of the 1807 zone, minor green mica (possibly fuchsite) is also present. The entire mineral assemblage in the felsic volcanic rocks is consistent with the upper-greenschist metamorphism of a sericitic alteration type (Bernier et al., 1987; Barrett and MacLean, 1994; Bonnet and Corriveau, 2007). Moreover, in the lower footwall (>50 m below sulphide horizons), the predominant hydrothermal alteration products include chlorite associated with two textural varieties of biotite porphyroblasts and pyrite and chalcopyrite as the main sulphide phases (Fig. 5f). Based on the presence of chalcopyrite, this latter assemblage represents the high temperature core of the upflow zone of a VMS system because copper is only transported at temperatures greater than 300°C (e.g. Franklin et al., 2005). Considering the regional-scale thrusting in the Baie Verte peninsula (Castonguay et al., 2009) and the presence of shearing and faulting within the deposit, at present, it is likely that the spatial separation of the massive-sulphide horizons from the chloritic zone is due to faulting, but further structural and stratigraphic analyses are needed to confirm this.

Two main fabrics are evident in thin section, based on the orientations of biotite, with a 30° angle between them. Rotated σ-type mantled quartz porphyroclasts suggest a southwest-directed compressional regime (Fig. 5d). At present, it is not known if both fabrics are kinematically related. Thin sections cut perpendicular to the predominant lineation (trending 030 ± 005°N) show one fabric revealed by aligned biotite grains. Based on this, the two biotite varieties are most likely syn- to post-kinematic, and aligned parallel to foliation.

Mafic rocks – Lower Scrape Point Formation

The mafic rocks are minor to absent near the massive-sulphide horizon in underground exposures. Stratigraphic interpretations and descriptions are made based on drill core observations from the nearby 1806 zone. The mafic volcanic and volcaniclastic rocks overlying the felsic volcanic, and locally the massive-sulphide horizon, are mainly comprised of distal volcanic turbidites and ash to lapilli tuff of mixed composition (Fig. 6a).

Very fine-grained mafic tuff with felsic fragments (up to 3 cm in length) occurs near (<5 m) the basal contact with the footwall felsic lapilli tuff (Fig. 6b). The contact between the hanging wall and footwall is commonly sheared, truncated by mafic dykes, or contains quartz veins with disseminated chalcopyrite, pyrite, and pyrrhotite. The mafic volcaniclastic rocks are dark grey to light grey with subrounded elongate fragments (up to 3 cm in length) and range from thin beds of mafic tuff to lapilli-tuff rich units.

The mafic volcanic package is relatively undeformed and metamorphosed to upper-greenschist facies (Tuach and Kennedy, 1978). Both flows and volcaniclastic rocks are dominated by a very fine-grained matrix composed of (in decreasing order) porphyroblastic actinolite, quartz, chlorite, biotite, relict plagioclase, leucoxene (fine-grained mixture of rutile and anatase), and minor opaque phases such as magnetite and iron oxides (Fig. 6c-f).The rocks are dark green to dark blue, show a well developed foliation, and contain rotated porphyroclasts of feldspar. The actinolites are light

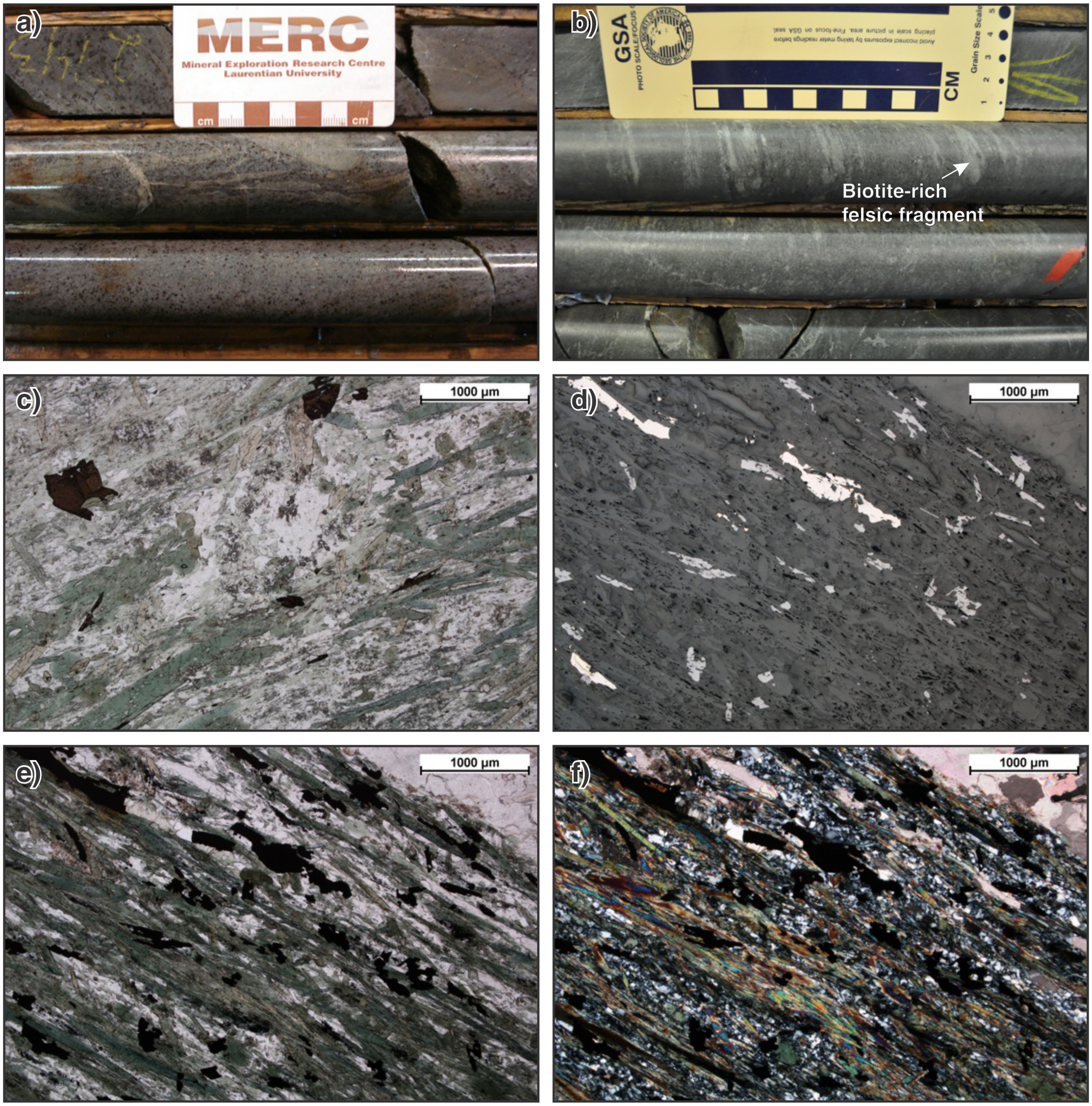

Figure 6. Representative drill core photographs and photomicrographs of the mafic volcanic and volcaniclastic rocks most immediately (<30 m) overlying the deposit. **a)** Mixed lapilli tuff with fragments of felsic composition, 1 m above the felsic volcanic flow hosting the massive sulphide (DDH RMUG08–123; 67 m downhole). 2013-293. **b)** Biotite-rich felsic lapilli fragments in a mafic tuffaceous matrix, 5 m above mineralization (DDH RMUG08–136; 52 m downhole). 2013-292. **c)** Actinolite-chlorite-leucoxene-quartz-calcite-rich basalt with relict plagioclase porphyroclasts in the centre of the photograph, 10 m above mineralization (sample 62176; DDH RM05–08; 990 m downhole). 2013-303. **d)** Disseminated chalcopyrite and pyrite grains within a chlorite-actinolite-quartz-rich rock, 104 m above mineralization (cross-polarized; sample 62167; DDH RM05–08; 896 m downhole). 2013-304. **e)** (2013-298) and **f)** (2013-302) same sample as d) but in plane-polarized and cross-polarized, respectively. The sample is cut by later concordant calcite vein (upper right corner).

to olive green, euhedral, and commonly glomero-porphyroblastic, ranging from 0.5 to 2 mm in length and concordant to discordant to foliation. Quartz is very fine grained, anhedral, and ubiquitously present. It also occurs in pressure shadows of feldspar porphyroclasts. Fine-grained chlorite is interstitial to foliate, and occurs together with quartz. Moreover, the biotite and chlorite grains occur together and are aligned in the plane of the foliation. Later calcite veins crosscut the main foliation in the rocks.

Intrusive Rocks

Three generations of dykes have been recognized in the field, based on crosscutting relationships. Their absolute ages are not yet known and the relationships with the rocks they crosscut have long been unclear. Samples of all three phases of dykes were collected for petrographic and lithogeochemical analysis. The most abundant phase are medium-grained, equigranular, hypidiomorphic, gabbroic dykes (IN1) that vary from 10 to 20 m in thickness, have an east-west orientation, dip 45 to 50° to the north, and their magmatic contacts with felsic volcanic rocks have been offset by faulting locally (Fig. 7a). The structural contact indicates that deformation postdated dyke solidification. Furthermore, the contacts of the dykes with felsic volcanic rocks contain slickensides indicative of shearing and strike-slip motion parallel to the regional dominant stretching lineation (Castonguay et al., 2009). Despite IN1 having a structural relationship with the felsic volcanic rocks in some areas, clear intrusive contacts have been identified (e.g. in level 481 of the Ming mine; Fig. 7b).

The second-most abundant intrusive phase is medium-grained granodioritic dykes (IN2) composed of (in decreasing order of abundance) quartz, biotite, and actinolite with minor calcite, chlorite, epidote, and magnetite. These dykes are east-northeast trending, and dip at a 50° ± 5° angle to the northwest-north. Their contacts with the felsic volcanic rocks are sharp and irregular, with cuspate-lobate and flame-like morphologies (Fig. 7c). On the 469 level an IN2 dyke crosscuts an IN1 dyke, suggesting that the former postdate IN1 dykes (Fig. 7d). The IN2 dykes have been boudinaged (seen on the 469 and 481 levels) and dismembered during extension along the axis of the dyke, indicating that the dyke is syndeformational; this may explain the nature of the contact with the host felsic volcanic rocks. This dyke has been subsequently truncated attendant with the remobilization of the sulphide minerals (Fig. 4).

The third phase of dykes (IN3) are diorite and are composed of (in decreasing order) quartz, biotite, actinolite, calcite, zircon, iron oxide, and chlorite. These dykes vary from 2 to 3 m in width and have clear intrusive contacts with the felsic volcanic rocks (Fig. 4 and 7e). On the 469 and 481 levels, the dykes cut the massive sulphides and have been tightly folded, displaying axial planes oriented 030°N, and parallel to the main foliation and lineation in the felsic volcanic rocks (Fig. 7f).

PRELIMINARY INTERPRETATIONS AND ECONOMIC IMPLICATIONS

The stratigraphy of the Rambler Rhyolite formation has long been recognized to be complex, and correlations across the Baie Verte Peninsula have been difficult (Tuach, 1976; Tuach and Kennedy, 1978; Hibbard, 1983). Rocks in the area have been subjected to at least four deformation events (D_1 to D_4: Skulski et al., 2009, 2010; Castonguay et al., 2009) and metamorphism has obliterated many primary textures, making interpretations difficult. Preliminary detailed mapping of the 1807 zone allows some further constraints to be placed on the nature and origin of the felsic to mafic volcanic and intrusive rocks.

Based on stratigraphic relationships determined from underground mapping, the up-plunge section (levels 375 and 389) of the 1807 zone has felsic volcanic rocks overlying the massive sulphides that have been silicified and these are assumed to have acted as a cap (physical barrier) to the metal-rich hydrothermal fluids. Such a cap, composed of quartz-phyric tuff and coherent flow, is also documented in the 1806 zone (Brueckner et al., 2011). However, in the down-plunge section of the 1807 zone (levels 469 and 481), the massive sulphide is truncated by mafic intrusive dykes that have commonly been structurally displaced to form the structural hanging wall to the mineralization. Overall, the 1807 zone is structurally more complex than the other zones of the deposit, including the extensively described 1806 zone (Brueckner et al., 2011, unpub. data).

The relatively thin sulphide-bearing felsic volcaniclastic sequence overlying the massive sulphide in the up-plunge section of the 1807 zone may have served as a semipermeable cap that allowed hydrothermal fluids to percolate into the mound and promote subseafloor replacement and the accumulation (and preservation) of sulphides (Gibson et al., 1999). Such a semipermeable cap has also been recognized in drill core in other zones; its absence in the lower part 1807 zone could be a result of removal by structural displacement or dyke emplacement after sulphide deposition.

Based on the presence of intrusive contacts, both the IN1 and IN2 dykes intruded along the primary contact between the felsic volcanic footwall host rocks and the mineralization of the 1807 zone. Preliminary structural analyses of the tightly folded IN3 dyke cutting the massive sulphides indicate that the latter have been remobilized during dyke emplacement. On this basis, IN1 and IN2 dykes are older than IN3 dykes. The crosscutting relationship between dykes IN1 and IN2 has been determined on the 469 level, and this, together with the observation that emplacement of IN1 dykes has thermally metamorphosed sulphides in the 1806 zone (Brueckner et al., 2011), suggests that all mafic dykes were emplaced after VMS formation. The orientations of the fold axes in the IN3 dyke on the 469 and 481 levels are parallel to the predominant lineation found everywhere in the mine, (i.e. shallowly plunging 030°N). However, additional

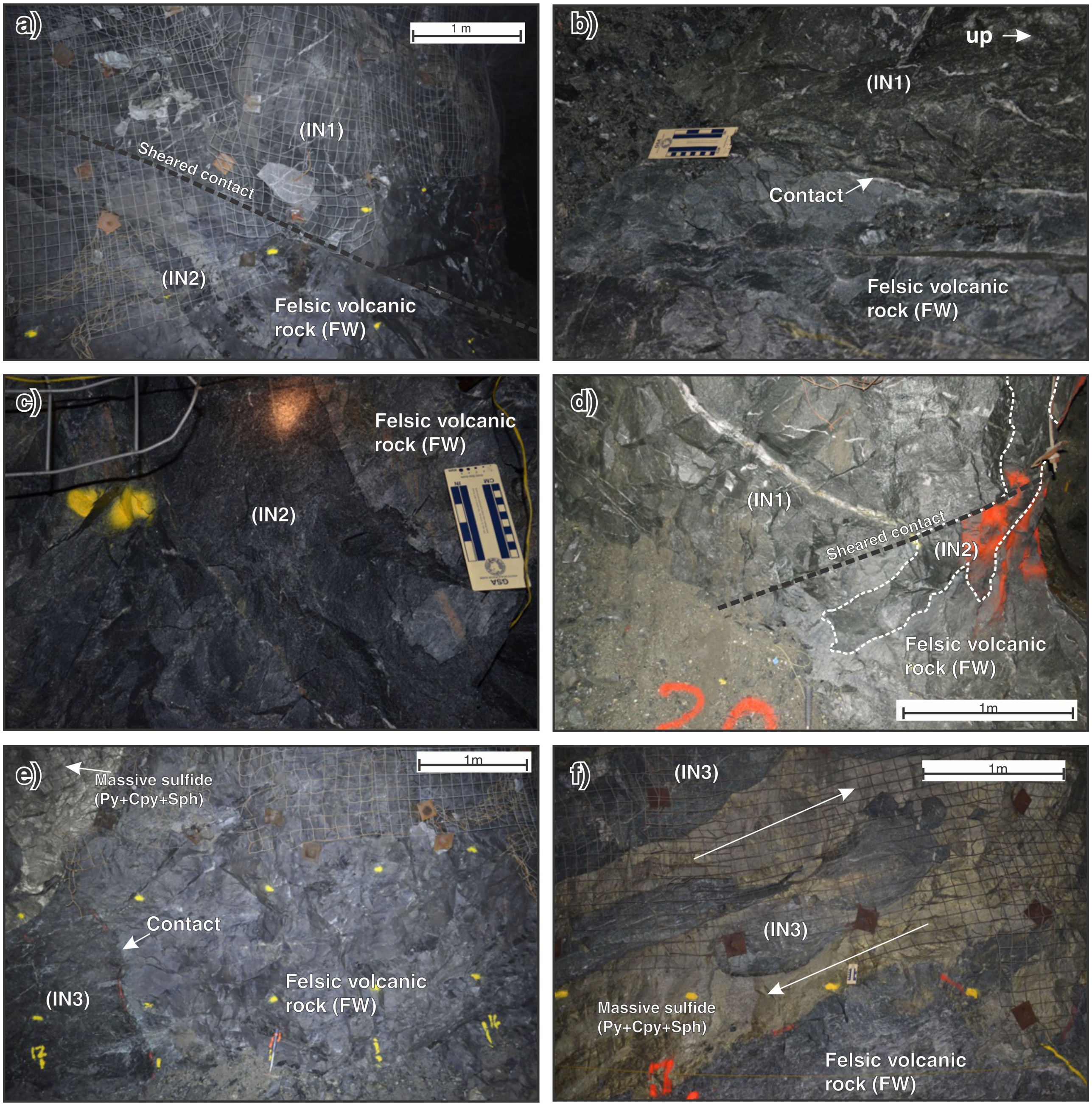

Figure 7. Photographs of underground exposures of relationships of the intrusive phases in the 1807 zone, Ming mine. **a)** View looking southwest on the 469 level of the structural contact between the massive melanocratic gabbroic dyke (IN1) and the coherent felsic volcanic footwall rocks. The mesocratic hornblende-rich intermediate dyke (IN2) is emplaced near the contact. 2013-290. **b)** View looking northeast on the 481 level of the magmatic contact between IN1 and the felsic volcanic footwall rocks. 2013-299. **c)** View looking southwest on the 481 level of the irregular contact between IN2 and the felsic volcanic footwall rocks. 2013-289. **d)** View looking northeast on the 469 level showing the relationship between dykes IN1 and IN2 that have been displaced by the structural contact between IN1 and the felsic volcanic footwall rocks. 2013-288. **e)** View looking southwest on the 469 level showing the nature of the magmatic contact between IN3 and the felsic volcanic and volcaniclastic footwall rocks. 2013-296. **f)** View looking southwest on the 481 level of the folded IN3 within the massive sulphide with northeast-directed movement. 2013-300. Abbreviations are as in Figure 5.

structural measurements are needed in order to differentiate deformation events. Nonetheless, our preliminary data suggest that IN3 dykes were emplaced synkinematically, whereas dykes IN1 and IN2 were emplaced subsequent to VMS formation but prior to the main phases of deformation (e.g. D2 of Castonguay et al., 2009). The IN1 mafic dykes did not play a role in the genesis of the sulphides, but they may have controlled the distribution of the sulphides during deformation due to the differences in competency with the felsic volcanic rocks.

Previous work in the lower Pacquet Harbour Group south of the Rambler Brook Fault suggested that there is a comagmatic relationship between the mafic dykes cutting the lower Pacquet Harbour Group and mafic volcanic rocks of the ophiolite cover Sequence (Piercey et al., 1997). Although the absolute ages of these dykes have not yet been determined, a correlation (if possible) of the overlying mafic volcanic cover sequence with the feeder dykes will place constraints on the timing of deformation. The disconformity is poorly exposed, but gabbro of the equivalent Pointe Rousse Cover sequence which hosts mineralization at Sto'ger Tight has yielded an age of 481 Ma (Ramezani et al., 2000), and this constrains the timing of volcanism in the suprasubduction zone. Regional reconstruction of the Baie Verte peninsula area indicates obduction occurred at ca. 479 Ma, based on ages of granitoid clasts in the Flat Water Pond Group (Fig. 1) basal conglomerate that giving a maximum age of deposition (V. McNicoll, unpub. data, 2009; *in* Skulski et al., 2010). The evolution from a suprasubduction ophiolitic complex (at ca. 489 Ma) to juvenile island arc in which the Rambler Rhyolite formed (at ca. 487 Ma) must have occurred in a very short period of time, and within an extensional to neutral regime. The presence of iron-formation and pillow basalt at the base of the cover sequence suggests that the environment was still subaqueous during obduction (at 479 Ma).

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