Geoscience BC

Geological Setting of Volcanogenic Massive Sulphide Occurrences in the Middle Paleozoic Sicker Group of the Cowichan Lake Uplift, Port Alberni Area, Southern Vancouver Island, British Columbia (NTS 092F/02, /07)

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Ruks, T. and Mortensen, J.K. (2008): Geological setting of volcanogenic massive sulphide occurrences in the Middle Paleozoic Sicker Group of the Cowichan Lake uplift, Port Alberni area (NTS 092F/02, /07), southern Vancouver Island, British Columbia; *in* Geoscience BC Summary of Activities 2007, Geoscience BC, Report 2008-1, p. 77–92.

Introduction

Volcanogenic strata of the mid-Paleozoic Sicker Group on Vancouver Island (Figure 1) occur in several distinct basement highs (referred to as 'uplifts' herein). These rocks host the world-class Myra Falls volcanogenic massive sulphide (VMS) deposit (combined production and proven and probable reserves in excess of 30 million tonnes of Zn-Cu-(Au-Ag) ore), as well as numerous other VMS deposits and occurrences, especially in the Big Sicker Mountain area in the southeastern part of the Cowichan Lake uplift (Figure 1). Three of these deposits, the Lenora, Tyee and Richard III (MINFILE occurrences 092B 001, 002, 003) have seen limited historical production, and the Lara deposit (MINFILE occurrence 092B 129), farther to the northwest, also contains a significant drill-indicated resource. Geological mapping (Massey and Friday, 1987; Mortensen, 2005; Ruks and Mortensen, 2006) suggests that the geology of the Mount Sicker area consists mainly of deformed mafic to felsic volcanic and volcaniclastic rocks of the Nitinat and McLaughlin Ridge formations, and high-level intrusions of the Saltspring intrusive suite, as well as abundant gabbroic dikes and sills of the Triassic Mount Hall gabbro.

Geological mapping in the Cowichan Lake uplift of the Port Alberni area (Massey and Friday, 1989) indicates that this area is largely underlain by basalt to basaltic-andesite volcanic rocks of the Duck Lake and Nitinat formations, respectively, in addition to felsic tuffaceous volcaniclastic rocks belonging to the McLaughlin Ridge Formation. The nature of the McLaughlin Ridge Formation rocks in the Port Alberni area is interpreted to represent deposition distal from a volcanic centre, which is thought to be represented in the Saltspring Island–Cowichan Lake area by felsic intrusive rocks of the Saltspring intrusive suite (Massey and Friday, 1989).

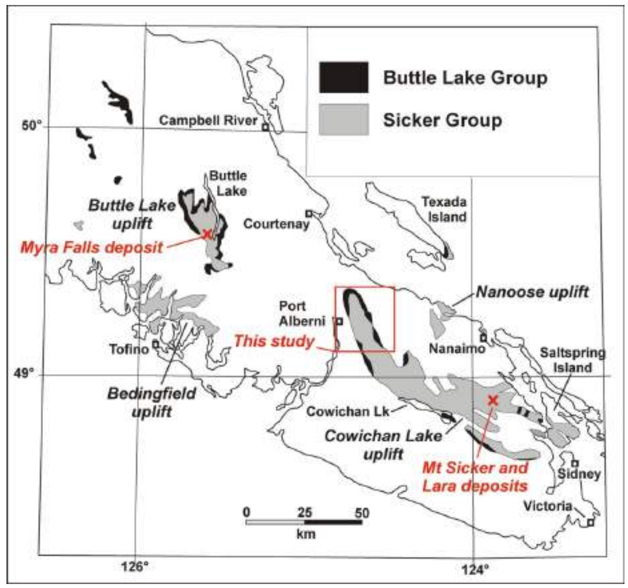

Figure 1. Distribution of Paleozoic strata of the Sicker and Buttle Lake groups on Vancouver Island and the Gulf Islands.

The Debbie 3 VMS occurrence is hosted by Sicker Group rocks of the Port Alberni area (MINFILE occurrence 092F 445) but, unlike the majority of VMS occurrences in the Sicker Group, is not associated with felsic volcanic rocks of the McLaughlin Ridge Formation. Instead, the occurrence is interpreted to be hosted by mafic volcanic rocks of the underlying Duck Lake and Nitinat formations and may therefore represent the oldest known VMS mineralization in the Sicker Group.

Abundant iron formations that may be exhalitive in origin are also present in Sicker Group rocks of the Port Alberni area (e.g., the Lacy Lake and Esary Lake showings; MINFILE occurrences 092F 245 and 244, respectively). These iron formations are similar to those occurring in

Keywords: Sicker Group, Paleozoic, Vancouver Island, Cowichan Lake uplift, VMS deposit, stratigraphy, U-Pb zircon geochronology, lithogeochemistry

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rocks that are stratigraphically above VMS mineralization at the Myra Falls, Lara, Lenora, Tyee and Richard III occurrences, and are believed to represent oxide-facies iron mineralization related to hydrothermal mineralizing systems similar to those that formed the underlying VMS deposits. As with the Debbie 3 VMS occurrence, however, the iron formations of the Port Alberni area are underlain by mafic volcanic rocks of the Duck Lake or Nitinat formations.

If the Debbie 3 VMS occurrence is indeed the same age as the potential VMS-related exhalitive iron formations in the same general area, this makes the Port Alberni area, specifically where it is underlain by rocks of the Nitinat and Duck Lake formations, significantly more prospective for VMS mineralization than was previously appreciated. Logging activity in the area over the past decade has provided abundant new outcrops and greatly improved access, and has prompted a re-examination of the geological setting of VMS mineralization and of the potential for new discoveries in this area.

Both reconnaissance and detailed geological mapping, together with sampling for lithogeochemistry, U-Pb zircon dating, and Nd, Hf and Pb isotopic studies, were conducted over a 20-day period in the Port Alberni area in October 2007. This work was concentrated in the vicinity of the Debbie 3 VMS occurrence and the area of potentially correlative exhalitive iron formations to the west. This report presents a preliminary version of revised geological mapping in this area, with emphasis on understanding the geology in the vicinity of the Debbie 3 VMS occurrence and the potentially correlative Lacy and Esary Lake exhalitive iron formations.

Regional Geology of the Sicker Group

The mid-Paleozoic Sicker Group on southern and central Vancouver Island represents the stratigraphically lowest portion of the Wrangellia Terrane. Equivalents of the Sicker Group are not present in Wrangellia in northwestern British Columbia, southwestern Yukon and southern Alaska, where the oldest rock units are the Skolai Group, which is no older than Pennsylvanian (e.g., Katvala, 2006). This, and other differences between the Wrangellian stratigraphy on Vancouver Island and that in more northerly exposures, emphasizes the lack of understanding regarding much of Wrangellia (e.g., Katvala, 2006) and the need for further studies. The Cowichan Lake uplift on Vancouver Island and adjacent portions of the Gulf Islands, which is the main focus of this study, is the largest of four uplifts that expose the Sicker and overlying late Paleozoic Buttle Lake groups (Figure 1).

Previous detailed studies of the Sicker Group have focused mainly on the stratigraphic setting of VMS mineralization at the Myra Falls deposits in the Buttle Lake uplift (Figure 1; e.g., Juras, 1987; Barrett and Sherlock, 1996). Regional mapping of the Cowichan Lake uplift by Massey and Friday (1987, 1989) and Yorath et al. (1999) led to an interpreted stratigraphic framework that may be applicable to the entire Sicker Group (Figure 2). This stratigraphic framework, however, is based on mapping in only one of the four main uplifts of Sicker Group rocks, and is supported by a very limited amount of biostratigraphic and isotopic age data (e.g., Brandon et al., 1986). Major along- and across-strike facies changes and geochemical variations are to be expected in submarine volcanic sequences such as the one that forms the Sicker Group; hence, the regional applicability of the proposed stratigraphic framework of Yorath et al. (1999) must be tested with detailed mapping and subsequent lithogeochemical and U-Pb dating studies. This is critical for regional exploration for VMS deposits within the Sicker Group. For example, the questions of whether VMS deposits and occurrences in the Cowichan Lake uplift are all of the same age, and whether their hostrocks are directly correlative with those that host the Myra Falls deposit, are of obvious importance.

The Sicker Group within the Cowichan Lake uplift is presently interpreted to represent three distinct and regionally mappable volcanic and volcaniclastic assemblages that together are thought to record the evolution of an oceanic magmatic arc (Massey, 1995; Yorath et al., 1999). The lowermost Duck Lake Formation yields mainly normal mid-ocean-ridge basalt (N-MORB) geochemical signatures (Massey, 1995) and is interpreted to represent the oceanic crust basement on which the Sicker arc was built. The upper portions of the Duck Lake Formation yield tholeiitic to calcalkaline compositions and may represent primitive arc rocks. The Duck Lake Formation is overlain by the Nitinat Formation, which comprises mafic, submarine, volcanic and volcaniclastic rocks with dominantly calcalkaline compositions and trace-element signatures typical of volcanic arc settings. These rocks are interpreted as an early stage of arc development. The andesitic to mainly dacitic and rhyolitic McLaughlin Ridge Formation that overlies the

<table>
<tr><th colspan="2">Muller, 1977 (Vancouver Island)</th><th colspan="2">Juras, 1987 (Buttle Lake Uplift)</th><th colspan="2">Yorath et al., 1999 (Alberni area)</th></tr>
<tr><td></td><td></td><td rowspan="3">Buttle Lake Gp</td><td>Henshaw Fm</td><td rowspan="3">Buttle Lake Gp</td><td>St. Mary Lk Fm</td></tr>
<tr><td rowspan="7">Sicker Gp</td><td>Buttle Lk Fm</td><td rowspan="2">Mt Mark Fm</td><td>Mt Mark Fm</td></tr>
<tr><td>Sediment Sill Unit</td><td>Fourth Lk Fm</td></tr>
<tr><td rowspan="3">Myra Fm</td><td rowspan="5">Sicker Gp</td><td>Flower Ridge Fm</td><td rowspan="5">Sicker Gp</td><td rowspan="3">McLaughlin Ridge Fm</td></tr>
<tr><td>Thelwood Fm</td></tr>
<tr><td>Myra Fm</td></tr>
<tr><td rowspan="2">Nitinat Fm</td><td rowspan="2">Price Fm</td><td>Nitinat Fm</td></tr>
<tr><td>Duck Lk Fm</td></tr>
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Figure 2. Stratigraphic nomenclature for the Sicker and Buttle Lake groups on Vancouver Island (Yorath et al., 1999).

Nitinat and hosts the Myra Falls deposit reflects a more evolved stage of arc activity. Eruption of Nitinat volcanic and volcaniclastic rocks appears to have occurred from several widely scattered centres, whereas the McLaughlin Ridge Formation within the Cowichan Lake uplift is thought to represent eruption from one or more major volcanic edifices. The abundance of proximal felsic volcaniclastic rocks and the presence of voluminous comagmatic felsic intrusions (Saltspring intrusions) in the Saltspring Island and Duncan areas (Figure 1) indicates that one of these major volcanic centres was located in this area. Plant material and trace fossils indicate that at least a minor amount of the McLaughlin Ridge volcanism occurred in a subaerial setting. In the Port Alberni area, the McLaughlin Ridge Formation comprises felsic, fine-grained tuffaceous volcaniclastic and epiclastic rocks, indicating deposition distal from a volcanic centre. Deposition of sedimentary and volcano-sedimentary rocks of the overlying Fourth Lake Formation of the Buttle Lake Group followed the cessation of Sicker arc magmatism, and scarce mafic volcanic rocks contained within the Fourth Lake Formation yield enriched tholeiitic rather than the calcalkaline compositions that characterize the McLaughlin Ridge. Massey (1995) speculated that the Buttle Lake Group may represent a marginal-basin assemblage that developed on top of the Sicker arc.

Studies of the Sicker and Buttle Lake groups on southern Saltspring Island at the southeastern end of the Cowichan Lake uplift by Sluggett (2003) and Sluggett and Mortensen (2003) provided new U-Pb zircon age constraints on both felsic volcanic rocks of the McLaughlin Ridge Formation and several bodies of Saltspring intrusions. This work demonstrates that two distinct episodes of felsic magmatism occurred in this portion of the Cowichan Lake uplift. One sample of felsic volcanic rocks from the McLaughlin Ridge Formation and three samples of Saltspring intrusions yielded U-Pb ages in the range 359.1–356.5 Ma. A somewhat older U-Pb age of 369.7 Ma was obtained from a separate body of the Saltspring intrusions at Burgoyne Bay on the southwest side of Saltspring Island, indicating that magmatism represented by the McLaughlin Ridge Formation and associated Saltspring intrusions occurred over a time span of at least 15 million years. There is insufficient age control available at this point to determine whether the magmatism was continuous or episodic during this time period.

Results of New Mapping in the Port Alberni Area

Mapping of Sicker Group bedrock geology and sampling for lithogeochemistry, U-Pb zircon and Ar-Ar hornblende geochronology, and Pb, Nd and Hf isotope tracer studies was conducted in the Port Alberni area (Figure 3). This work was concentrated in three main areas: 1) in the vicinity of the Lacy Lake and Esary Lake iron formations, located between Lacy and Horne lakes; 2) in the vicinity of a previously mapped dacite unit to the north of the Port Alberni highway; and 3), in the vicinity of the Debbie 3 VMS occurrence, located to the south of the Port Alberni highway (Figure 3). Mapping was conducted using ESRI's Arcpad™ 7 on an HP IPaq HX4700 Pocket PC hardwired to a Garmin 76CS GPS. The British Columbia Geological Survey's regional geology compilation for UTM zone 10, southwestern British Columbia was used (Massey et al., 2005). Bedrock outcrop in both areas is moderate, with the best exposures contained in logging-road cuts. Off-road exposures are typically covered with thick layers of moss and organic detritus, often in forested, low-light conditions.

Lacy Lake–Horne Lake Area

Stratified Rocks

The oldest rocks in the Lacy Lake–Horne Lake area are assigned to the Duck Lake Formation (Figure 4; Massey and Friday, 1989). These consist largely of massive, dominantly aphyric to weakly plagioclase-phyric, variably hematite-altered basalt flows, flow breccias, lapilli tuffs, and tuff breccias (Figure 5). In the vicinity of the Lacy Lake iron formation, weakly to strongly hematite-altered, commonly highly vesicular basalt flow autobreccias, lapilli tuffs, and tuff breccias are abundant (Figure 5a). Carbonate alteration is locally abundant in these volcanic rocks as pink ankerite veins up to 7 cm wide, and as carbonate amygdules up to 3 mm in size (Figure 5b). Ankerite veining is most prevalent in basaltic rocks with the strongest hematite alteration. Duck Lake Formation lapilli and tuff breccias in this area are commonly rich in strongly hematite-altered, vesicular, variably carbonate amygdule–bearing basalt clasts (Figure 5c).

Jasperoid iron formation of the Lacy Lake showing (MINFILE 092F 245) is interbedded with green- to cream-coloured chert and is in very sharp contact with underlying hematite- and carbonate-altered autobreccia assigned to the Duck Lake Formation (Figures 5a and 6). The iron formation itself is dark red and silica rich. The Lacy Lake iron formation showing is approximately 21 m thick and passes gradationally upwards into a package of interbedded green chert– and silica-rich mudstone and siltstone. Farther upsection, interbedded green chert– and silica-rich mudstone grade into a package of moderately to well-sorted, green-grey, intermediate volcanic crystal tuff, sandstone and siltstone. These units display excellent normal graded bedding, indicating they are upright (Figure 7). Still farther upsection, a dominantly matrix-supported, hematitic heterolithic breccia to boulder conglomerate becomes prevalent. This unit is strongly heterolithic and varies from matrix to clast supported, with clasts up to boulder size consisting of angular, intermediate volcanic sand-

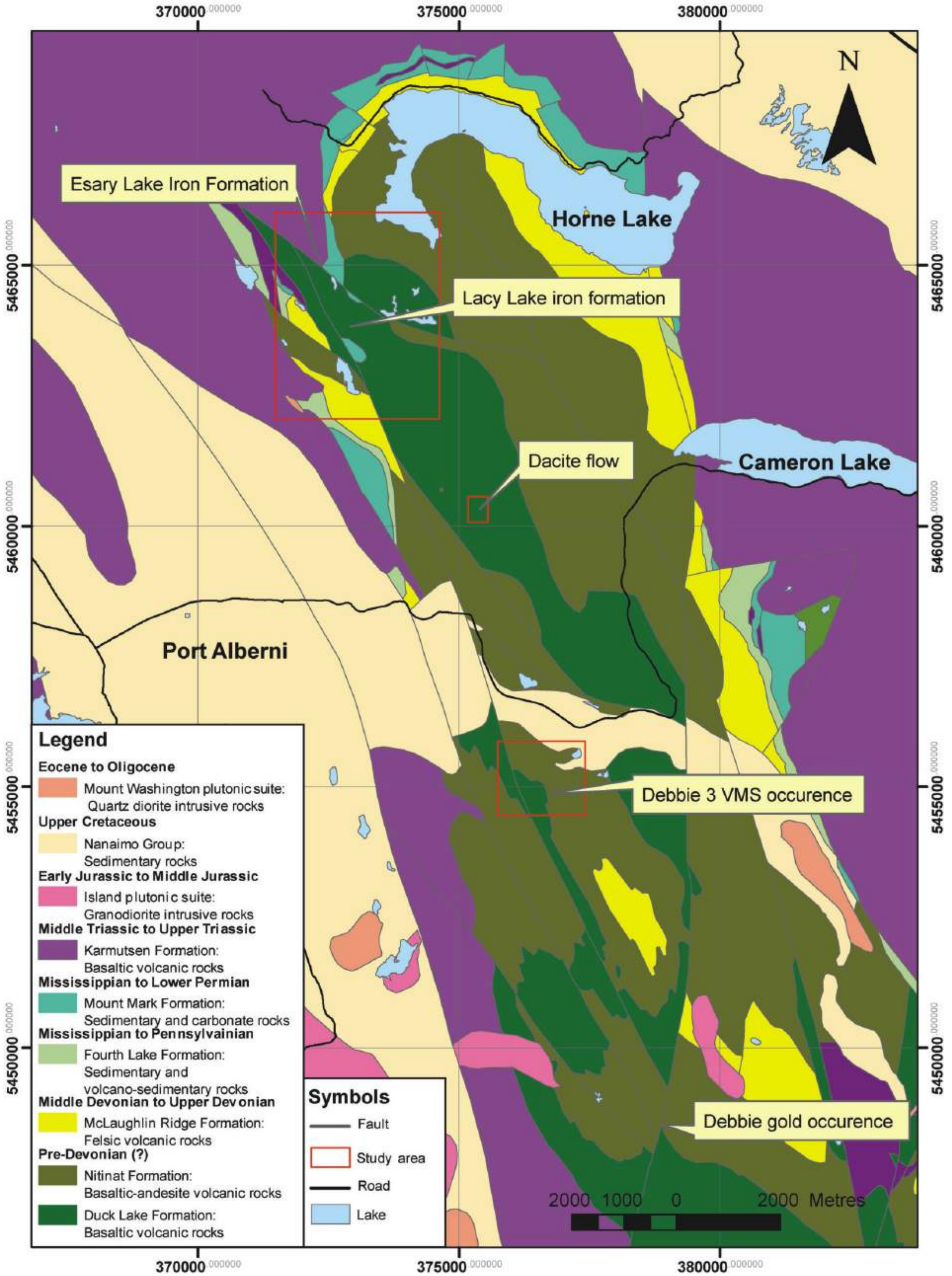

Figure 3. Regional geology (*after* Massey et al., 2005) of the Port Alberni area, with areas of study outlined in red.

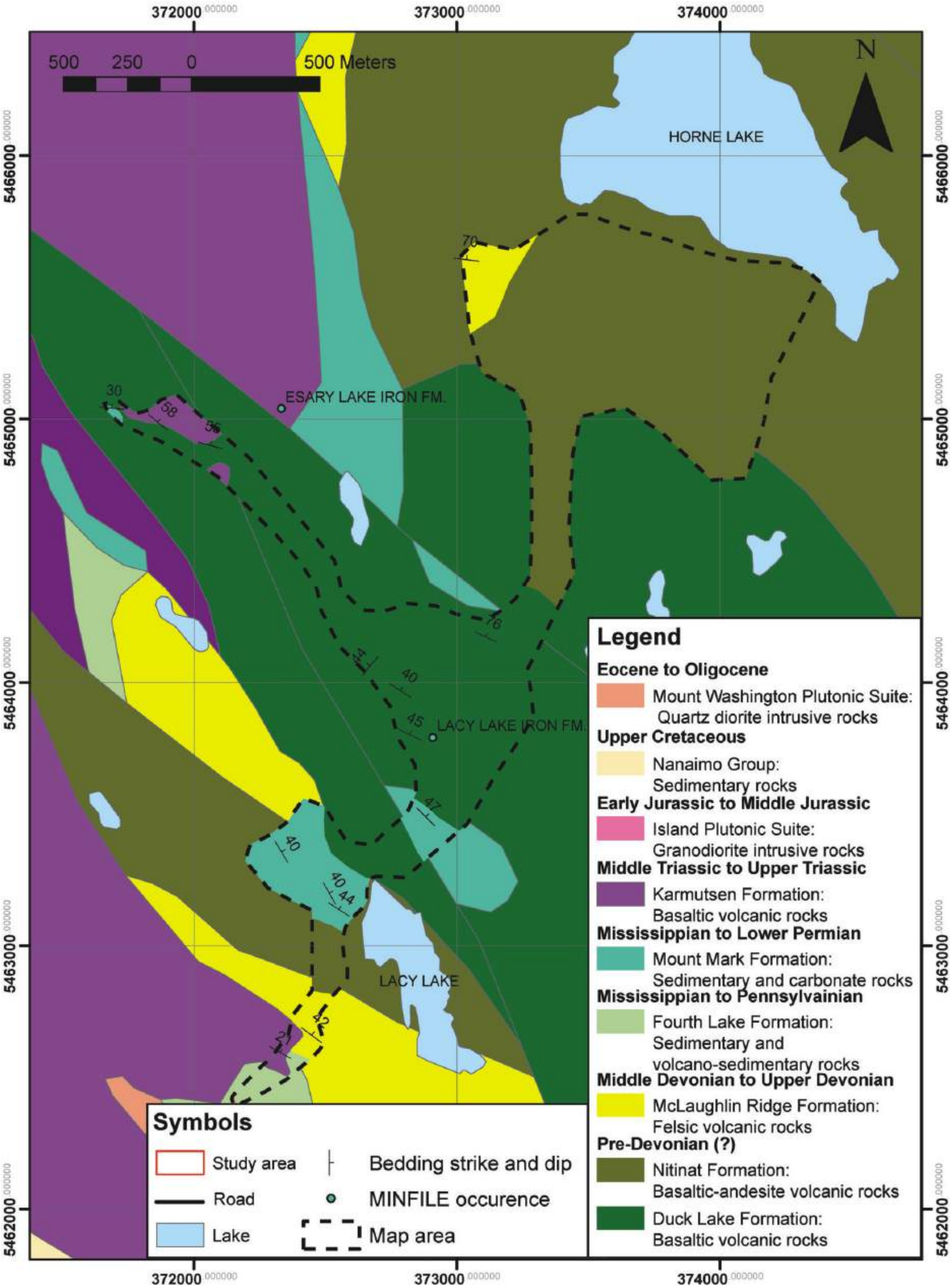

Figure 4. New geological mapping in the Lacy Lake–Horne Lake area, Port Alberni area. Regional geology *after* Massey et al. (2005).

stone; dark red, angular, jasperoid iron formation clasts; dark green, vesicular basalt clasts; and cream to white, subangular to rounded, variably crinoidal limestone boulders (Figure 8).

In a second outcrop, approximately 450 m to the northwest of the Lacy Lake iron formation showing, jasperoid iron formation with increasing elevation grades into hematite-bearing, intermediate volcanic sandstone, which becomes progressively more clast rich and coarse grained until it ul-

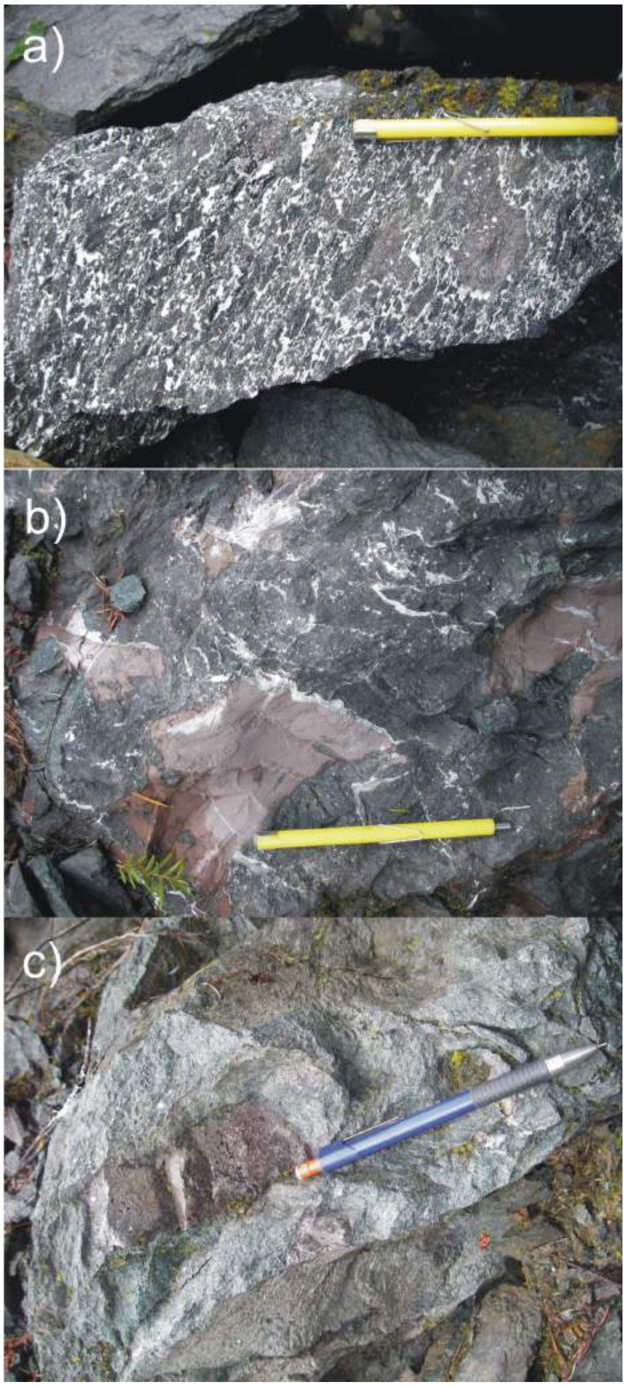

Figure 5. Basaltic volcanic rocks of the Duck Lake Formation in the Lacy Lake–Horne Lake area: **a)** hematite-altered basalt autobreccia with carbonate matrix; **b)** carbonate amygdule–bearing basalt with pink carbonate (ankerite) veins; **c)** basalt tuff-breccia containing vesicular, hematite-altered clasts.

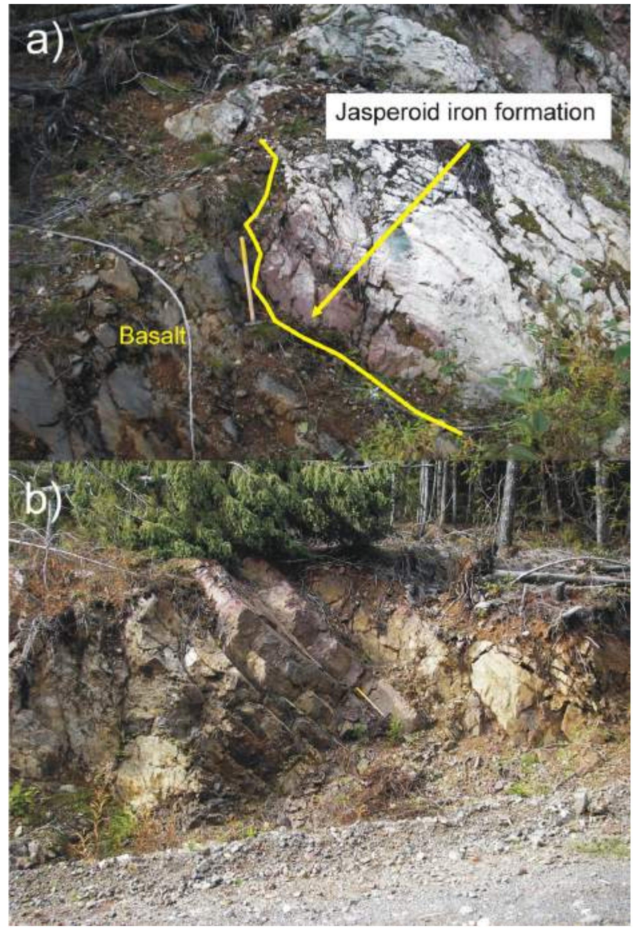

Figure 6. a) Sharp contact between underlying basalt and jasperoid iron formation and green chert of the Lacy Lake occurrence (MINFILE 092F 245). **b)** Jasperoid iron formation of the Lacy Lake MINFILE occurrence is approximately 21 m in thickness.

Figure 7. Moderately to well-sorted, green-grey, intermediate volcanic crystal tuff, sandstone and siltstone exhibiting normal grading.

timately becomes hematitic crinoidal limestone-bearing heterolithic breccia (Figures 9 and 10). The presence of crinoidal limestone as clasts within the heterolithic breccia that sits apparently conformably above the Lacy Lake iron formation suggests that these iron formations and the accompanying sedimentary rocks may not be part of the Duck Lake Formation, as previously interpreted, but instead may be part of the Fourth Lake Formation, which is believed to be, in part, temporally equivalent to crinoid-bearing limestone of the Mt. Mark Formation (Buttle Lake Group; Yorath et al., 1999). Float boulders of dacite tuff-breccia were also observed proximal to an outcrop of crinoidal limestone–bearing heterolithic breccia (Figure 11a). These boulders are highly angular in shape, suggesting local sourcing, and contain abundant feldspar-phyric dacite clasts, with minor, rounded, hematite-altered basaltic-andesite clasts, (Figure 11b). In addition, a small roadbed outcrop of grey-green, pebble to boulder conglomerate with abundant subrounded pebble- to boulder-size quartz-feldspar–phyric rhyolite clasts is present near the contact between rocks assigned to the Duck Lake Formation and those assigned to the Nitinat Formation, to the north (Figure 12).

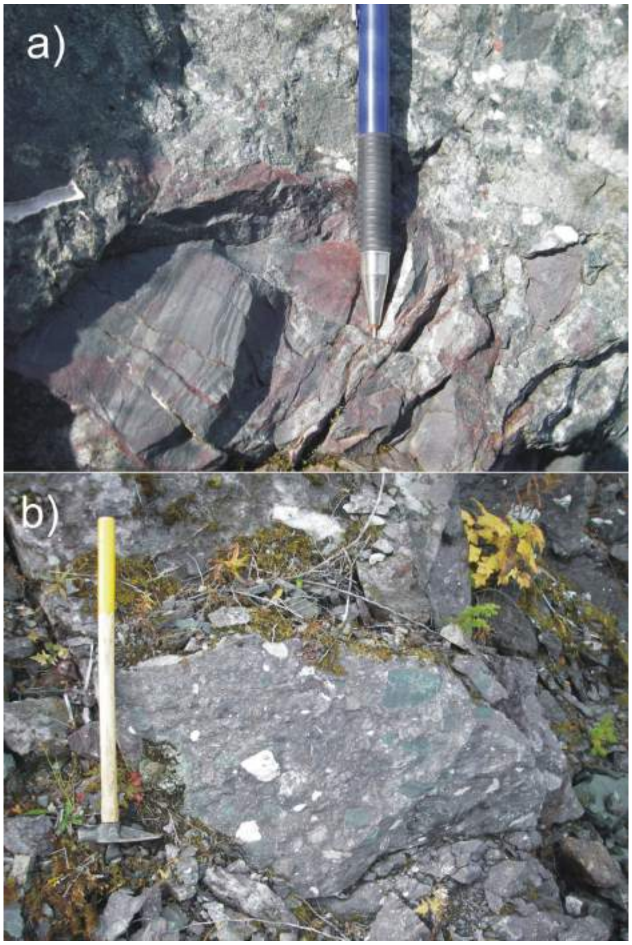

Figure 8. a) and **b)** Matrix- to clast-supported heterolithic breccia, with clasts up to boulder size consisting of angular, intermediate volcanic sandstone; dark red, angular, jasperoid iron formation clasts; dark green, vesicular basalt clasts; and cream to white, subangular to rounded, variably crinoidal limestone boulders.

Figure 9. Interbedded jasperoid iron formation and chloritic siltstone, approximately 450 m northwest of the Lacy Lake occurrence (MINFILE 092F 245).

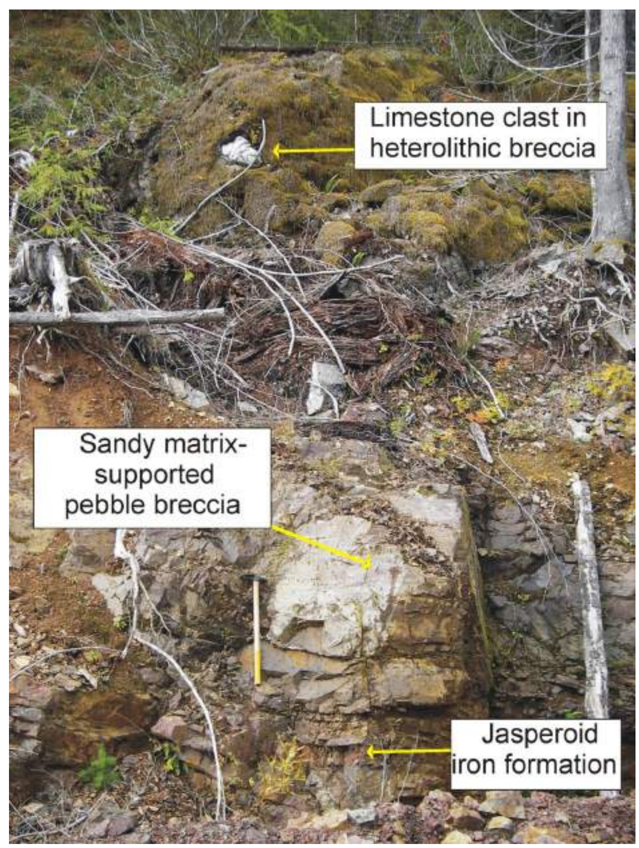

Figure 10. Jasperoid iron formation with increasing elevation grades into hematite-bearing, intermediate volcanic sandstone, which becomes progressively more clast rich and coarse grained until it ultimately becomes hematitic crinoidal limestone–bearing heterolithic breccia.

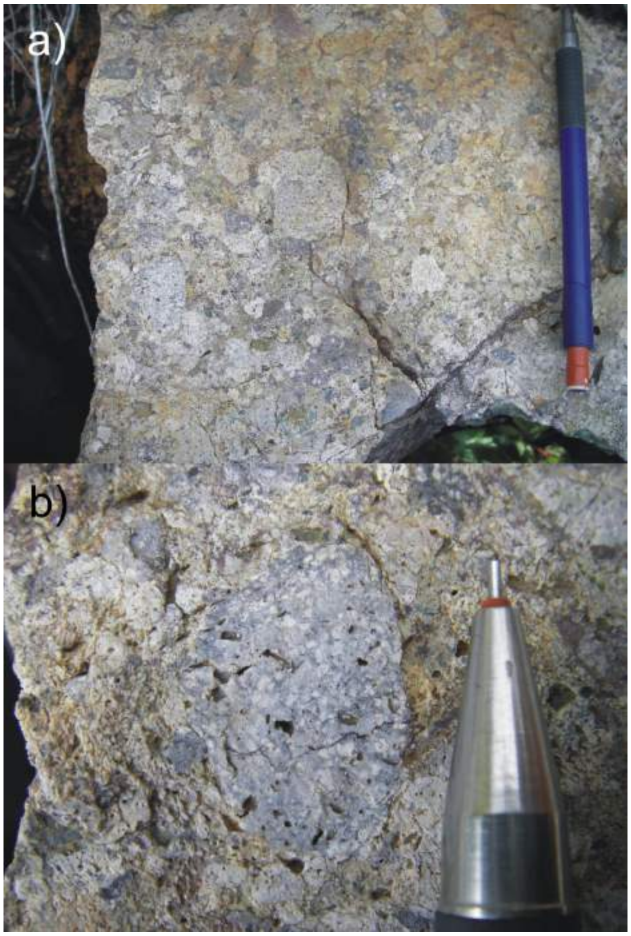

Figure 11. a) Float boulders of dacite tuff-breccia located proximal to an outcrop of crinoidal limestone–bearing heterolithic breccia. **b)** Close-up of dacite tuff-breccia boulders that shows them to be highly angular, suggesting local sourcing, and to contain abundant subangular to subrounded feldspar-phyric dacite clasts, with minor, rounded, hematite-altered basaltic-andesite clasts.

Figure 12. Clasts of pebble- to boulder-size quartz-feldspar–phyric rhyolite clasts are found in a small roadbed outcrop of grey-green, pebble to boulder conglomerate near the contact between rocks assigned to the Duck Lake Formation and those assigned to the Nitinat Formation, to the north.

The presence of felsic volcano-sedimentary rocks suggests that the sedimentary rocks in this area are part of the McLaughlin Ridge Formation or possibly the Fourth Lake Formation. Furthermore, if the Lacy Lake iron formations are indeed hosted by the Fourth Lake or uppermost McLaughlin Ridge Formation, this suggests that underlying mafic volcanic rocks in this area, which are in sharp contact with the iron formations, may represent a component of mafic volcanism belonging to the McLaughlin Ridge or Nitinat Formation. Exhalitive iron formations are abundant elsewhere in the Sicker Group, hosted in rocks assigned to the Fourth Lake and Thelwood formations of similar age, which stratigraphically overlie VMS mineralization hosted by the McLaughlin Ridge Formation in the eastern Cowichan Lake and Buttle Lake areas, respectively. To constrain the age of the Lacy Lake iron formations, abundant samples of iron formation and associated chert were taken for possible radiolarian biostratigraphic studies.

Rocks assigned to the Nitinat Formation were observed in two main areas. First, strongly pyroxene-phyric basaltic-andesite agglomerate was observed on the south side of

Figure 13. a) Pyroxene-phyric basaltic-andesite agglomerate of the Nitinat Formation. **b)** Pyroxene phenocrysts in basaltic-andesite clast; in places, the pyroxene phenocrysts can reach 1 cm in size.

Lacy Lake, with the best examples found directly beneath a power line (Figure 13a). Here, euhedral, green pyroxene phenocrysts constitute up to 5% of the rock and reach up to 1 cm in size (Figure 13b). Nitinat Formation volcanic rocks in this location appear to be in fault contact along their northern margin on the west side of Lacy Lake with a belt of Mt. Mark Formation crinoidal limestone. The southern margin of this outcrop of Nitinat Formation volcanic rocks appears to be in contact with felsic tuffaceous rocks belonging to the McLaughlin Ridge Formation.

The second main area of Nitinat Formation observed in this study occurs along the southern shore of Horne Lake and extends approximately 1500 m to the south, where it is in contact with mafic volcanic rocks of the Duck Lake Formation. Nitinat Formation along the southern edge of Horne Lake comprises mostly pyroxene-phyric agglomerate, tuff breccia and lesser lapilli tuff. Mapping during this study has identified a zone of Nitinat Formation basaltic-andesitic volcanic rocks extending well into an area previously mapped as Duck Lake Formation basalt. To accommodate this new zone, the contact between the Nitinat and Duck Lake formations south of Horne Lake has been extended an additional 600 m to the south (Figure 4).

Felsic volcanic rocks assigned to the McLaughlin Ridge Formation in this study were encountered in two areas (Figure 4). The southernmost exposure of this formation in the study area is located south of Lacy Lake. It comprises mainly light green-grey, dacitic ash tuff with small feldspar crystals; medium-grained, dacitic volcanic sandstone; and heterolithic, dacitic lapilli tuff, consisting of chert clasts up to 4 mm in size, dark green, highly chlorite-altered andesite clasts up to 4 mm in size, and medium to light green, strongly sericite-altered dacite clasts up to 5 mm in size set in a matrix that may contain fine-grained feldspar and quartz crystals (Figure 14a). The northernmost exposure of McLaughlin Ridge Formation in the study area comprises largely well-sorted, medium-grained arkosic sandstone, and thinly bedded to laminated mudstone, siltstone and buff- to creamy-weathering chert, with potential felsic ash tuff components (Figure 14b, c). Finer grained McLaughlin Ridge sedimentary rocks in this area exhibit normal graded bedding, indicating an upright orientation (Figure 14a).

Rocks belonging to the Fourth Lake Formation (Yorath et al., 1999) were recognized to the south of Lacy Lake. This small exposure, heavily inundated with basaltic dikes belonging to the Karmutsen Formation, consists of thinly bedded, cream-coloured chert; black mudstone; grey siltstone; and grey to buff, well-sorted, fine-grained sandstone (Figure 15).

A significant zone of crinoidal limestone and associated sedimentary rocks belonging to the Mt. Mark Formation of the Buttle Lake Group has been recognized along the western shore of Lacy Lake, in areas previously mapped as Nitinat and McLaughlin Ridge formations. These carbonate rocks are typically medium grey to buff, medium-grained, sandy-textured crinoidal packstone with up to 4% by volume of crinoid ossicles up to 4 mm in diameter (Figure 16a). Lesser amounts of darker grey wackstone and

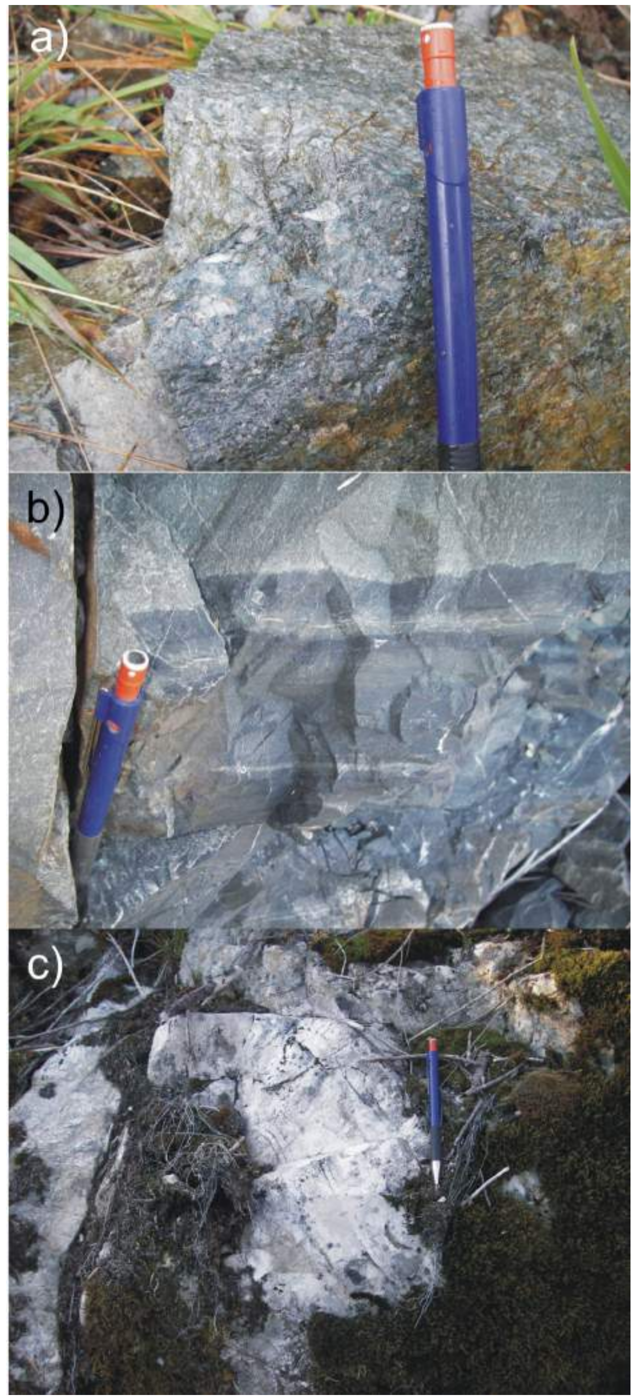

Figure 14. Felsic volcano-sedimentary rocks of the McLaughlin Ridge Formation: **a)** dacitic heterolithic lapilli tuff; **b)** well-sorted, medium-grained arkosic sandstone, siltstone and thinly bedded to laminated mudstone; **c)** white-weathering, laminated chert or cherty tuff.

white-weathering radiolarian chert are also present (Figure 16b). The western limits of this zone were not determined during this study. This package of Mt. Mark Formation carbonate and sedimentary rocks was traced approximately 500 m to the northwest of Lacy Lake.

Intrusive Rocks

Basaltic to diabasic volcanic rocks belonging to the Karmutsen Formation are abundant in the field area, typically occurring as large dikes (Figure 17a). They are typically dark green to black, moderately magnetic and dominantly equigranular, with acicular hornblende and plagioclase phenocrysts averaging 1 mm in length.

Hornblende granodiorite intrusions assigned to the Mount Washington intrusive suite are present in the field area, but are less abundant than basaltic dikes of the Karmutsen Formation. These rocks are typically porphyritic, with up to 30% medium-grained feldspar phenocrysts and 1–2% hornblende phenocrysts. In places, hornblende phenocrysts can be up to 2 cm in length. These rocks tend to form dikes and small intrusions ranging from 10 to 500 m in length, often with excellent chilled margins at their contacts (Figure 17b).

Structural Geology of the Lacy Lake–Horne Lake Area

Bedding of sedimentary and volcano-sedimentary rocks in the Lacy Lake–Horne Lake area is dominantly northwest striking, with moderate dips to the northeast (Figure 4). Rare disruptions to this fabric were observed approximately 350 m northwest of the Lacy Lake iron formation, and may indicate the hinge area of a localized, tight, parasitic, isoclinal antiformal structure related to regional F_1 folding.

Felsic Volcanic Rocks of the Duck Lake Formation

A minor amount of geological mapping and sampling was focused in the immediate vicinity of a quartz-feldspar–phyric dacite flow-dome hosted in Duck Lake Formation basaltic volcanic rocks to the south of the BC Tel microwave tower, north of the Port Alberni highway (Figure 3).

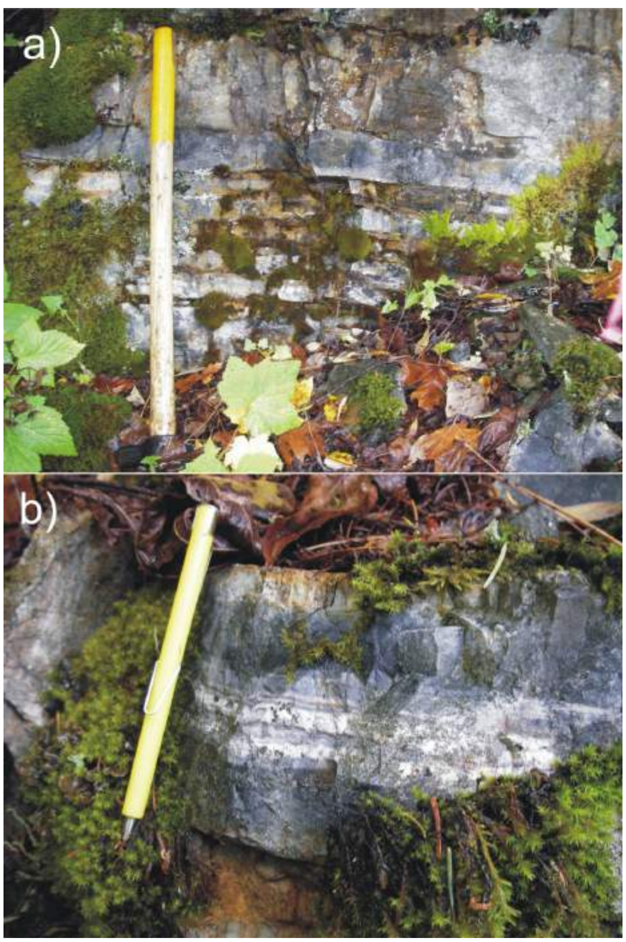

Figure 15. Sedimentary rocks of the Fourth Lake Formation: **a)** thinly bedded chert, siltstone and mudstone; **b)** laminated chert and mudstone.

Figure 16. Carbonate and sedimentary rocks of the Mt. Mark Formation: **a)** grey to buff, medium-grained, sandy-textured crinoidal packstone with up to 4% crinoid ossicles up to 4 mm in diameter; **b)** white-weathering radiolarian chert.

The goal of this mapping was to elucidate whether or not this unit was an intrusion of McLaughlin Ridge Formation age or a previously unrecognized felsic volcanic component of the dominantly basaltic Duck Lake Formation that would be datable by U-Pb zircon geochronology.

Previous workers have interpreted this quartz-feldspar–phyric dacite as a flow, and have traced it for approximately 1.5 km along strike (Laanela et al., 1987). During the course of this study, both massive dacite porphyry and dacite breccia were observed in roadcut outcrops. Massive dacite porphyry in this area is characterized by large, buff- to creamy-weathering outcrops with 0.5% feldspar and quartz phenocrysts up to 1 mm in size (Figure 18a). Feldspar is the dominant phenocryst phase, with quartz phenocrysts rare to absent in hand sample. Fresh surfaces are grey-green in colour. Chlorite-altered phenocrysts (possibly biotite) that form 0.25–0.5% of the rock are also present. Weak to moderate sericite alteration is present locally, as are carbonate veinlets and rare disseminated pyrite. Rare chalcopyrite is also locally present. Dacite breccia was recognized approximately 150 m to the northwest of the main dacite body, and consists of abundant, variably feldspar-phyric, variably silica-altered, angular dacite clasts up to 10 cm in size, commonly with autobrecciated margins (Fig-

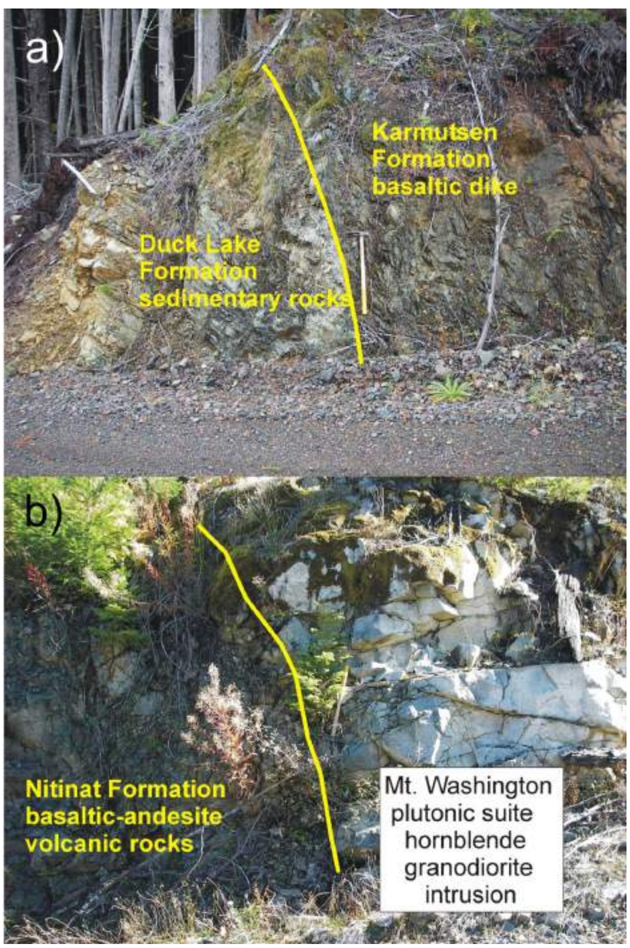

Figure 17. a) Karmutsen Formation basaltic dike cuts sedimentary rocks assigned to the Duck Lake Formation. **b)** Intrusion of hornblende granodiorite cuts basaltic-andesite rocks of the Nitinat Formation.

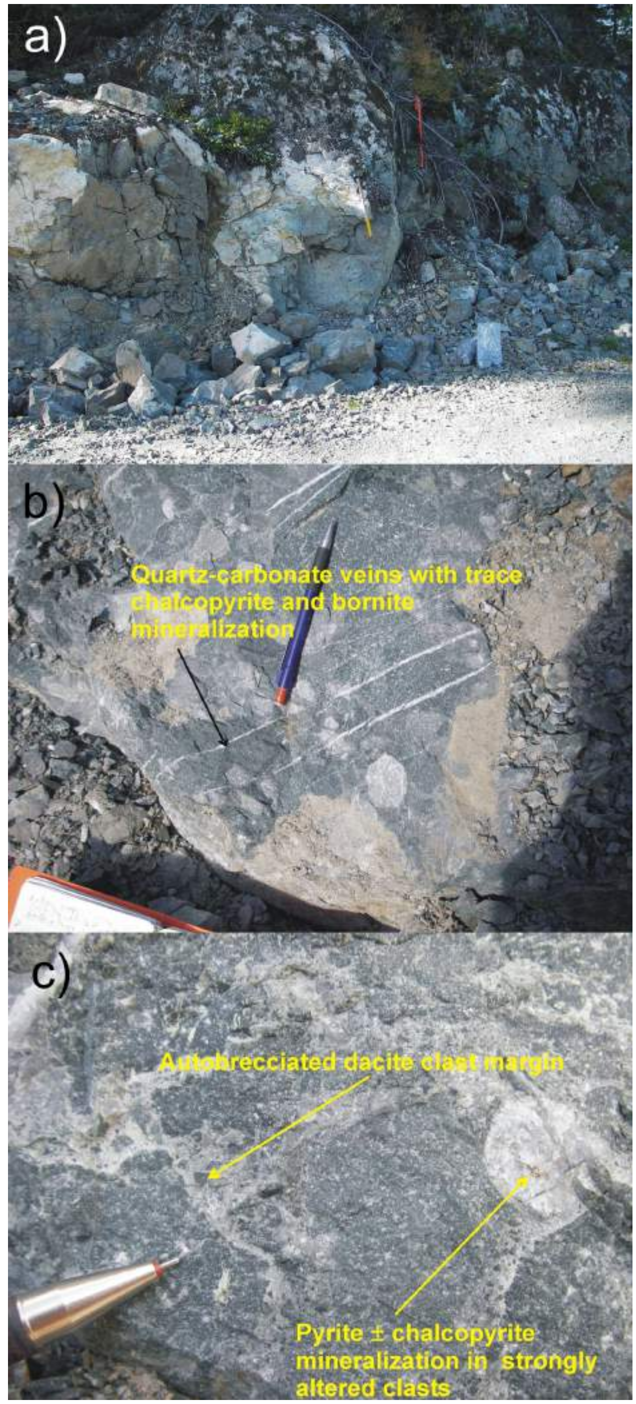

Figure 18. a) Massive feldspar+quartz–phyric dacite flow in basalt assigned to the Duck Lake Formation. **b)** Dacite breccia with strongly silica+sericite–altered clasts, often containing sulphide mineralization; crosscutting quartz-carbonate veinlets contain trace chalcopyrite and bornite. **c)** Autobrecciated dacite clasts and intensely silica+sericite–altered clasts with pyrite±chalcopyrite mineralization.

ure 18b). The most intensely silica-altered clasts commonly contain fine-grained disseminated sulphide (pyrite±chalcopyrite) mineralization (Figure 18c). Sulphide blebs and possible sulphide clasts up to 4 cm in size are also present in the breccia. The dacite breccia is crosscut by quartz-carbonate veinlets, some of which contain trace chalcopyrite and bornite.

Debbie 3 Volcanogenic Massive Sulphide Occurrence

The Debbie 3 volcanogenic massive sulphide occurrence (MINFILE occurrence 092F 445), currently owned by Bitterroot Resources Ltd., occurs in mafic volcanic and volcano-sedimentary rocks assigned to the Duck Lake and Nitinat formations, and is located along the Cameron Main logging road, close to the intersection with the Mt. Arrowsmith ski road. The showing consists of four stratiform lenses of banded massive sphalerite, with minor chalcopyrite and galena, each band ranging between 5 and 20 cm in thickness. The best grade obtained from sampling of this mineralization by previous workers includes 14.1% Zn, 0.87% Pb and 0.12% Cu over a 20 cm thickness (MINFILE, 2007). The mineralization is hosted in fine-grained chloritic schist with variable carbonate, sericite and silica alteration.

Mapping of the Debbie 3 area has identified alternating zones of massive basaltic and basaltic-andesite volcanic rocks, with variably chlorite-, sericite- and silica-altered mafic schist (Figure 19). Mafic volcanic rocks in this area tend to occur as robust, massive outcrops with little to no foliation. In the northern portion of the map area, these outcrops comprise dominantly massive, grey-green, pyroxene-phyric basalt flows and agglomerate. Pyroxene phenocrysts can reach abundances of 0.5–1.5% and sizes up to 3–4 mm. Feldspar-phyric basalt flows with abundant chlorite amygdules become more abundant towards the west. Here, variably epidote-altered plagioclase phenocrysts with diffuse margins average 1.5 mm size, and chlorite amygdules reach abundances up to 3.5% and sizes up to 1–2 mm. Epidote alteration patches up to 5–10 cm in width are also present. In the southern portion of the map area, massive, largely unfoliated mafic volcanic rocks comprise mainly chlorite amygdule–bearing basalt flows, pyroxene-phyric basaltic-andesite agglomerate and mafic lapilli tuff with abundant flattened, chlorite-altered pumice clasts. Mafic schist in both the northern and southern portions of the map area comprises strongly foliated, strongly chlorite-altered mafic tuff with variable carbonate, sericite and silica alteration (Figure 20a). Mineralization is observed in this mafic schist only in the southern part of the area, and is present as stratiform bands of massive sphalerite with minor chalcopyrite and galena that reach up to 20 cm in thickness (Figure 20b). Strong carbonate and sericite alteration of the mafic schist is present in the immediate vicinity of sulphide mineralization. Approximately 320 m west of the showing, a zone of intensely silica+sericite+carbonate–altered mafic schist is associated with quartz-carbonate and blue-green gypsum veins (Figure 21). In this zone, quartz-carbonate veins carry blebs of chalcopyrite. The presence of this stockwork-style sulphide mineralization to the west of the stratiform sulphide mineralization of the Debbie 3 VMS occurrence suggests that rocks to the west of the main showing may reflect deeper stratigraphic levels, and the stratigraphic package may young to the east.

Debbie 3 Structural Geology

Structures in the area are best observed in fine-grained mafic volcanic rocks in the vicinity of the Debbie 3 occurrence (Figure 19). These rocks, typically chloritic schist, display a prominent northwest strike, with moderate to steep dips to the northeast. Folding of this fabric was observed only in two areas. In the northwestern part of the map area, chloritic schist was observed to strike northeast for a limited extent, with weak dips to the southeast. This may represent F_2 kink folding. Additional kink folding was observed in chloritic schist approximately 415 m west of the Debbie 3 occurrence. Here, warping of the main fabric is represented by small, outcrop-scale, F_2 kink folds with hinges plunging steeply towards the northeast.

New Sulphide Mineralization and Implications for VMS Exploration in the Alberni Area

Two new occurrences of significant sulphide mineralization were discovered during the course of this mapping. The first, along the power line overlooking the south side of Lacy Lake (Figure 4), occurs near the contact between pyroxene-phyric basaltic-andesite agglomerate of the Nitinat Formation and overlying felsic tuffaceous rocks belonging to the McLaughlin Ridge Formation. Here, a 20 m long float train consists of bleached, highly sericite-, silica- and fuchsite-altered subangular boulders up to 40–50 cm in size that contain up to 4% pyrite, occurring as disseminations, stringers and blebs up to 2 cm in size (Figure 22). This float train was traced into a small exposure of hematite+chlorite–altered basalt. Trenching of this outcrop exposed bleached, strongly sericite+silica–altered, pyrite-mineralized rock similar to that observed in the nearby mineralized float. This sulphide occurrence is significant in that it occurs at the contact between mafic to intermediate volcanic rocks of the Nitinat Formation and overlying felsic tuffaceous volcanic rocks of the McLaughlin Ridge Formation. In the Buttle Lake uplift, this contact is associated with the giant HW deposit, which has a pre-mining inventory of 16.5 million tonnes of ore with an average grade of 2.2 g/t Au, 39.6 g/t Ag, 1.7% Cu, 0.4% Pb and 4.3% Zn (Robinson, 1992). In the Port Alberni area, this contact may be especially significant, as the lack of overlying felsic volcanic rocks intimately associated with high-energy eruptive activity (i.e., rhyolite flows, felsic tuff-breccia, etc.)

would provide ample time for the accumulation of VMS mineralization.

The second significant new sulphide occurrence discovered during the course of this mapping is associated with the dacite flow-dome within basalt assigned to the Duck Lake Formation that was described above (Figure 3; Massey and Friday, 1989). Here, disseminated to bleb-sized pyrite±chalcopyrite mineralization is associated with strongly silica-altered clasts in a dacite breccia occurring along the flanks of a massive, feldspar+quartz–phyric dacite dome (Figure 18c). In addition, both the massive

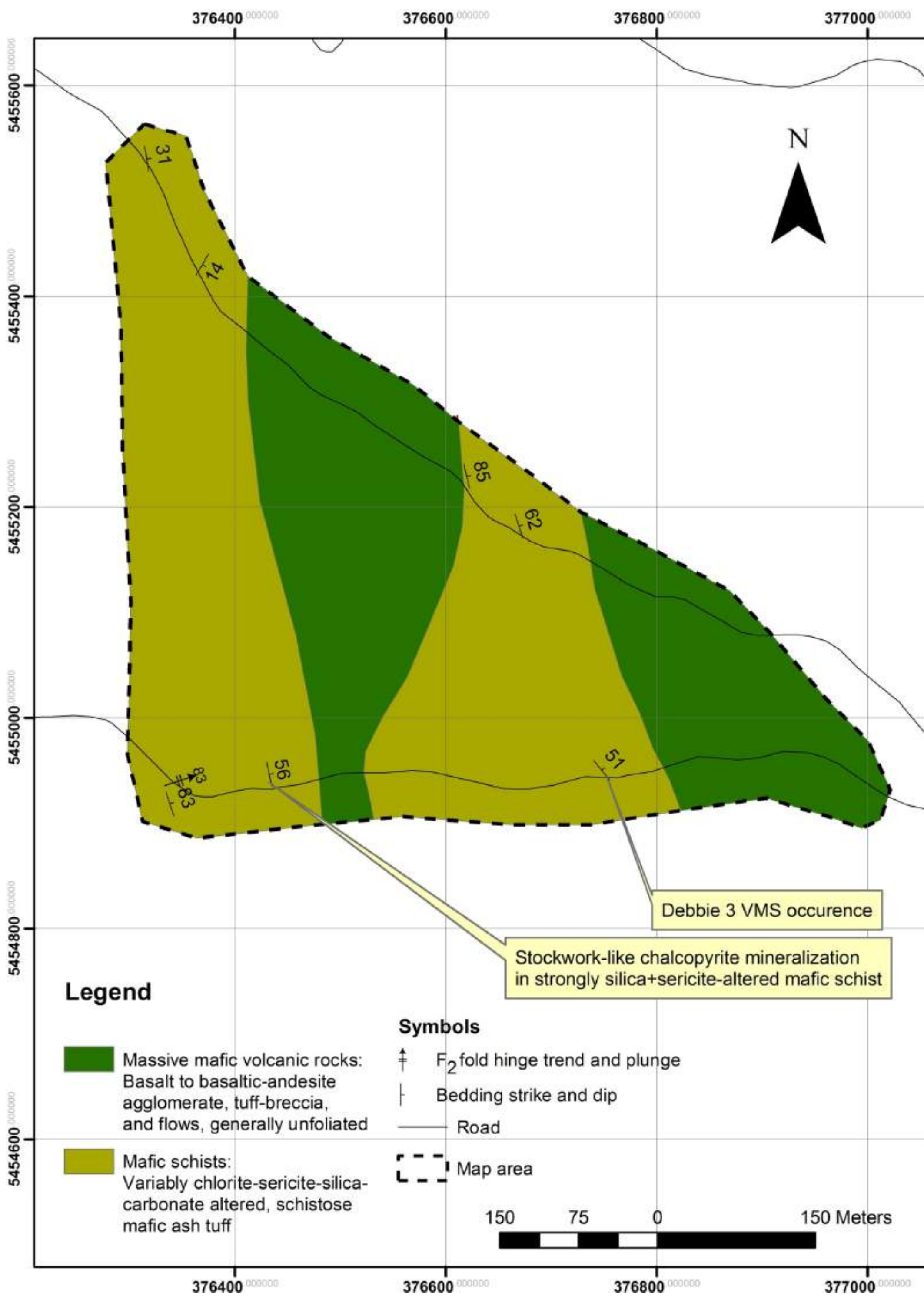

Figure 19. Geology of the Debbie 3 VMS occurrence, Port Alberni area.

Figure 20. a) Strongly foliated mafic tuff with variable chlorite, carbonate, sericite and silica alteration. **b)** Stratiform bands of massive sphalerite with minor chalcopyrite and galena, hosted in strongly foliated, sericite+chlorite+carbonate–altered mafic ash tuff.

dacite and the dacite breccia are crosscut by quartz-carbonate veins containing trace chalcopyrite and bornite mineralization. This dacite unit may represent a locus of hydrothermal activity related to potential volcanogenic massive sulphide mineralization in the area.

Lastly, the association of polymetallic massive sulphide mineralization of the Debbie 3 occurrence with fine-grained, chloritic mafic tuff assigned to either the Nitinat or the Duck Lake Formation indicates that significant hiatuses in mafic volcanism exist in the formations where VMS mineralization could develop. This suggests that further VMS exploration in mafic volcanic rocks belonging to the Duck Lake and Nitinat formations is warranted. This work should concentrate on identifying zones of significant interflow sedimentation, similar to that hosting VMS mineralization of the Debbie 3 occurrence.

Future Work

Fieldwork planned for the winter of 2007 will include logging and sampling of recent drillcore from the Debbie property (Bitterroot Resources Ltd.). This work has several goals, including identifying and sampling marker horizons within mafic volcanic rocks of the Duck Lake and Nitinat formations, with the ultimate goal of constraining the age of these formations, which are currently understood to be the oldest rocks in the Wrangellia Terrane. It will aid in determining the age and stratigraphic position of VMS-prospective horizons within the Nitinat and Duck Lake formations, and will assist in constraining relative motions along fault systems, which are host to significant epithermal gold mineralization at the Debbie occurrence (MINFILE occurrence 092F 079). In addition, sampling of sulphide mineralization from the Debbie property for Pb-isotope studies will provide a framework through which epigenetic sulphide occurrences associated with gold mineralization on the

Figure 21. Intensely silica+sericite+carbonate–altered mafic schist with quartz-carbonate and blue-green gypsum veins; in places, quartz-carbonate veins contain blebs of chalcopyrite.

Figure 22. Bleached, highly sericite+silica+fuchsite–altered mafic volcanic rock with up to 4% pyrite mineralization as disseminations, stringers and blebs up to 2 cm in size.

property (e.g., the Debbie occurrence) can be distinguished from those associated with VMS mineralization (e.g., the Debbie 3 VMS occurrence).

Fieldwork planned for 2008 will be concentrated in the Cowichan and Port Alberni areas, with additional work in potential outcrops of Sicker Group rocks in the Bedingfield Bay and Muchalat Inlet areas. In the Cowichan area, continued work will focus on understanding the stratigraphic and volcanological setting of VMS occurrences hosted by the Sicker Group, particularly those of the Lara/Coronation, Randy and Anita zones, north and west of Big Sicker Mountain (MINFILE occurrences 092B 129, 128 and 037, respectively), and other potential VMS occurrences in the immediate vicinity and west of Cowichan Lake. Additional regional work in the Alberni area will focus on identifying stratigraphic marker horizons within the Sicker Group that can be used to constrain the age of lithological units in the area, particularly those belonging to the Duck Lake and Nitinat formations.

In the Bedingfield Bay and Muchalat Inlet areas, similar regional and focused outcrop-scale mapping and sampling will be conducted to understand the stratigraphy and volcanological setting of potential Sicker Group rocks and VMS occurrences, most notably in the vicinity of the Rant Point and Dragon (Paget Resources Corp.) VMS occurrences (MINFILE occurrences 092F 494 and 092E 072, respectively). In parallel with the geological mapping and synthesis work, the authors will also carry out additional U-Pb dating, lithogeochemical, and Nd, Hf and Pb isotopic studies in order to constrain the age and magmatic evolution of Sicker Group volcanic rocks, and to develop a framework through which VMS occurrences hosted by the Sicker Group can be distinguished from younger, epigenetic sulphide occurrences.

Acknowledgments

This project is jointly funded by a Geoscience BC grant, Bitterroot Resources Ltd., Paget Resources Corp. and a Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grant to Mortensen. The authors thank N. Massey for discussions and insights into the geology of the Sicker Group, and K. Hickey for having provided a critical review of this manuscript. They also thank several prospectors, consultants and explorationists working on Vancouver Island, especially M. Becherer of Mineral Creek Ventures Inc., M. Carr of Bitterroot Resources Ltd., J. Bradford of Paget Resources Corp., E. Specogna of Specogna Minerals Corp., A. Francis, J. Houle, H. McMaster and S. Tresierra, for sharing their time and knowledge of Sicker Group geology and mineralization.

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