

Geological characteristics of high-level subvolcanic porphyritic intrusions associated with the Wolverine Zn-Pb-Cu volcanic-hosted massive sulphide deposit, Finlayson Lake District, Yukon, Canada¹

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ABSTRACT

During the 2000 field season, a project was initiated to study the geology, geochemistry and alteration characteristics of high-level subvolcanic porphyritic intrusions associated with the Wolverine volcanic-hosted massive sulphide deposit in the Finlayson Lake district, Yukon. Subvolcanic porphyritic intrusions within the Wolverine deposit are located approximately 10-20 m beneath exhalative sulphide bodies or iron-formation in four zones (Wolverine/Lynx, Fisher, Sable and Puck). Most intrusions are K-feldspar porphyritic (Fisher and Wolverine/Lynx Zones); however, a few are quartz and K-feldspar porphyritic (Puck and Sable zones). Feldspar-porphyritic intrusions consist of euhedral to subhedral grains of K-feldspar in a grey fine-grained matrix. Quartz-feldspar porphyritic intrusions contain slightly smaller feldspar crystals and blue to black glassy quartz eyes set in a fine-grained matrix. Most of the intrusions have non-peperitic upper margins with carbonaceous argillite (Wolverine/Lynx, Fisher, Puck). Some of the quartz-feldspar porphyritic intrusions are in contact with fine-grained volcanoclastic rocks along their upper margins (Sable); both types of intrusions have lower contacts with fine-grained volcanoclastic sedimentary rocks. These intrusions are, for the most part, unaltered and have only minor sericite-silica±chlorite±pyrite alteration and small mm- to cm-scale veinlets of quartz-sericite±chlorite±pyrite±sphalerite. This suggests a pre- to syn-mineralization timing for the emplacement of the intrusions. The contribution of these intrusions to the heat and metal budget of the Wolverine deposit is the focus of ongoing research.

RÉSUMÉ

Un projet a été entrepris au cours de la saison des travaux de terrain de l'an 2000 afin d'étudier les caractéristiques géologiques, géochimiques et d'altération des intrusions subvolcaniques porphyriques présentes dans la partie supérieure du gisement de sulfure massif encaissé dans des roches volcaniques de Wolverine. Dans ce gisement, les intrusions porphyriques subvolcaniques se trouvent dans quatre zones (Wolverine/Lynx, Fisher, Sable et Puck), à environ 10 à 20 m en moyenne sous les sulfures exhalatifs ou les formations de fer. La plupart de ces intrusions sont composées de porphyres à feldspath potassique (zones de Fisher et de Wolverine/Lynx), bien que quelques-unes soient formées de porphyres à quartz et feldspath potassique (zones de Puck et de Sable). Les intrusions de feldspath porphyrique renferment des grains de feldspath potassique automorphes à hypidiomorphes enrobés dans une matrice grise à grain fin. Les intrusions quartzo-feldspathiques porphyriques contiennent des cristaux de feldspath légèrement plus petits et du quartz oeilé vitreux de couleur bleu à noir englobé par une matrice à grain fin. La plupart des intrusions sont entourées dans leur partie supérieure de bordures dépourvues de péperite et renfermant des argilites carbonacées (zones de Wolverine/Lynx, Fisher et Puck). Cependant, certaines intrusions quartzo-feldspathiques porphyriques se trouvent en contact avec des roches sédimentaires volcanoclastiques à grain fin le long de leurs bordures supérieures (zone de Sable). Les deux types d'intrusions sont en contact, dans leur partie inférieure, avec des roches sédimentaires volcanoclastiques à grain fins. Bon nombre de ces intrusions ne sont pas altérées et n'ont été l'objet que d'une légère altération en séricite-silice±chlorite±pyrite; elles ne contiennent que de petites veinules millimétriques à centimétriques de quartz-séricite±chlorite±pyrite±sphalérite. Ces caractéristiques permettent de supposer que les intrusions ont été formées avant ou pendant la minéralisation. Le rôle relatif que celles-ci ont joué dans le bilan calorifique et métallique du gisement de Wolverine est l'objet principal des recherches en cours.

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INTRODUCTION

Numerous workers have suggested that subvolcanic intrusions play a critical role in the generation and maintenance of hydrothermal systems responsible for the formation of volcanic-hosted massive sulphide (VHMS) deposits (Campbell et al., 1981; Cathles, 1981, 1983; Leshner et al., 1986; Galley, 1996; Large et al., 1996; Barrie et al., 1999). Most workers suggest that these high-level subvolcanic intrusions provide the heat for generating and maintaining hydrothermal systems (Campbell et al., 1981; Galley, 1996; Barrie et al., 1999), and some workers also suggest that these intrusions may contribute metals to the hydrothermal system (Large et al., 1996).

As part of the Ancient Pacific Margin NATMAP project (Thompson et al., 2000) and the Finlayson Lake Project, funded under the proposal approval system of GSC (Project PAS1017), the authors have undertaken a study of subvolcanic intrusive rocks in the Finlayson Lake district (FLD), southeast Yukon. Within the Wolverine VHMS deposit, high-level subvolcanic porphyritic intrusions are spatially associated with massive sulphide mineralization in many areas. Herein we provide field and petrographic observations of these high-level subvolcanic porphyritic intrusions. This paper is a companion to a more extensive study of the genesis and setting of the Wolverine VHMS deposit (Bradshaw et al., this volume) and on chemical sedimentary (exhalative) rocks associated with this deposit (Peter et al., in prep.).

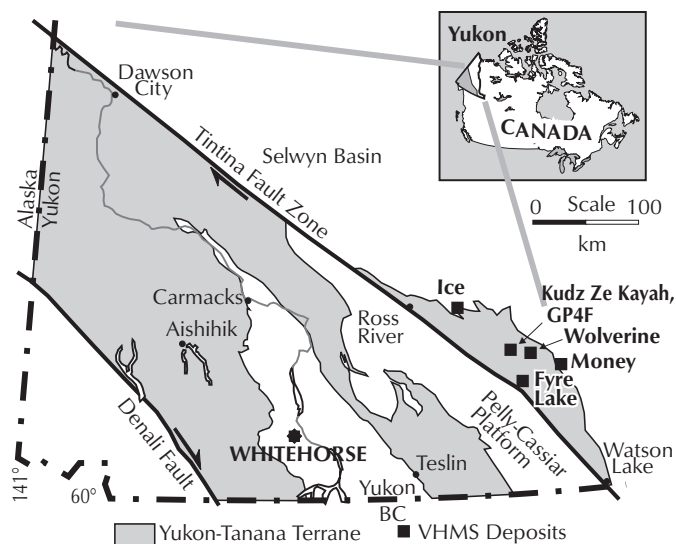


Figure 1. Geological setting and distribution of the Yukon-Tanana Terrane in the Yukon, and the location of the study area with respect to the Finlayson Lake region. Map modified from Hunt (1998).

REGIONAL SETTING

The Finlayson Lake VHMS district (Figs. 1 and 2) is hosted by variably deformed and metamorphosed (greenschist to lower amphibolite facies) Devonian-Mississippian volcanic, intrusive and sedimentary rocks of the Yukon-Tanana Terrane (Tempelman-Kluit, 1979; Mortensen and Jilson, 1985; Mortensen, 1992; Murphy and Timmerman, 1997; Murphy, 1998; Murphy and Piercey, 1999a,b,c, 2000; Piercey and Murphy, 2000; Murphy, this volume). Although the rocks are metamorphosed, most rocks have discernable primary features and, where applicable, the prefix 'meta-' is used in the following text for ease of reading. Murphy and co-workers (*op. cit.*) have broken the volcanic, intrusive, and sedimentary rocks of the district into three stratigraphic successions (Grass Lakes, Wolverine Lake, and Campbell Range successions), which have been formed on a substrate of non-carbonaceous, biotite-rich clastic metasedimentary rocks and associated metacarbonates and marble (unit 1; Fig. 2).

The base of the Grass Lakes succession, unit 1 (metaclastic rocks), is overlain by rocks of the Fyre Lake unit (unit 2), which consist of a Devonian-Mississippian (~365-360 Ma; Mortensen, 1992; Mortensen and Murphy, unpublished data) package of mafic volcanic and intrusive rocks, with lesser felsic volcanic and sedimentary rocks (Fig. 2). These rocks are interpreted to represent arc magmatic activity that progressed to back-arc basin formation (Grant, 1997; Sebert and Hunt, 1999; Piercey et al., 1999, 2000a). Boninitic volcanic rocks within this package host the Besshi-style Cu-Co-Au VHMS deposits (Foreman, 1998; Sebert and Hunt, 1999).

The Kudz Ze Kayah unit (unit 3) stratigraphically overlies the Fyre Lake unit and is a ~360 Ma felsic-volcanic and sedimentary rock dominated unit with lesser mafic volcanic and intrusive rocks and felsic intrusive rocks (Grass Lakes suite intrusions; Fig. 2). These rocks host the felsic-volcanic-associated Zn-Pb-Cu Kudz Ze Kayah and Zn-Pb GP4F VHMS deposits and are interpreted to represent an Okinawa Trough-style ensialic back-arc basin (Piercey et al., 2000a).

The Wolverine succession unconformably overlies the Grass Lakes succession and consists of a lower package (unit 5l) of quartz-feldspar pebble conglomerate, overlain by ~345 Ma (Piercey, unpublished data) rhyolitic flows, volcaniclastic rocks, quartz-feldspar bearing volcaniclastic and epiclastic sedimentary rocks, and high-level feldspar± quartz porphyritic rhyolitic intrusive rocks (unit 5f/qfp; Fig. 2). This felsic-dominated package is overlain by unit

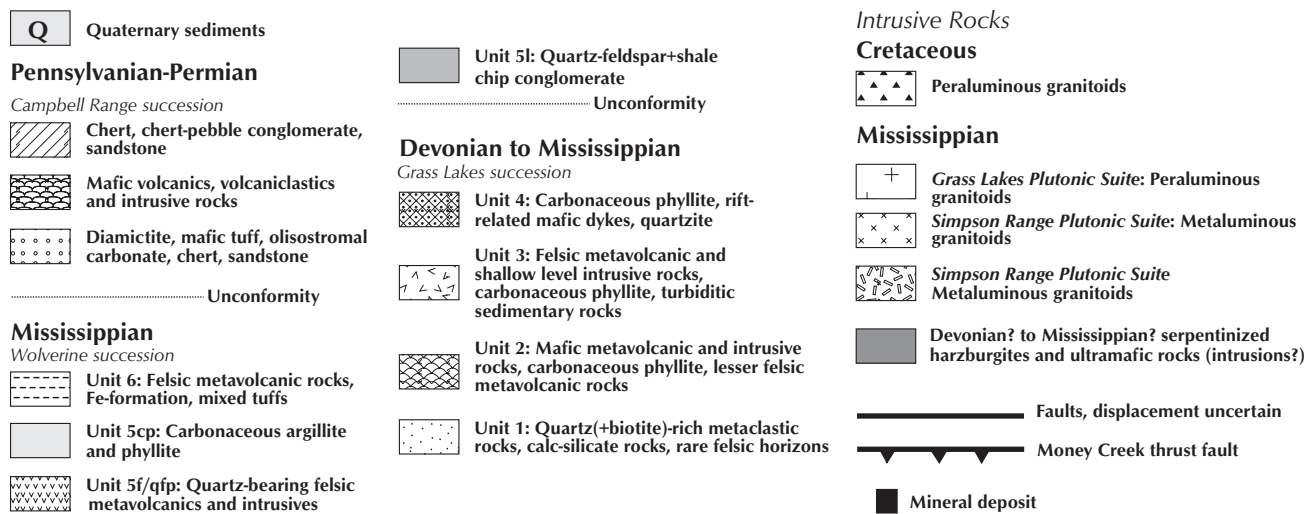
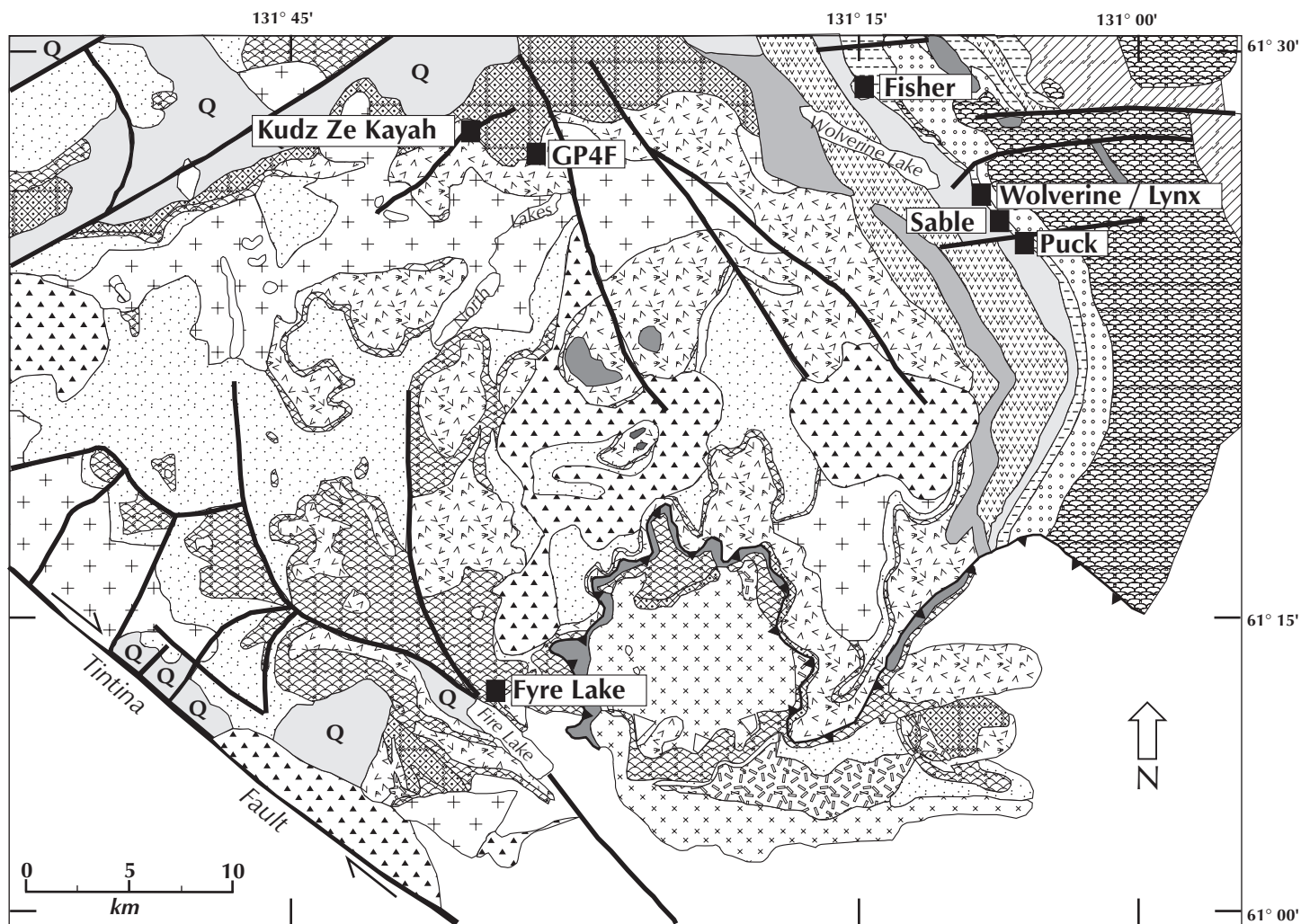


Figure 2. Geological map of the Finlayson Lake region modified from Murphy (1998) and Piercey et al. (1999) with locations of different zones of the Wolverine VHMS deposit and other VHMS deposits of the Finlayson Lake district.

5cp, carbonaceous argillite and quartzite of regional extent, which forms part of the deeper footwall of the Wolverine deposit (Tucker et al., 1997; Bradshaw et al., this volume; Fig. 2). The Wolverine deposit is hosted by unit 6, which consists of rhyolitic volcanoclastic and epiclastic rocks, high-level rhyolitic intrusive rocks and flows, variably carbonaceous sedimentary rocks, and is capped by interlayered felsic and mafic volcanoclastic and basaltic lava flows (cf. Bradshaw et al., this volume;

Figs. 2-4). Geochemical compositions of the felsic volcanic rocks in the Wolverine succession suggest that the rocks formed within an ensialic back-arc basin setting, akin to that of the Grass Lakes succession (Piercey et al., 2000a,b).

Capping the entire Finlayson Lake district, and unconformably overlying the rocks of the Wolverine succession, are Pennsylvanian-Permian (T. Harms, *in*: Plint and Gordon, 1997, p. 124) rocks of the Campbell Range

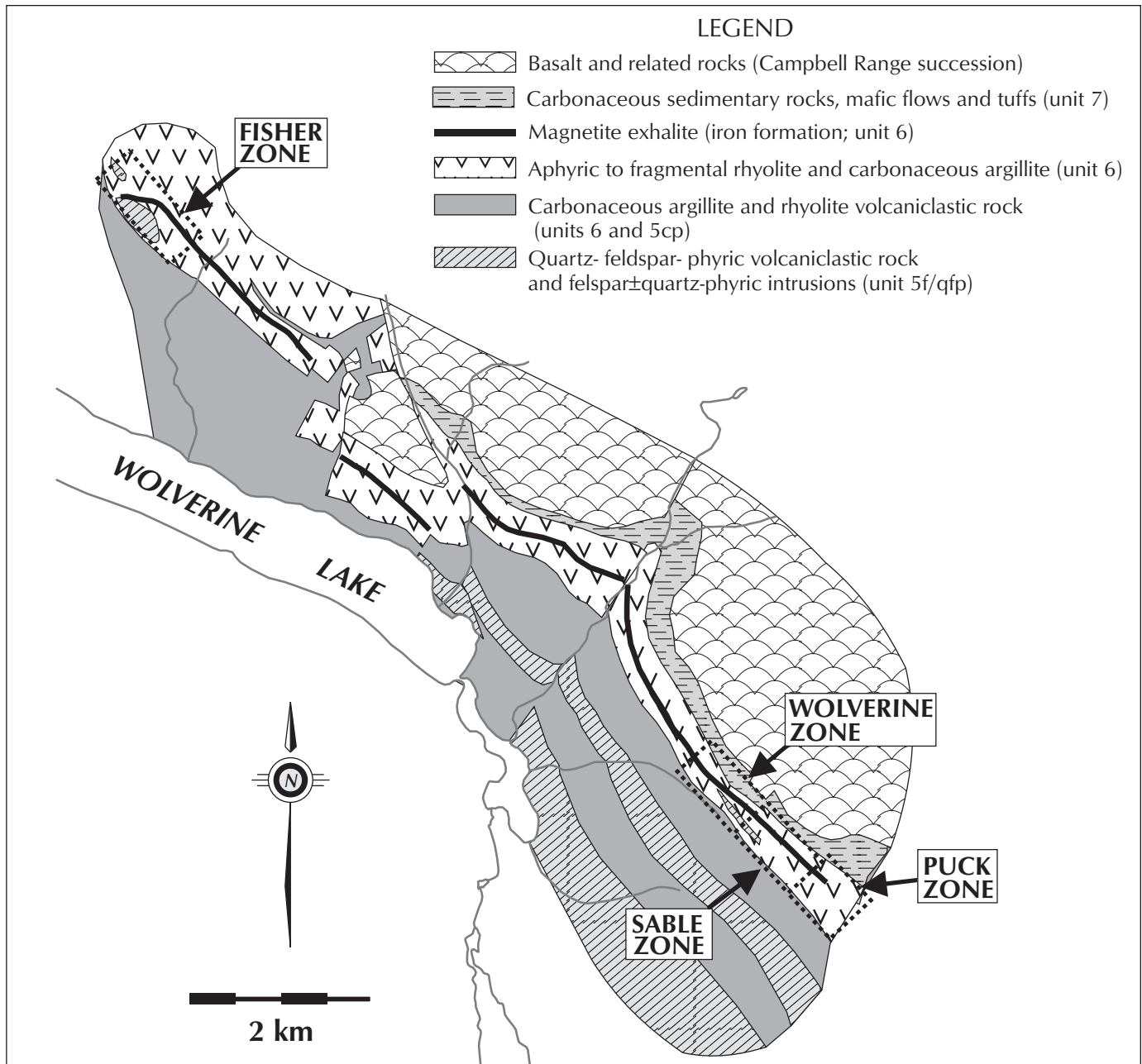


Figure 3. Geological map of Wolverine VHMS deposit area. Numbers of units in the map legend are from Murphy and Piercey (1998); CRS = Campbell Range succession. Map modified after Westmin Resources and Atna Resources (unpublished).

succession (cf. Murphy, this volume; Fig. 2). This succession consists of largely clastic sedimentary rocks, pillowed to massive mafic lava flows, high-level diabase intrusive rocks, leucogabbroic intrusive rocks of MORB chemistry and chert-rich sedimentary rocks, that host numerous Cyprus-style VHMS occurrences (Mann and Mortensen, 2000; M. Baknes, *in*: Hunt, 1997; Pigage, 1997). Plint and Gordon (1997) and Murphy and Piercey (1999a,b,c) give more detailed descriptions of the geology of the Campbell Range succession.

GEOLOGICAL FEATURES OF PORPHYRIES ASSOCIATED WITH THE WOLVERINE VHMS DEPOSIT

Within the Wolverine VHMS deposit area, most intrusions are K-feldspar porphyritic and only a few are quartz-feldspar porphyritic. In all cases the intrusions are spatially associated with, and underlie, massive sulphide mineralization or iron formation (Wolverine/Lynx, Fisher, Sable and Puck zones; Fig. 3). Notably, to date significant massive sulphide accumulations have only been delineated in the Wolverine/Lynx zone; however, all zones contain iron formation and carbonate exhalite suggesting that they are part of the same hydrothermal system. The zones discussed in this paper are treated as representing parts of the same system and are

distinguished partly on the geographic distribution of diamond drill holes outlined during exploration and delineation of the Wolverine VHMS system. Outlined below are the geological attributes of porphyritic intrusions within the four zones of the Wolverine VHMS system (cf. Fig. 3). Salient geological features of the intrusions are given in Table 1.

WOLVERINE/LYNX ZONE

Porphyritic intrusions associated with the Wolverine/Lynx zones and the Wolverine deposit are sill-like feldspar porphyritic intrusions (FPI; Fig. 4) with euhedral to subhedral 0.1-1 cm K-feldspar phenocrysts in a grey, siliceous fine-grained matrix; the phenocrysts comprise ~20% of the rock on average (Fig. 5). The upper contacts of intrusions are against black carbonaceous argillite, and for the most part are sheared due to Cretaceous deformation (cf. Murphy, 1998). Where the contacts are not sheared, the intrusions do not exhibit peperitic margins indicating they had minimal interaction with wet, unconsolidated sedimentary rocks. The lower margins of the intrusions are in contact with fine-grained, variably crystal-rich, felsic volcanoclastic rocks (tuffs). Most of the intrusions are sill-like in morphology (Fig. 4), ranging in true thickness from ~1 to 14 m, with an average thickness of ~7.5 m. These intrusions are located on average 20 m

Table 1. Outline of the salient geological features of porphyritic intrusions from different zones within the Wolverine VHMS system. Descriptions are outlined in zones from northwest to southeast.

Zone	Fisher	Wolverine / Lynx	Sable	Puck
Intrusion Type ¹	FPI	FPI	QFP	FPI + QFP
Massive Sulphide?	minor	abundant	minor	minor
Exhalites	yes	yes	yes	yes
Upper Contacts	argillite and silicified argillite; partly sheared	argillite and silicified argillite; partly sheared	fine-grained felsic vol-aniclastic	FPI: siliceous to weakly siliceous argillite; QFP: argillite
Lower Contacts	med-fine grained felsic volcanoclastic	fine-grained felsic volcanoclastic ± argillite	fine-grained felsic volcanoclastic	fine-grained felsic volcanoclastic argillite
Alteration ²	veinlets of py-ser-qtz ± chl; secondary black K-fsp	veinlets of py-ser-qtz ± chl; secondary black K-fsp	veinlets of py-ser-qtz -sph	veinlets of py-ser; py replacement in K-fsp; secondary black K-fsp
Notes				
¹ FPI - feldspar porphyritic intrusion, QFP - quartz-feldspar porphyritic intrusion				
² py - pyrite; ser - sericite; qtz - quartz; chl - chlorite; sph - sphalerite; fsp - feldspar				

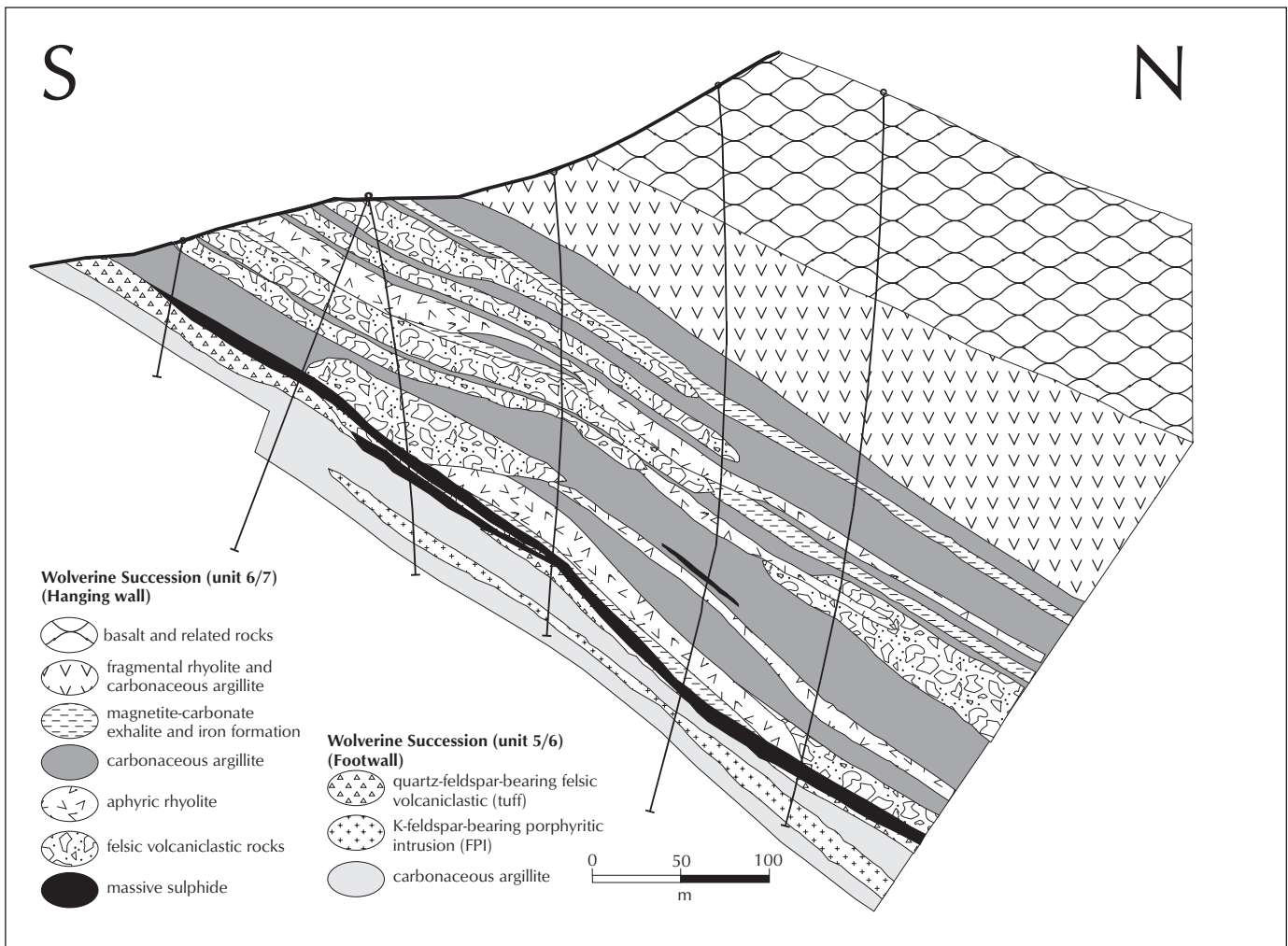


Figure 4. Cross-section of 16250E of the Wolverine VHMS deposit, with outline of the size, shape and distribution of porphyritic intrusions within the Wolverine/Lynx zone and their relationship to massive sulphide mineralization and iron formation/carbonate exhalite. The sill-like morphology of the intrusions is typical of intrusions in all zones within the Wolverine VHMS deposit area. Figure modified after Bradshaw et al. (this volume). Abbreviations: Qtz – quartz; fsp – feldspar.

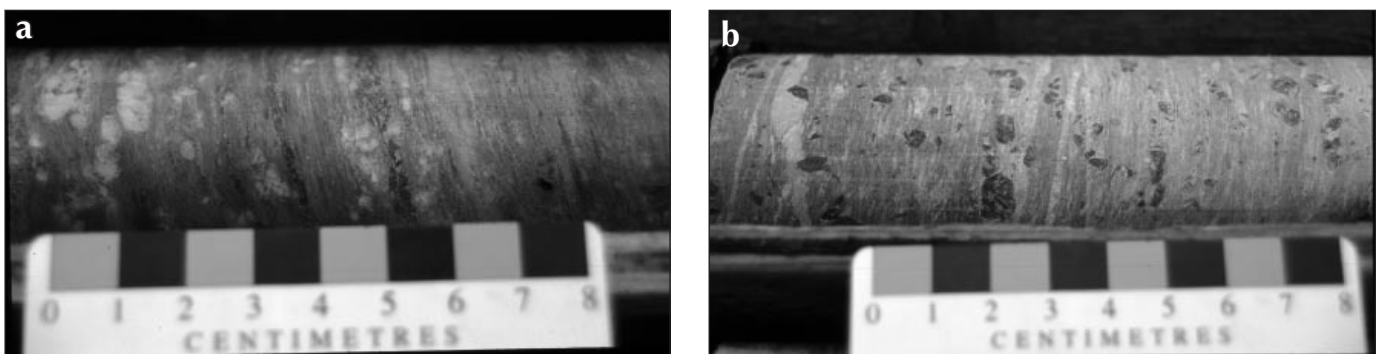


Figure 5. a. Feldspar porphyritic intrusions from the Wolverine/Lynx zone with subhedral K-feldspar grains in a siliceous matrix. Note the dark grey to black crosscutting quartz-sulphide-sericite veinlets; b. partial to fully replaced K-feldspar grains with secondary black K-feldspar.

below the massive sulphide mineralization in the Wolverine/Lynx zones (cf. Bradshaw et al., this volume).

The feldspar porphyritic intrusions of the Wolverine/Lynx zone are unaltered to weakly altered. The most common type of alteration within the FPI consists of a patchy distribution of partial to complete replacement of K-feldspar by grey to black secondary K-feldspar (as identified by X-ray diffraction at the Geological Survey of Canada; Fig. 5b). Within the porphyries veinlet-style alteration is less common than secondary K-feldspar. It consists of millimetre-scale veinlets of weak fine-grained sericite and quartz (Fig. 5a). Pyrite-quartz and pyrite-quartz-sericite veinlets commonly crosscut many of the samples; in a few samples chlorite-pyrite-quartz veinlets are present (e.g., Fig. 5a). The intensity of veinlet-style alteration commonly decreases with distance from the upper and lower contacts.

FISHER ZONE

The porphyritic intrusions of the Fisher zone have strong petrographic similarities to those from the Wolverine/Lynx zone. The intrusions are mostly feldspar porphyritic intrusions with some portions having minor quartz (QFP). Euhedral to weakly subhedral 0.1-1 cm K-feldspar phenocrysts make up ~20% of the rock within a grey fine-grained matrix (Fig. 6). Some QFP have 1-2 mm, quartz-filled amygdules. In one drill hole the edges of the FPI have rhyolite extrusive characteristics with autobrecciated rhyolite fragments and a less feldspar-porphyric margin that grades inward into a more feldspar-rich interior, suggesting rapid quenching of the margin and slower cooling of the interior. As with intrusions associated with the Wolverine/Lynx zone, the Fisher zone intrusions appear to be at the same stratigraphic level



Figure 6. Unaltered to weakly altered feldspar porphyritic intrusion from the Fisher zone with black to grey quartz-sericite-chlorite-sulphide veinlets cutting across it.

having upper contacts with black argillite that lack peperitic textures; and the lower contacts are against fine-grained felsic volcanoclastic rocks (tuffs?). The average thickness of the intrusion varies from 1 m to ~50 m; however, there may have been considerable structural thickening within the nose of a Cretaceous fold (cf. Murphy, 1998); primary interpreted thicknesses are estimated to vary from ~1 to 14 m. The feldspar porphyritic intrusions from the Fisher zone are not associated with significant amounts of massive sulphide mineralization; however, they lie at a similar stratigraphic level, and are overlain by minor disseminated sulphide and iron-formation (cf. Peter et al., in prep.), inferring a correlation with the Wolverine/Lynx zone intrusions.

The Fisher zone intrusions are relatively unaltered. Partial to complete replacement and patchy overprinting of feldspars by black, secondary K-feldspar is the prevalent type of alteration. The Fisher zone intrusions also contain minor veinlet-style alteration. This veinlet-style alteration consists of 1- to 7-mm-wide veins of pyrite-sericite-quartz \pm chlorite and is very similar to that in the Wolverine/Lynx zone, with a similar spatial distribution displayed in some diamond drill holes (Fig. 6).

SABLE ZONE

The Sable zone intrusions differ significantly from the Wolverine/Lynx and Fisher zone intrusions. All of the Sable zone intrusions are quartz-feldspar-porphyrific intrusions (QFP) with quartz and K-feldspar phenocrysts comprising ~20-30% of the rock within a grey to weak grey-green, fine-grained matrix (Fig. 7). Quartz phenocrysts are dark grey to black, glassy, eye-shaped, and 0.1-0.5 cm in diameter (Fig. 7). Potassic feldspar phenocrysts are less abundant than quartz phenocrysts and comprise ~5-10% of the rock as euhedral grains 0.1-0.5 cm in diameter (Fig. 7). The QFP have non-peperitic upper and lower contacts with fine-grained felsic volcanoclastic rocks. Intrusions within the Sable zone are 2-16 m thick and lie below minor amounts (~30 cm) of massive sulphide, which in turn are overlain by exhalative iron formation, similar to the other zones (cf. Peter et al., in prep.). However, given their distinctive petrographic characteristics and stratigraphic position these intrusions are not likely correlative to those in the Wolverine/Lynx and Fisher zones.

Only veinlet-style alteration is present in the Sable zone QFP and it is associated with 1- to 4-mm-wide veinlets of sericite-pyrite, pyrite-quartz \pm fine-grained sphalerite, and

pyrite-sphalerite. In some samples sulphide veinlets constitute 5-10% of the rock.

PUCK ZONE

Both quartz-feldspar and feldspar-porphyrific intrusions are present in the Puck zone. Feldspar porphyritic intrusions are present in 2 drill holes and are similar to those in the Wolverine/Lynx and Fisher zones. These intrusions are 0.5-3.5 m thick and consist of euhedral, 0.1-2 cm diameter K-feldspar phenocrysts within a grey, fine-grained matrix (Fig. 8). The Puck feldspar porphyritic intrusions have non-pepperitic upper contacts with black argillite and lower contacts against fine-grained felsic volcanoclastic rocks, akin to feldspar porphyritic intrusions in other zones. A 25-m-thick QFP occurs in one drill hole and consists of 3-4 mm elliptical-shaped blue quartz and euhedral K-feldspar in a siliceous grey matrix. Upper and lower contacts of the QFP are similar to those of the feldspar-porphyrific intrusions. Both QFP and feldspar porphyritic intrusions are stratigraphically overlain by minor massive sulphide mineralization and iron formation (cf. Peter et al., in prep.), inferring a possible correlation to intrusions within the Wolverine/Lynx and Fisher zones.

Similar to intrusions in other zones, the alteration intensity is weak. Feldspar-porphyrific intrusions have some fine

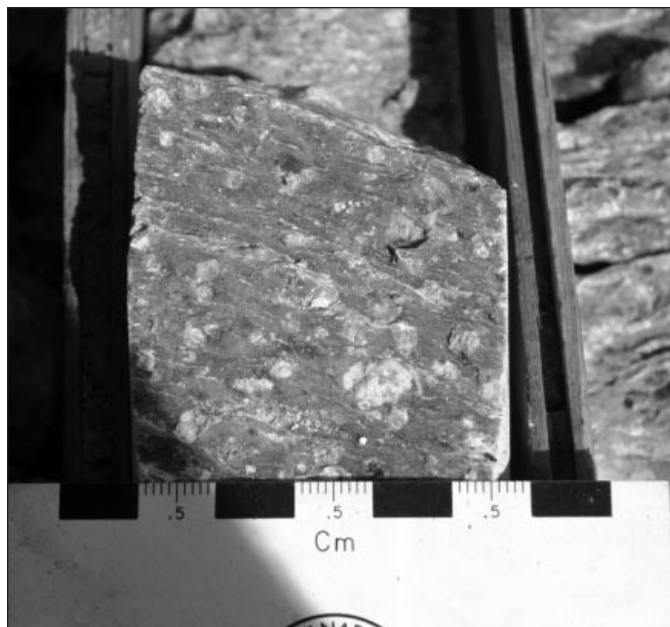


Figure 7. Sable zone quartz-feldspar porphyritic intrusion with darker grey quartz eyes and lighter grey K-feldspar. Note the smaller size of feldspar grains as compared to the Wolverine/Lynx and Fisher zones (Fig. 5).

sericite-pyrite veins and notably the K-feldspar phenocrysts are partially to completely replaced by patchy secondary K-feldspar (Fig. 8). The QFP have minor disseminated pyrite throughout and some of the feldspars are incipiently replaced by pyrite. Both intrusion types have low-level alteration and mineralization.

DISCUSSION

The spatial proximity of high-level subvolcanic intrusions to massive sulphide mineralization and iron formation within the Wolverine VHMS deposit points to a passive (to possibly active) role of these intrusions in the genesis and localization of the Wolverine VHMS deposit. The following discussion will briefly address two questions, namely: 1) Are the porphyritic intrusions pre-, syn- or post-mineralization?; and 2) What is the significance of the porphyritic intrusions to the localization of sulphide mineralization?

PRE-, SYN- OR POST-MINERALIZATION EMPLACEMENT OF THE PORPHYRIES

The close spatial association of the porphyritic intrusions to massive sulphide mineralization and iron formation within the Wolverine deposit raises the question of whether the intrusions are of syn-, post- or pre-hydrothermal origin. Some possible evidence for a post-mineralization origin for the porphyritic intrusions is their non-pepperitic upper margins and lack of other evidence for interaction with wet unconsolidated material (e.g., modification of bedding, etc.). This would suggest emplacement into solidified material and a likely non-



Figure 8. Puck zone feldspar porphyritic intrusion with variably broken K-feldspar grains with partial replacement by secondary K-feldspar.

syn-volcanic/syn-sedimentary and post-hydrothermal origin. It is notable, however, that many of the contacts between the intrusions and overlying argillites are sheared due to Cretaceous deformation, and much of the evidence for intrusion-sediment interaction may have been removed or obscured. Further evidence for a post-hydrothermal origin is quite strong. Firstly, the intrusive rocks within the deposit only occur stratigraphically below the massive sulphide mineralization or iron formation. Although this does not necessarily prove that they are not post-mineralization, the presence of interpreted VHMS-related alteration of the intrusions (e.g., sericite-chlorite-quartz veinlets), and crosscutting sulphide-bearing veinlets in the intrusions suggest that they were not emplaced after hydrothermal activity.

Determining the syn- or pre-mineralization timing of intrusion is less clear. A pre-mineralization origin is compatible with the presence of hydrothermal alteration and crosscutting sulphide veining. For example, the intrusions may have been emplaced prior to generation of the VHMS system and then subsequently altered as hydrothermal activity commenced to generate the Wolverine deposit and related iron formations. Similarly, geological evidence for a syn-mineralization history (syn-sedimentary/syn-volcanic in origin) for the intrusions (e.g., peperites, contorted bedding) is lacking and, at present, most evidence points to a pre-mineralization origin. Nevertheless, the spatial association of these intrusions to VHMS mineralization is significant (see below) and further facies mapping of the intrusion-sediment contacts is required to test the syn- versus pre-mineralization origin of these intrusions.

SIGNIFICANCE OF PORPHYRIES FOR LOCALIZATION OF SULPHIDE MINERALIZATION

The presence of porphyritic intrusions proximal to (~10-20 m below) the Wolverine VHMS deposit and iron-formation/exhalites is significant from a regional perspective. There are high-level intrusions outside of the Wolverine succession (e.g., Murphy and Piercey, 1999a); however, they are not as volumetrically condensed and are more regionally dispersed when compared to those proximal to the Wolverine VHMS system. The presence of these coherent magmatic rocks (i.e., flows and intrusions, not volcanoclastic or epiclastic) close to exhalative activity, and their relatively minor abundance elsewhere in the Wolverine succession, suggests that unique conditions prevailed proximal to the Wolverine deposit area that

controlled the emplacement of these rocks. The authors suggest that the presence of coherent volcanic facies in the Wolverine deposit was likely controlled by synvolcanic structures (growth faults?). Furthermore, the structures that controlled the intrusion emplacement were also likely responsible for controlling the hydrothermal fluids that formed the Wolverine deposit and related exhalites. It is also notable that coherent aphyric rhyolitic flows (Fig. 4) that overlie the Wolverine massive sulphides are also restricted to the area proximal to the Wolverine deposit and have not been recognized, thus far, elsewhere in the district. It is possible that coherent facies (i.e., not volcanoclastic or epiclastic) felsic volcanic rocks may reflect proximity to volcanic vents and through-going structural conduits that allowed their emplacement. The authors acknowledge, however, that they have not yet documented facies changes, thickness variations or syn-volcanic dyking to support the proximity of the intrusions to syn-volcanic faults. Further mapping of thickness variations, and volcanic facies associated with the intrusions and coherent facies rocks is required to test this syn-volcanic-emplacement hypothesis.

The proximity of these intrusions to massive sulphide mineralization also suggests that they were possible heat and/or metal sources. The authors are presently unable to address whether these intrusions were the sources of metals and further data is required; however, some insight can be provided into the possibility of these intrusions as heat sources for hydrothermal circulation that formed the Wolverine deposit. When compared to many subvolcanic intrusive rocks in world-class VHMS districts (e.g., Flavrian-Noranda; Biedelman Bay-Mattabi; Cambrian granites-Mount Read; cf. Galley, 1996; Large et al., 1996), which are considered to be the heat and/or metal source for VHMS mineralization, the intrusions that constitute the footwall of the Wolverine system are volumetrically minor (i.e., 10s of m² rather than 10s of km²). Therefore, the authors suggest that these intrusions alone are of insufficient size (see Fig. 4 as compared to Cathles, 1981, 1983; Barrie et al., 1999) to be the sole thermal control on the generation and maintenance of the hydrothermal system responsible for the Wolverine deposit. What the intrusions likely reflect, however, are 'leaks' from a larger underlying intrusive system that has yet to be identified that may have driven hydrothermal circulation. It is possible that a subvolcanic intrusive system akin to the Grass Lakes suite intrusions in the Kudz Ze Kayah unit underlies the Wolverine succession. However, the Wolverine succession has not been uplifted significantly, unlike the Kudz Ze Kayah unit and Grass Lakes succession

(cf. Murphy and Piercey, 1999a). The lack of uplift may have prevented the surface expression of a deeper intrusive system to the Wolverine succession.

SUMMARY AND CONCLUSIONS

Initial results from our study of high-level subvolcanic porphyritic intrusions within the Wolverine VHMS deposit show that footwall intrusions are largely K-feldspar porphyritic with lesser quartz- and K-feldsparporphyritic intrusions. Most of the intrusions have non-peperitic upper margins against carbonaceous argillite (Wolverine/Lynx, Fisher, Puck); however, some of the QFP intrusions have upper margins in contact with fine-grained volcanoclastic rocks (Sable); both have lower margins in contact with fine-grained volcanoclastic sedimentary rocks. These intrusions are located at variable distances (~10-20 m) below exhalative sulphide bodies or iron formation. For the most part, the intrusions are unaltered to weakly altered having sericite-quartz±chlorite±pyrite alteration and small mm- to cm-scale veinlets of quartz-sericite±chlorite±pyrite±sphalerite. The presence of alteration and mineralization within the intrusions suggests a pre- to syn-mineralization timing for their emplacement. The large number of coherent intrusive rocks proximal to the Wolverine deposit, and their relative scarcity elsewhere in the district, suggests that the emplacement of these intrusions may have been controlled by synvolcanic faults, which themselves controlled hydrothermal fluid flow. Although abundant, the volume of the intrusions is quite small (10s of m²), and the authors suggest that the size of these intrusions was insufficient to have generated the hydrothermal fluid flux required to form the Wolverine deposit. However, the intrusions may represent 'leaks' (or apophyses?) from a larger intrusive system at depth that may have controlled the hydrothermal budget of the Wolverine deposit. The authors are presently uncertain of the role the intrusions have played in the metal budget of the Wolverine deposit, and this is the focus of ongoing research.

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