Geological Setting of Volcanogenic Massive Sulphide Occurrences in the Middle Paleozoic Sicker Group of the Southeastern Cowichan Lake Uplift (NTS 092B/13), Southern Vancouver Island[1]

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

INTRODUCTION

Volcanogenic strata of the mid-Paleozoic Sicker Group on Vancouver Island (Fig 1) 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 (Fig 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) suggests that the Big Sicker Mountain area is underlain mainly by 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. Logging activity in the Big Sicker Mountain area over the past decade has provided abundant new outcrops and prompted a re-examination of the geological setting of VMS mineralization and of the potential for new discoveries in this area. This report presents a preliminary version of a revised geological map of the Big Sicker Mountain area, as well as new lithogeochemical and U-Pb zircon geochronology results that bear on the geological setting of VMS mineralization in the southeastern Cowichan Lake uplift, as well as the potential for new discoveries in the area.

Reconnaissance sampling for lithogeochemistry, U-Pb zircon dating and Pb isotopic studies in the Big Sicker Mountain area was carried out in 2005 (Mortensen, 2005), and a total of two weeks of geological mapping was done in October 2006.

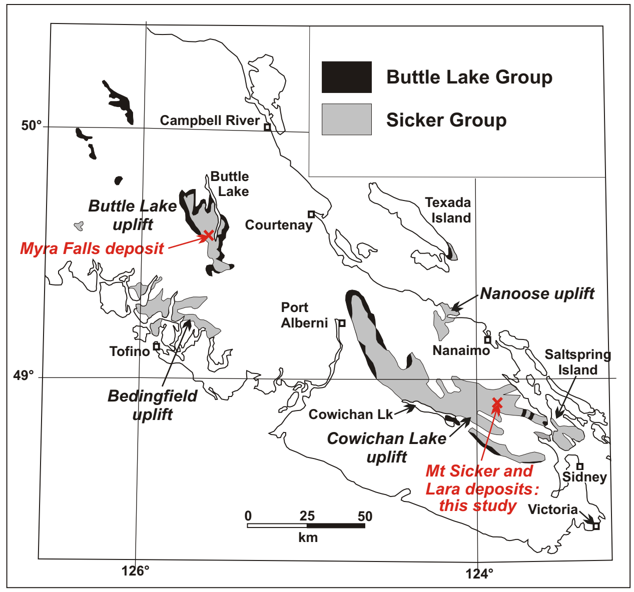

Figure 1. Distribution of Paleozoic strata of the Sicker and Buttle Lake groups on Vancouver Island and the Gulf Islands.

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 elsewhere in Wrangellia farther to the north 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 studies such as this. The Cowichan Lake uplift on Vancouver Island and adjacent portions of the Gulf Islands, which is the focus of this study, is the largest of four structural uplifts that expose the Sicker and overlying late Paleozoic Buttle Lake groups (Fig 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 (Fig 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 inter-

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preted stratigraphic framework that may be applicable to the entire Sicker Group (Fig. 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 lithogeochemical and U-Pb dating studies. This is critical for regional exploration for VMS deposits within the Sicker Group. For example, the question of whether VMS deposits and occurrences in the Cowichan Lake uplift are all of the same age, and how 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, 1995a, b, c; Yorath *et al.*, 1999). The Duck Lake Formation, at the base of the section, consists of dominantly tholeiitic basalt, which passes upward into calcalkaline lava. The lowermost Duck Lake Formation yields mainly normal mid-ocean-ridge basalt (N-MORB) geochemical signatures (Massey, 1995a) 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 to represent an early stage of arc development. The andesitic to mainly dacitic and rhyolitic McLaughlin Ridge Formation that overlies the 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 area (Fig 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. Deposition 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 (1995a) speculated that the Buttle Lake Group may represent a marginal-basin assemblage that developed on top of the Sicker arc.

Muller, 1977 (Vancouver Island)		Juras, 1987 (Buttle Lake Uplift)		Yorath et al., 1999 (Alberni area)	
—	—	Buttle Lake Gp	Henshaw Fm	Buttle Lake Gp	St. Mary Lk Fm
Sicker Gp	Buttle Lk Fm		Mt Mark Fm		Mt Mark Fm
	sediment sill unit				Fourth Lk Fm
	Myra Fm	Sicker Gp	Flower Ridge Fm / Thelwood Fm / Myra Fm	Sicker Gp	McLaughlin Ridge Fm
	Nitinat Fm		Price Fm		Nitinat Fm / Duck Lk Fm

Figure 2. Stratigraphic nomenclature for the Sicker and Buttle Lake groups on Vancouver Island.

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 356.5 to 359.1 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 m.y. There is insufficient age control available at this point to determine whether the magmatism was continuous or episodic during this time period. Lithogeochemical data reported by Sluggett (2003) for samples of the McLaughlin Ridge and Nitinat formations on Saltspring Island, together with data previously reported by Massey (1995a, b, c), provide a geochemical framework with which to compare the new results from the Big Sicker Mountain study area.

RESULTS OF NEW MAPPING IN THE BIG SICKER MOUNTAIN AREA

Field Geology

Preliminary mapping of an area of Big Sicker Mountain covering approximately 25 km^2 was conducted over 12 days in October 2006 (Fig 3). The mapping concentrated primarily in the area of the past-producing Lenora, Richard III and Tyee VMS deposits, and nearby MINFILE (2006) occurrences. Bedrock outcrop on Big Sicker Mountain is generally poor and is mainly restricted to logging-road cuts and slashes. As a result, contact locations between major rock types are mostly inferred.

The oldest rocks in the Big Sicker Mountain area are mafic volcanic rocks assigned to the Nitinat Formation (Massey and Friday, 1987). During the course of 2006 mapping, rocks of the Nitinat Formation were encountered only in a small area along the western flanks of Little Sicker Mountain (Fig 3). They consist of dark green, dominantly aphyric basalt with abundant ovoid epidote-quartz alteration patches up to 4 to 5 cm in diameter (Fig 4a). Sulphide mineralization is observed in one outcrop of Nitinat Formation, and consists of pyrite stringers up to 5 cm in width hosted in a vertically dipping fault zone approximately 2 m

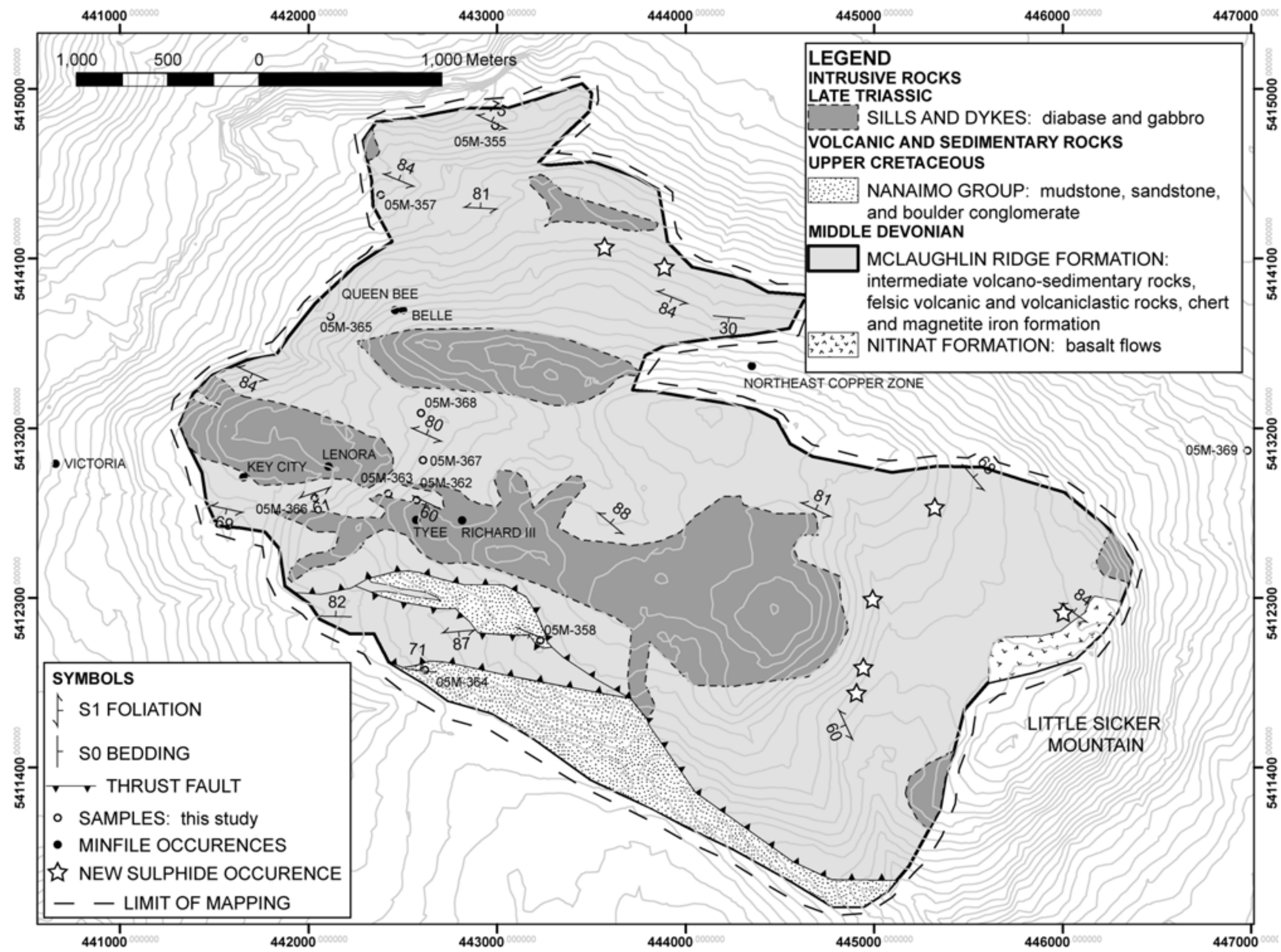

Figure 3. Preliminary revised geology of the Big Sicker Mountain area, based on fieldwork conducted for this study.

in width (Fig 4b). This outcrop appears to have been trenched for mineral exploration purposes.

Rocks of the McLaughlin Ridge Formation sit stratigraphically above those of the Nitinat Formation (Massey and Friday, 1987) and consist of intermediate volcanosedimentary rocks, felsic volcanic and volcaniclastic rocks, and, to a lesser degree, mudstone, chert and magnetite iron formation. Mafic to intermediate volcanosedimentary rocks are most prevalent along the northern to northeastern boundary of the map area. These rocks consist of thinly bedded to laminated, dark green, variably chlorite, sericite and silica-altered siltstone to fine sandstone, and more massive, medium-grained, feldspar-bearing sandstone or sandy tuff (Fig 5). Felsic rocks of the McLaughlin Ridge Formation include predominantly rhyolitic to dacitic ash, quartz-feldspar crystal tuff, aphyric flows, quartz-feldspar porphyry and, to a lesser extent, tuff-breccia (Fig 6).

Sericite and quartz alteration is commonly very strong in the felsic volcanic rocks. This, together with a well-developed foliation, makes it difficult to distinguish between those that formed from lavas (*i.e.*, a porphyry or flow) versus those that are crystal-bearing volcaniclastic rocks (*i.e.*, a crystal tuff). Dark grey to black, variably graphitic mudstone has only been observed locally within the vicinity of the main deposits (Fig 7a). Chert is not abundant and has been identified thus far only in a restricted area in the northern and south-southwesternmost parts of the study area (Fig 7b). In the southwestern part of the field area, laminated chert is associated with dacitic tuff, jasper and a localized magnetite iron formation (Fig 7c).

Triassic gabbro and diabase intrude rocks of the Sicker Group (Fig 8), are very prevalent throughout the field area (Fig 3), and are of variable thickness. Drillhole MTS-81 (Wells, 1990), located approximately 1 km southeast of the Richard III shaft in the vicinity of the BC Tel communication towers, encountered a gabbro thickness of >100 m before intersecting rocks of the Sicker Group at depth. However, the Richard III and Tyee shafts are sunk in gabbro, and are assumed to intersect rocks of the Sicker Group at a shallower depth, suggesting a westward thinning of these intrusions. The intrusive textures are quite variable from outcrop to outcrop, most likely due to localized shearing; however, the most common lithology is holocrystalline hornblende and plagioclase gabbro (Fig 8), consisting of variably chlorite-altered cumulus hornblende phenocrysts, up to 4 mm in size, in a matrix of intercumulus plagioclase.

Upper Cretaceous rocks of the Nanaimo Group lie unconformably on those of the Sicker Group (Massey and Friday, 1987) and crop out solely in the southernmost part of the field area. However, in the field area, the contact between the Sicker Group and Nanaimo Group marks the position of the Fulford fault and associated splays. In the field area, Nanaimo Group rocks consist largely of mudstone, shale, arkosic medium-grained sandstone and boulder conglomerate. The latter rock type contains abundant volcanic and gabbroic rock clasts that appear to have been derived from underlying Sicker Group and Triassic gabbro.

Structure

The most prominent fabric in the Big Sicker Mountain area is, on average, east to southeast-striking with a near-vertical dip, and represents both bedding and a bedding-parallel foliation herein termed S1 (Fig 9a). As mentioned before, due to extensive alteration in rocks of the McLaughlin Ridge Formation, it is commonly difficult to differentiate between those that originated as bedded volcaniclastic rocks and those that were originally massive flows or sills. Hence, some of the fabrics recorded as foliations may be bedding measurements. Small-scale (sub-metre wavelength), steeply plunging S and Z-shaped folds deform the primary layering in the volcanosedimentary package throughout the map area and are probably parasitic folds related to a larger F1 structure (Fig 9b). Second phase (D2) kinking of D1 structures occurs in several localities. Third phase (D3) structures consist of small-scale, shallowly plunging folds (2–3 cm wavelength) that were only observed in one locality (Fig 9a). The most prominent faults in the area are dominantly east striking, with near-vertical dips. In one such locality, shear-sense indicators in faulted dacite tuff of the McLaughlin Ridge Formation suggest a strong component of north-side-up motion (Fig 9c).

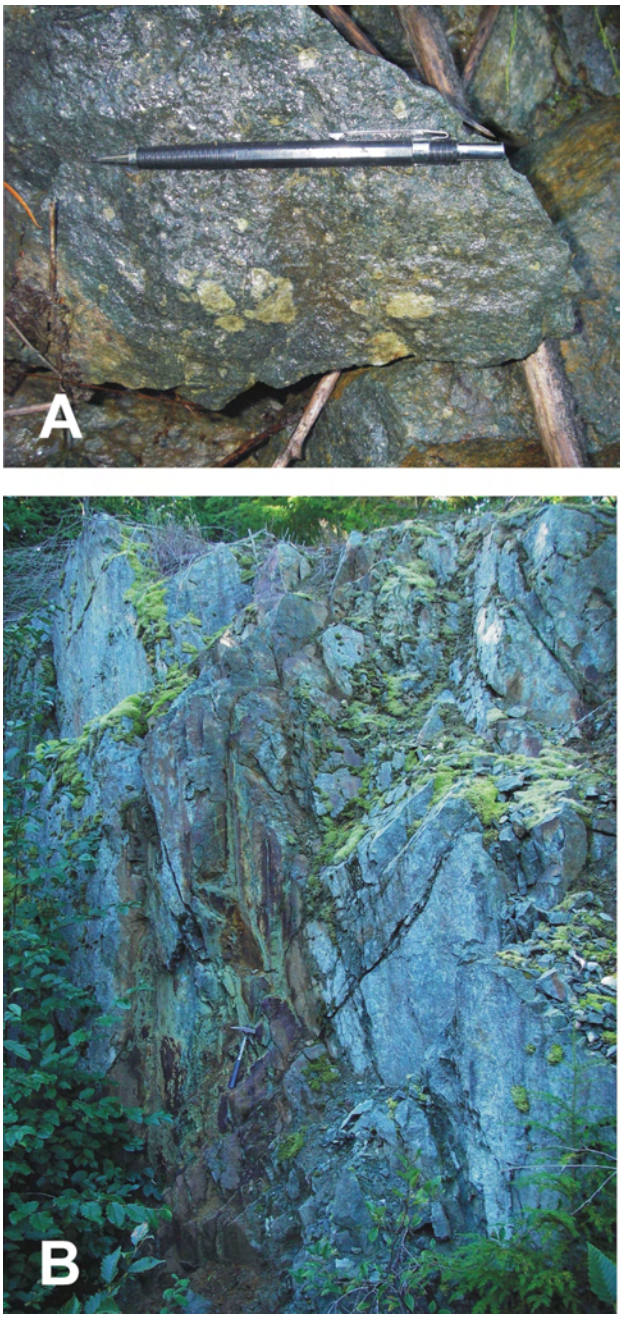

Figure 4. Intermediate to mafic volcanic rocks of the Nitinat Formation: A) aphyric basaltic andesite with ovoid quartz-epidote patches; B) pyrite-stringer-bearing fault in basaltic andesite flow (?); note hammer for scale in lower central part of photo.

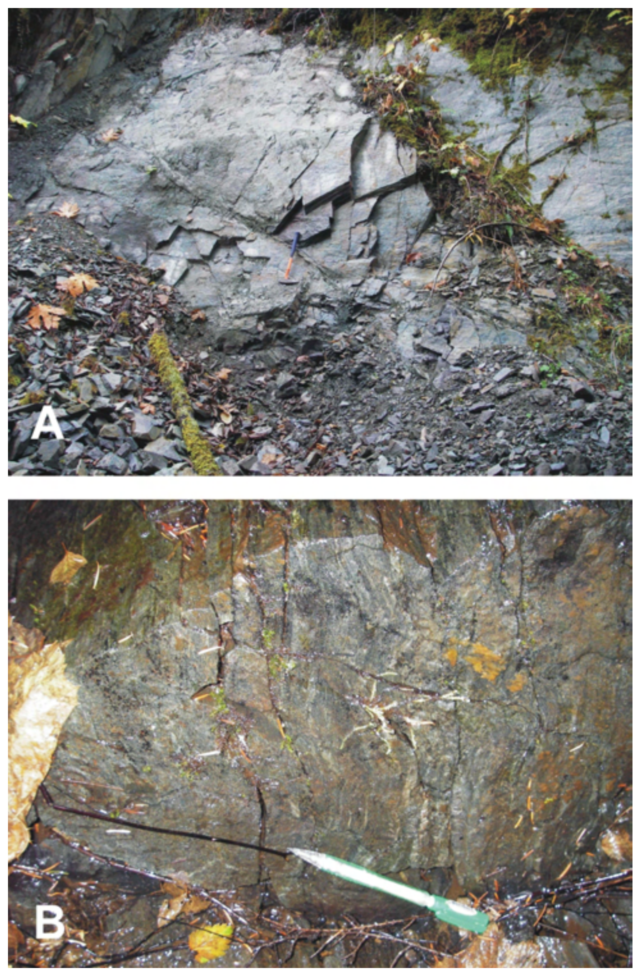

Figure 5. Intermediate volcanosedimentary rocks of the McLaughlin Ridge Formation (?) from the northern (A) and north-eastern (B) parts of the field area.

MINERALIZATION

Sulphide mineralization is widespread throughout the field area, and consists mainly of pyrite±chalcopyrite stringers and small pods/lenses associated with areas of intense sericite+silica alteration. Many of these sulphide occurrences are close to MINFILE (2006) occurrences, but some are not. For example, several zones of sulphide mineralization, consisting of pyrite±chalcopyrite stringers and patches up to 15 cm wide, occur in silicified and sericitized felsic volcanic rocks (tuff and quartz-feldspar porphyry) approximately 3 to 3.5 km east, along strike, from the known deposits (Fig 10).

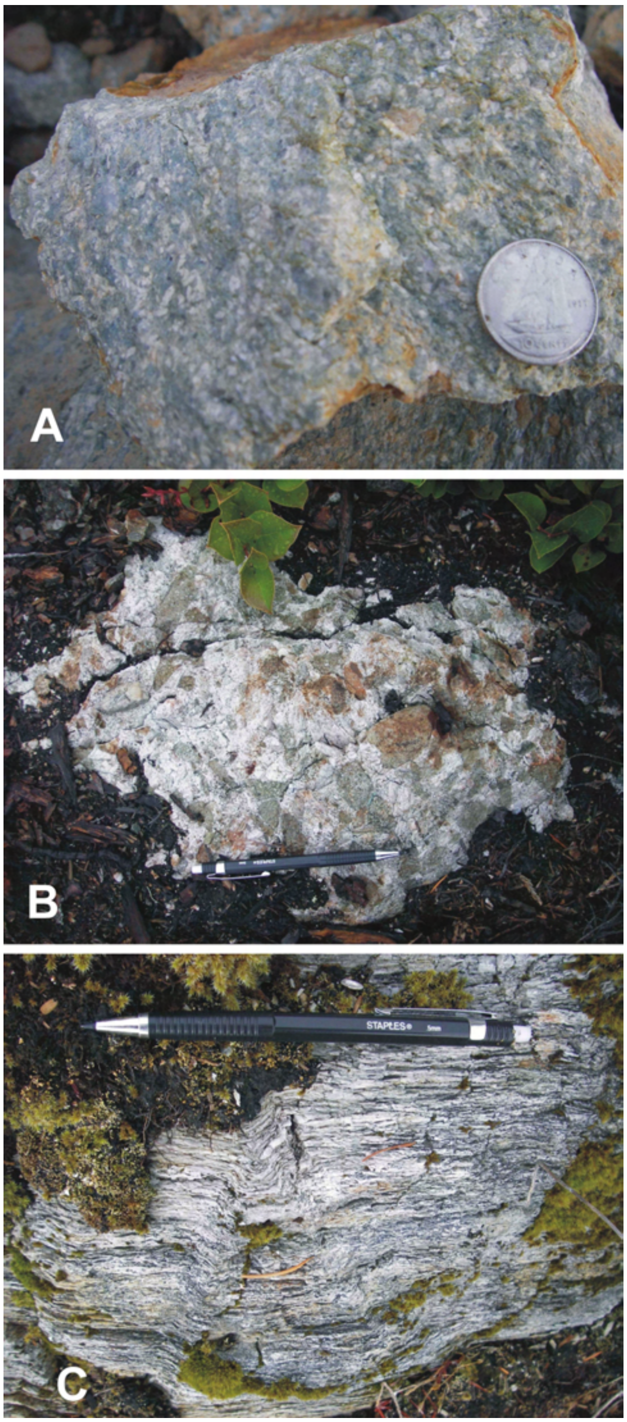

Figure 6. Felsic rocks of the McLaughlin Ridge Formation include A) rhyodacite porphyry, B) heterolithic tuff-breccia, and C) rhyodacite crystal tuff.

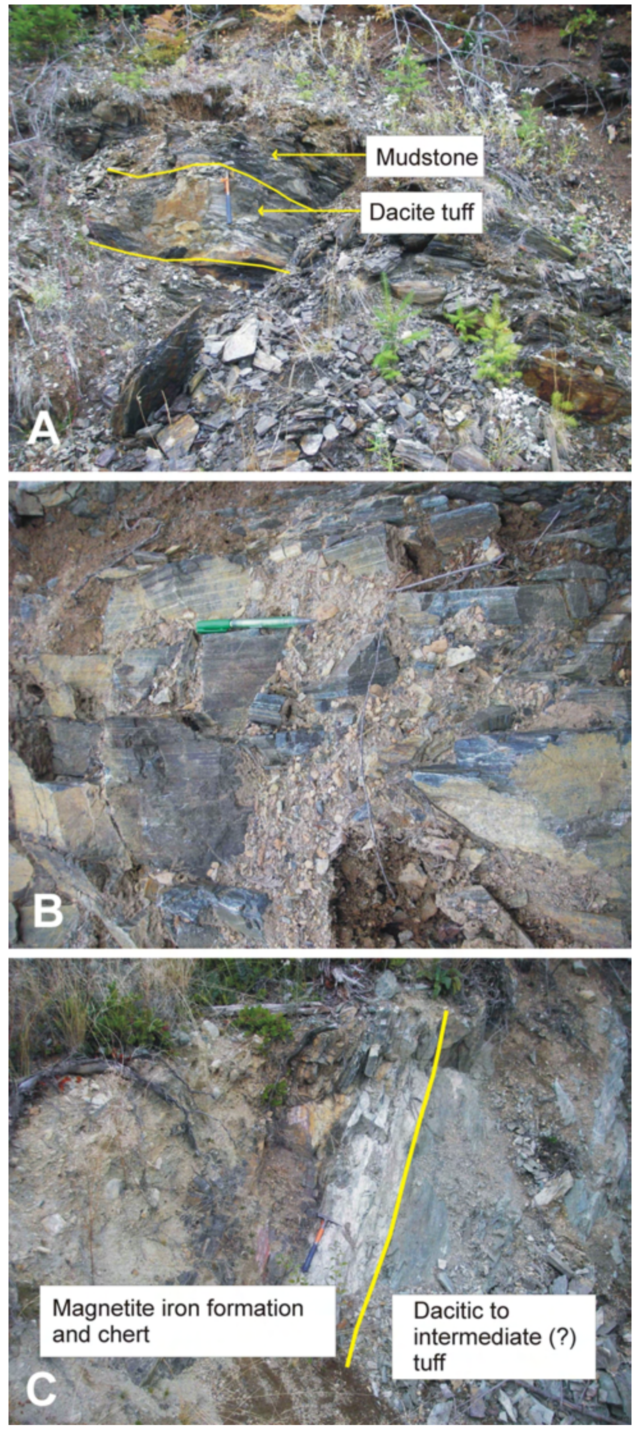

Figure 7. Rocks of the McLaughlin Ridge Formation: A) laminated mudstone interbedded with dacitic tuff; B) laminated chert; C) magnetite iron formation that forms a restricted layer (approximately 0.5–1 m thick) interbedded with laminated chert and dacitic to intermediate (?) tuff.

Also in the northeastern part of the map area (Fig 3), approximately 1.6 km northeast of the Lenora-Tyee deposits and approximately 900 m northeast of the Queen Bee MINFILE occurrence, abundant pyrite stringers up to 2 to 3 cm thick are associated with zones of intense silicification and sericitization of intermediate volcanosedimentary rocks. These occurrences are not documented in MINFILE, and do not show signs of significant exploration activity. Mineralization associated with the main workings is best documented in the vicinity of the Lenora deposit, where polymetallic massive sulphide mineralization was accessed via an adit trending 163°. This adit was excavated in highly silicified and sericitized felsic volcanic rocks with abundant silicified mudstone and/or chert (Fig 11). Here, sulphide mineralization consists of extensive foliation/bedding-parallel pyrite±chalcopyrite stringers and patches up to 15 cm wide, often associated with malachite staining.

Mineralization was not observed at the Richard III and Tyee workings, as the shafts used to access these deposits are sunk in gabbro. However, this suggests that the thickness of postmineral Triassic gabbro in many locations throughout the field area is not substantial enough to negate the potential for large VMS deposits.

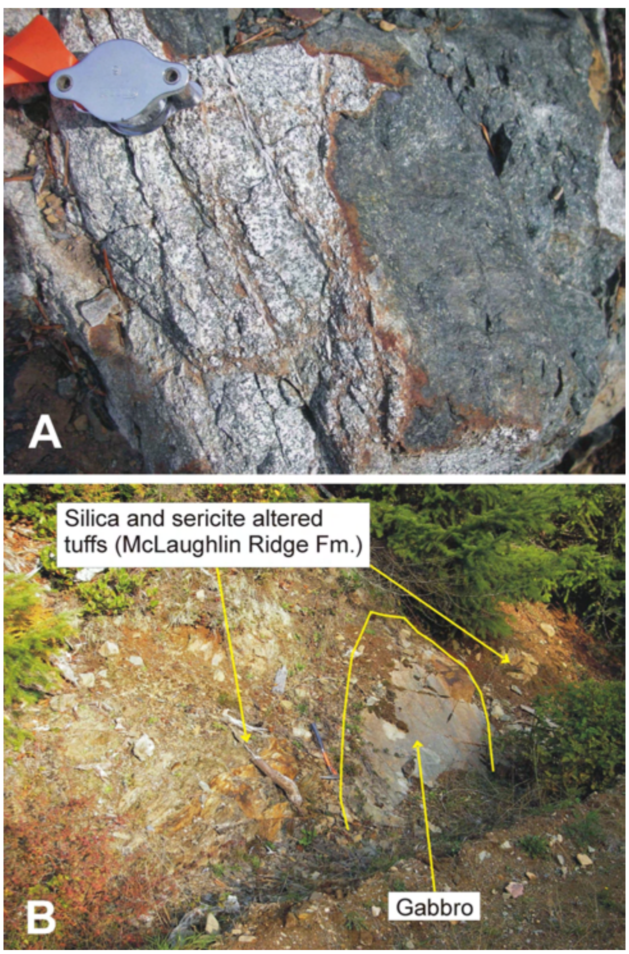

Figure 8. Triassic gabbros of the Big Sicker Mountain area: A) hornblende and plagioclase-bearing gabbro; B) gabbro crosscutting altered and gossanous volcanosedimentary rocks of the McLaughlin Ridge Formation

U-PB GEOCHRONOLOGY

Uranium-lead dating of zircons by laser-ablation inductively coupled plasma mass spectrometry (ICP-MS) is being used to constrain ages of eruption and/or intrusion of

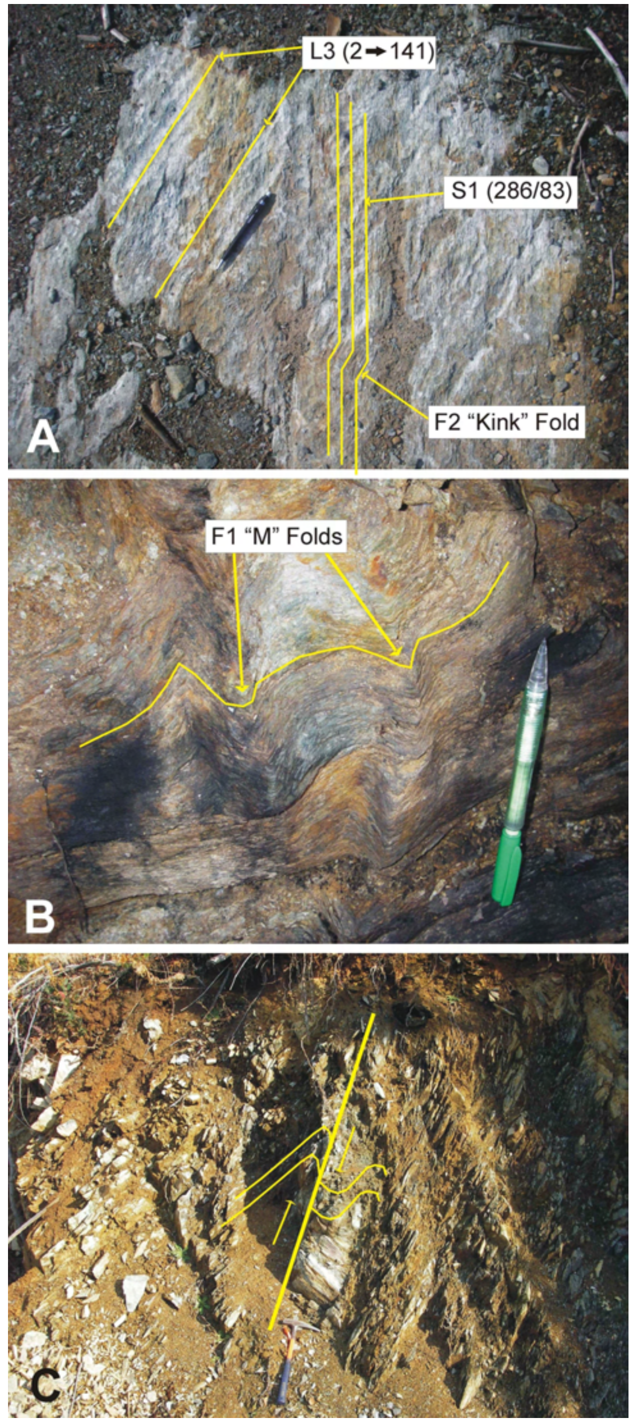

Figure 9. Structural geology of the Big Sicker Mountain area: A) east-striking S1 fabric in dacitic tuff is deformed by F2 kink folds; both of these structures are deformed by shallowly plunging F3 folds; B) steeply plunging F1 'M' folds in sericite and silica-altered rhyodacite tuff; C) north-side-up displacement in fault zone, indicated by drag folding in faulted dacitic tuff.

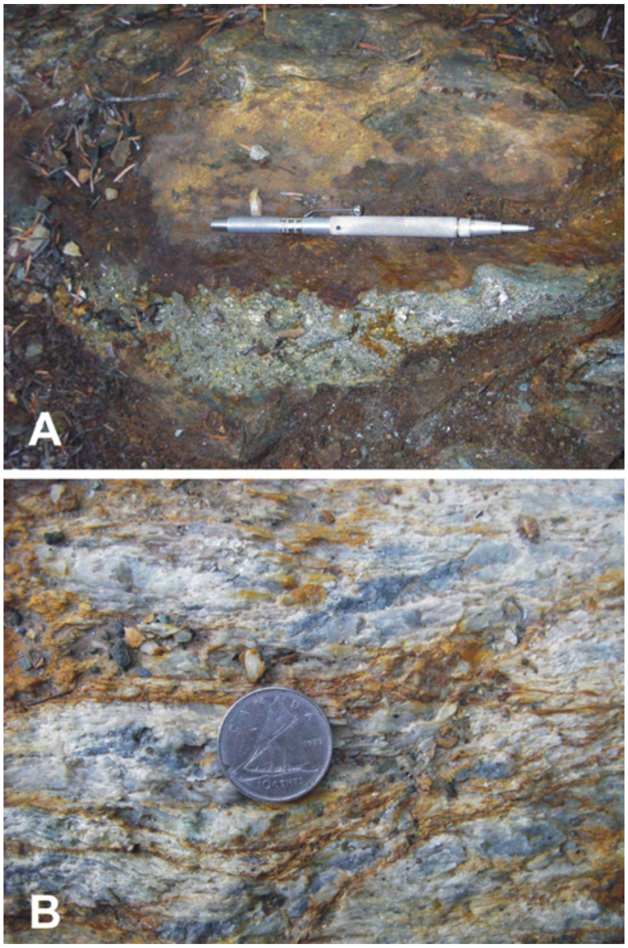

Figure 10. Selected new sulphide occurrences: A) 1 to 2% pyrite±chalcopyrite stringers (up to 15 cm wide) hosted in quartz-feldspar porphyry, eastern part of map area; B) strongly silica+sericite-altered volcanosedimentary rock with up to 3% disseminated and stringer pyrite, northeastern part of map area.

igneous rock units and to construct a chronostratigraphic framework for magmatism in the Sicker Group. This paper includes preliminary U-Pb zircon ages for six volcanic units in the southeastern Cowichan Lake uplift. Zircons were recovered from samples weighing approximately 10 kg using conventional crushing, grinding, wet shaking table, heavy liquids and magnetic methods. Selected grains were mounted in thermal-setting epoxy; the grain mounts were carefully ground down until the interior of the individual grains were exposed. The ground surfaces were then brought to a high polish using sequentially finer diamond pastes. The surfaces of the mounts were then washed with dilute nitric acid for ten minutes and rinsed with ultrapure water. Analyses were done in the Pacific Centre for Isotopic and Geochemical Research (PCIGR) facility at the University of British Columbia (UBC), using a New Wave™ 213 nm Nd-YAG laser coupled to a Thermo Finnigan™ Element2 high-resolution ICP-MS. Ablation took place within a New Wave 'Supercell' ablation chamber that is designed to achieve very high efficiency entrainment of aerosols into the carrier gas. Helium was used as the carrier gas for all experiments, and gas flow rates, together with other parameters such as torch position, were optimized prior to beginning a series of analyses. A 25 µm spot with 60% laser power was used, making line scans rather than spot analyses in order to avoid within-run elemental fraction. Each analysis consists of a 7 second background measurement (laser off), followed by an approximately 28 second data acquisition period with the laser firing. A typical analytical session consists of four analyses of the standard zircon, followed by four analyses of unknown zircons, two standard analyses, four unknown analyses, etc., and finally four standard analyses. Data were reduced using the GLITTER software, marketed by the Geochemical Evolution and Metallogeny of Continents (GEMOC) group at Macquarrie University, which automatically subtracts background measurements, propagates all analytical errors and calculates isotopic ratios and ages. Final ages for relatively young (Phanerozoic) zircons are typically based on a weighted average of the calculated $^{206}Pb/^{238}U$ ages for 10 to 20 individual analyses. Final interpretation and plotting of the analytical results employed the Isoplot software written by K.R. Ludwig.

Zircons recovered from all of the Sicker Group volcanic rocks form stubby, subhedral to euhedral pinkish prisms with vague internal growth zoning but no visible inherited cores. Approximately 25 grains were mounted from each sample and 12 to 20 individual analyses were carried out for each sample. The results are plotted in Figure 12, which shows a compilation of the calculated $^{206}Pb/^{238}U$ ages for individual analyses with a calculated weighted-average age.

Sample 05M-366 is from strongly foliated, sparsely quartz-phyric lapilli tuff collected 5 m north of the Lenora adit. Sixteen individual analyses were done and there is considerable scatter in the data (Fig 12a). One of the analyses gives a $^{206}Pb/^{238}U$ age of 403 Ma and is rejected as probably a xenocrystic grain incorporated into the tuff. A

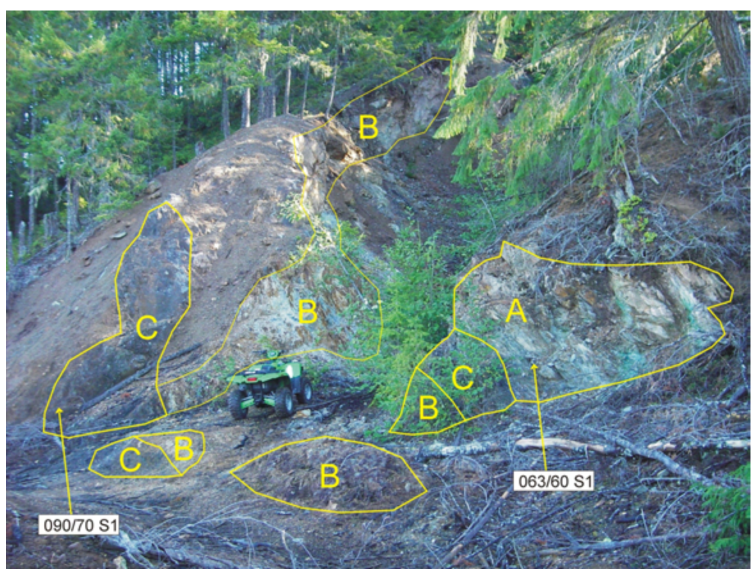

Figure 11. Geology of the Lenora adit area. Lithological units include A) rhyodacite crystal tuff (?) with abundant malachite staining and pyrite+chalcopyrite stringers up to 10 cm in size; B) variably silica-altered, black graphitic mudstone; and C) strongly sericite+silica-altered tuff (?) with abundant pyrite stringers.

weighted average of the remaining 15 analyses is 369.1 ±6.5 Ma. Note that the high mean standard weighted deviate (MSWD) of 10.7 reflects the large amount of scatter in the data. The calculated weighted average is considered to give an approximate age for eruption of the lapilli tuff unit that partly hosts the Lenora VMS deposit.

Sample 05M-393 is a strongly welded quartz and feldspar-phyric lapilli tuff at the main adit on the Lara property.

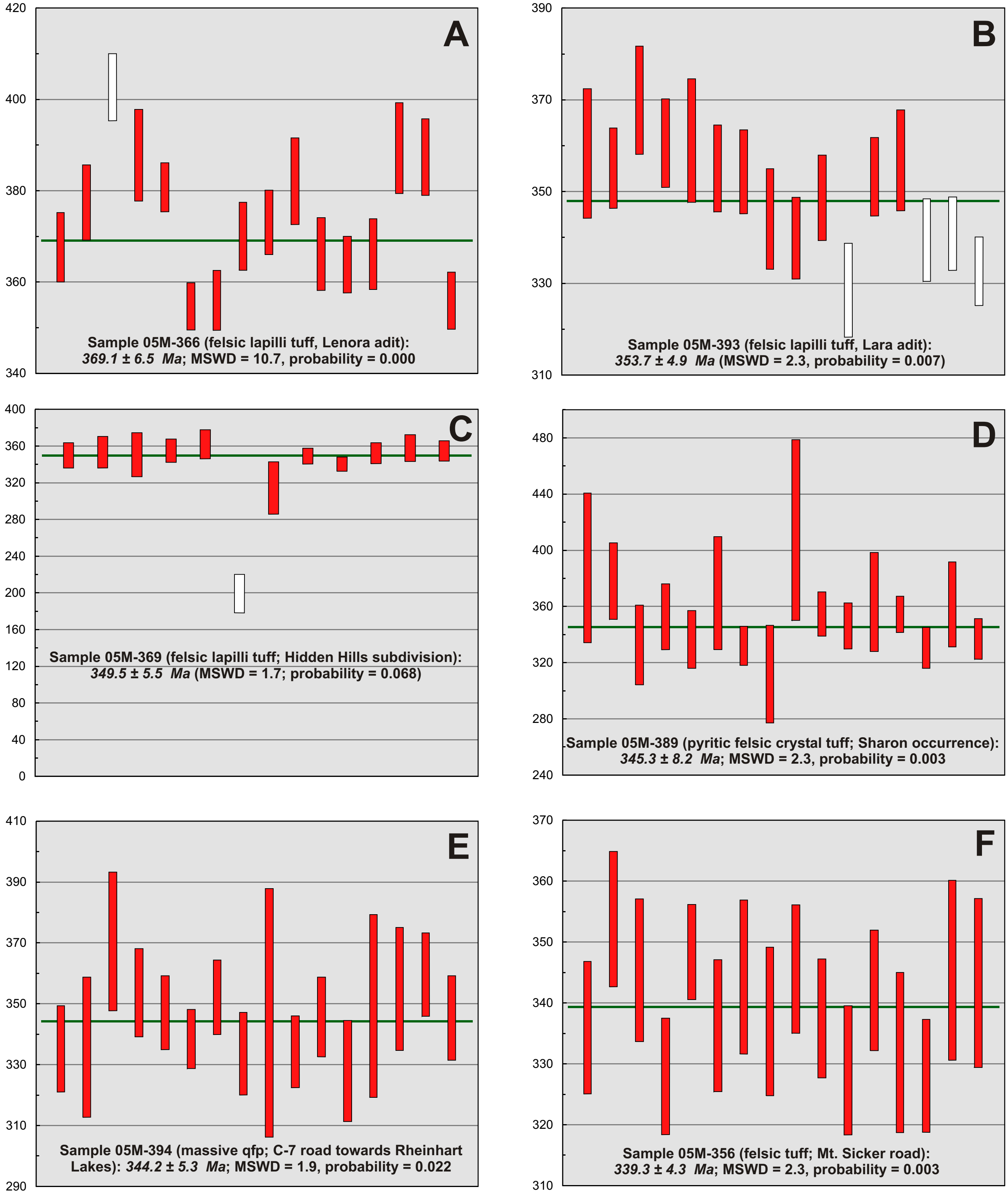

Figure 12. Calculated $^{206}Pb/^{238}U$ (zircon) ages for felsic volcanic rocks of the Sicker Group collected from the Cowichan Lake uplift during the course of this study.

Twelve of a total of sixteen individual analyses give a weighted average $^{206}Pb/^{238}U$ age of 353.7 ±4.9 Ma (Fig 12b), which is interpreted as the crystallization age for this felsic unit. The four remaining analyses appear to reflect minor postcrystallization Pb loss.

Sample 05M-369 is a moderately to strongly foliated, pyritic, quartz-phyric felsic lapilli tuff from a road exposure in the Hidden Hills subdivision, immediately east of the study area. Eleven of twelve individual analyses (Fig 12c) give a weighted average $^{206}Pb/^{238}U$ age of 349.5 ±5.5 Ma, which is interpreted as the crystallization age for this unit. One analysis gives a much younger $^{206}Pb/^{238}U$ age and is interpreted to have suffered postcrystallization Pb loss.

Sample 05M-389 is a strongly foliated, pyritic quartz-muscovite schist with scattered quartz eyes from the Sharon occurrence that is interpreted to be a deformed quartz-phyric crystal tuff. A weighted average $^{206}Pb/^{238}U$ age of 345.3 ±8.2 Ma for this sample, based on sixteen individual analyses (no rejects; Fig 12d), is interpreted as the crystallization age of the hostrocks for the Sharon mineralization.

Sample 05M-394 is a massive quartz-feldspar porphyry exposed along the C-7 road towards Rheinhart Lake, northwest of the Lara deposit. A weighted average $^{206}Pb/^{238}U$ age of 344.2 ±5.3 Ma was obtained for this sample, based on sixteen individual analyses (no rejects; Fig 12e), and is interpreted as the crystallization age for the porphyry body.

Sample 05M-356 was collected from a roadcut on the south side of the Mount Sicker road. It is a weakly to strongly foliated, quartz-phyric lapilli tuff. Sixteen individual analyses (no rejects) give a weighted average $^{206}Pb/^{238}U$ age of 339.3 ±4.3 Ma, which is interpreted as the crystallization age of this unit.

The range of ages obtained for felsic extrusive rocks and high-level felsic intrusions in this part of the Cowichan Lake uplift was unexpected. Only one other well-constrained age is presently available for any of the Sicker Group units in the Big Sicker Mountain area: a U-Pb zircon age of 362 ±2 Ma reported by Parrish and McNicoll (1992) for a quartz-feldspar porphyry body of the Saltspring intrusive suite along the Island Highway on the east side of Big Sicker Mountain. The preliminary age of 369.1 ±6.5 Ma reported here for felsic lapilli tuff that partly hosts the Lenora VMS orebody (sample 05M-366 above) is within uncertainty of both the porphyry body dated by Parrish and McNicoll (1992) and a separate body of Saltspring intrusions in the Burgoyne Bay area on western Saltspring Island that was dated at 369.7 ±1.9 Ma (Sluggett, 2003; Sluggett and Mortensen, work in progress). Two other samples of Saltspring intrusions from near Erskine Point and Lake Stowell on Saltspring Island, which were dated by Sluggett (2003) and Sluggett and Mortensen (work in progress), gave U-Pb ages of 359.1 ±1.4 and 356.5 ±1.7 Ma, respectively, and a sample of felsic tuff of the McLaughlin Ridge Formation near Isabella Point in the southwest part of Saltspring Island gave a U-Pb age of 354.1 ±1.2 Ma.

Previous work had therefore already demonstrated a significant age range for McLaughlin Ridge and Saltspring intrusive suite magmatism. The new data from this study, however, indicate that felsic magmatism lasted from *ca.* 370 Ma until at least as young as 339 Ma. More importantly, these data suggest that VMS mineralization of at least two separate ages is present in the southeastern part of the Cowichan Lake uplift. Mineralization at the Lenora deposit is hosted by felsic tuff (and interlayered sedimentary rocks) with a depositional age of *ca.* 369 Ma, whereas hostrocks for the Lara deposit give an age of 353.7 Ma. Felsic tuff that hosts bands of stratabound, possibly syngenetic sulphide minerals at the Sharon occurrence and in the vicinity of the Hidden Hills subdivision on the east side of Big Sicker Mountain are even younger, at 345.3 and 349.5 Ma, respectively. There are as yet no reliable crystallization ages for felsic volcanic rocks that host VMS mineralization at the Myra Falls deposit in the Buttle Lake uplift. Sampling of the Myra Falls hostrocks for U-Pb dating to facilitate comparison with the ages of VMS mineralization in the southeastern Cowichan Lake uplift is planned for the fall of 2006.

LITHOGEOCHEMISTRY OF IGNEOUS ROCKS IN THE BIG SICKER MOUNTAIN AREA

Sixteen samples of Sicker Group igneous rocks from the southeastern part of the Cowichan Lake uplift (from Rheinhart Lake on the northwest to southern Saltspring Island on the southeast) were analyzed for major, trace and rare earth elements in order to better characterize the petrochemistry of the various igneous units in the area. These analyses were conducted at ALS Chemex, using a combination of x-ray fluorescence (XRF) and ICP-MS methods. Data are presented in a series of plots in Figure 13, along with data from an additional 11 samples of Sicker Group rock units on Saltspring Island that were reported by Sluggett (2003). The two data sets compare very closely and the following observations are based on the combined dataset.

On a Zr/TiO_2 versus Nb/Y plot (Fig 13a; Winchester and Floyd, 1977), volcanic and volcaniclastic rocks of the Nitinat Formation fall in the subalkaline basalt and basaltic andesite fields. On a V versus Ti plot (Fig 13b; Shervais, 1982), the samples lie in the island arc tholeiite field. Samples of the Saltspring intrusive suite plot as subalkaline and rhyodacite/dacite to rhyolite in composition on a Zr/TiO_2 versus Nb/Y plot (Fig 13a; Winchester and Floyd, 1977), and are of volcanic arc affinity on a Nb versus Y tectonic discrimination diagram (Fig 13c; Pearce *et al.*, 1984). On a Zr/TiO_2 versus Nb/Y plot (Fig 13a; Winchester and Floyd, 1977), McLaughlin Ridge samples span the subalkaline rhyodacite/dacite to rhyolite compositional fields (except for one andesitic sample), and are of volcanic arc affinity on a Nb versus Y tectonic discrimination diagram (Fig 13c; Pearce *et al.*, 1984). A sample of dark green, chlorite-rich volcanosedimentary rock from the north end of the map area (05M-355) plots as subalkaline andesite on a Zr/TiO_2 versus Nb/Y diagram (Fig 13a; Winchester and Floyd, 1977), and as an island arc tholeiite on a V versus Ti diagram (Fig 13b; Shervais, 1982). A primitive mantle normalized multi-element diagram (Fig 13d; Sun and McDonough, 1989) for all samples shows weak to moderate light rare earth element (LREE) enrichment and negative Nb and Ti anomalies, typical for rocks generated in a volcanic arc setting.

Although samples from the McLaughlin Ridge Formation partially overlap with the roughly coeval and probably comagmatic Saltspring intrusive suite (Fig 13), they show considerably more scatter and include one andesitic outlier. This outlier may be the result of a volcaniclastic origin involving a mafic epiclastic component reworked from underlying Nitinat Formation, or a pulse of intermediate volcanism in the McLaughlin Ridge Formation. This scenario also applies to the intermediate tuff collected from the north end of the property (05M-355). Although this unit lacks the clinopyroxene phenocrysts that are characteristic of Nitinat Formation mafic units, the composition of this single sample is very similar to that of Nitinat units. If this unit is actually Nitinat rather than McLaughlin Ridge Formation, it would help constrain where the local base of the McLaughlin Ridge is and hence provide a useful stratigraphic marker in the vicinity of the known VMS deposits.

VOLCANOGENIC MASSIVE SULPHIDE MINERALIZATION IN THE BIG SICKER MOUNTAIN AREA

The southeastern portion of the Cowichan Lake uplift is one of two exposures of the Sicker Group where volcanogenic massive sulphide (VMS) mineralization is known to occur, the other being the Myra Falls area in the Buttle Lake uplift (Fig 1). Most known VMS occurrences in the Sicker Group are of the Kuroko type (or 'bimodal felsic type', as defined by Franklin *et al.*, 2005) and are hosted by felsic volcanic and volcaniclastic rocks of the McLaughlin Ridge Formation or equivalents. However, examples of manganiferous and/or pyritic chert horizons that may be exhalitive in origin are also locally present in

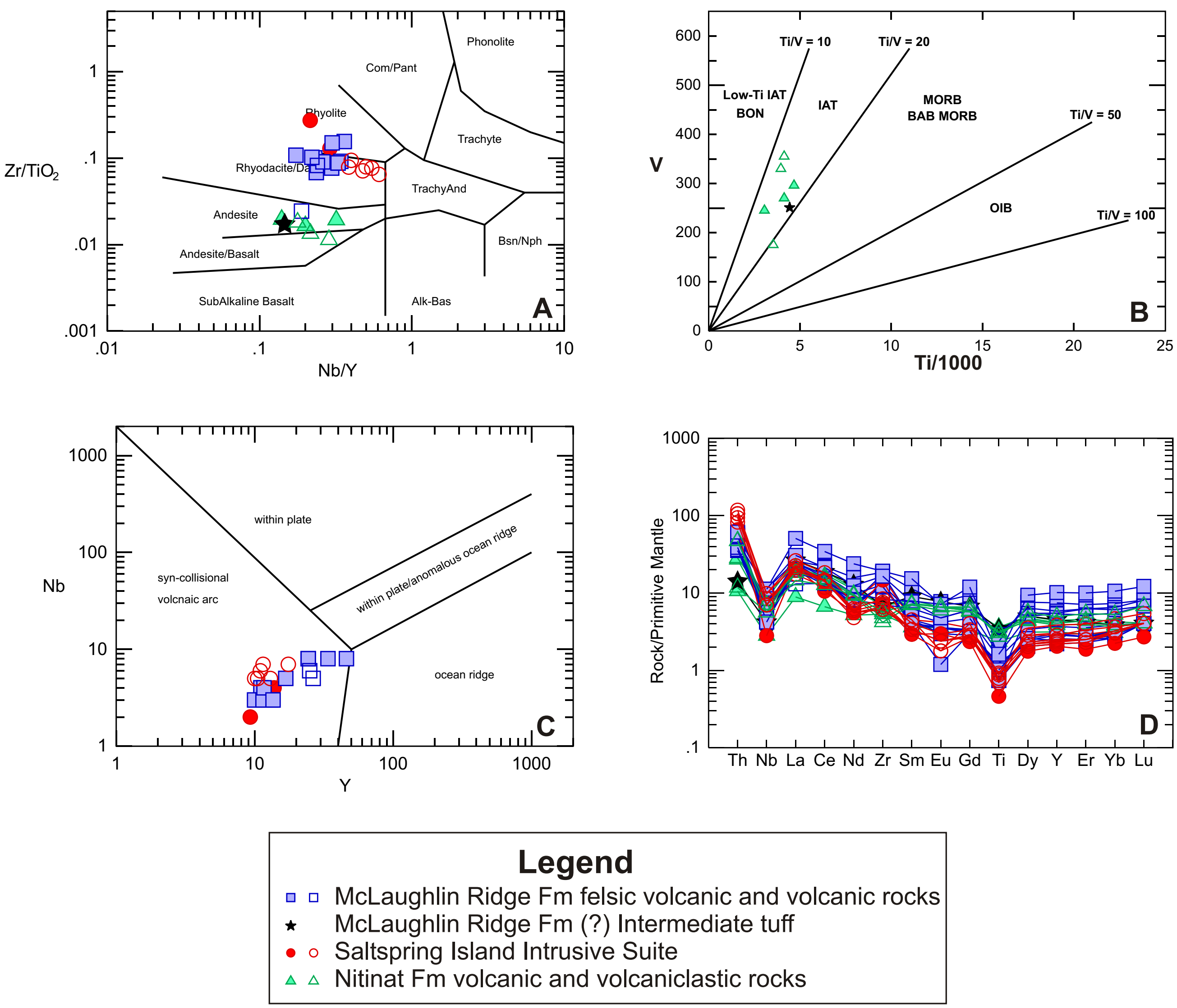

Figure 13. Lithogeochemical plots for Sicker Group igneous rock units in the southeastern part of the Cowichan Lake uplift. Solid symbols are from this study; open symbols are from Sluggett (2003). Petrochemical fields defined from the following sources: A) Zr/TiO_2 versus Nb/Y plot (Winchester and Floyd, 1977); B) V versus Ti (Shervais, 1982); C) Nb versus Y tectonic discrimination diagram (Pearce *et al.*, 1984); D) multi-element diagram normalized to primitive mantle (Sun and McDonough, 1989). Abbreviations: BAB, back-arc basin; IAT, island-arc tholeiite; BON, boninite; MORB, mid-ocean-ridge basalt; OIB, ocean-island basalt.

the upper Duck Lake Formation and the lowermost Fourth Lake Formation (*e.g.*, Massey and Friday, 1989; this study). Three VMS deposits have been mined historically in the Big Sicker Mountain area: the Lenora, Tyee and Richard III (MINFILE occurrences 092B 001–003, respectively; Fig 1). Production data reported in the MINFILE (2006) mineral inventory indicate that, between 1898 and 1909, a total of 229 221 t of ore were mined from these three deposits, with recovered grades of 4.0% Cu, 4.8 g/t Au and 100 g/t Ag. The three deposits were mined as a single operation (the Twin J mine) between 1942 and 1952; during that period, a total of 48 082 t of ore with a recovered grade of 7.6% Cu, 3.4% Pb, 1.0 g/t Au and 41.7 g/t Au were mined. Exploration of the Big Sicker Mountain area has been carried out sporadically since the early 1960s. The most recent estimate of existing resources, based on work between 1967 and 1970, is 317 485 tonnes grading 1.6% Cu, 0.7% Pb, 6.6% Zn, 4.1 g/t Au and 140.5 g/t Ag (The Northern Miner, 1969). Exploration by Minnova Incorporated in the late 1990s (Wells, 1990) included some diamond-drilling in the vicinity of the old mines but did not lead to a revised resource estimate. Stratiform and stratabound mineralization in the Lenora, Tyee and Richard III deposits is hosted mainly in cherty felsic tuff and fine-grained carbonaceous clastic rocks. Two main ore types are present: 1) polymetallic baritic ore with variable amounts of fine-grained pyrite, sphalerite, chalcopyrite and galena, and 2) quartz-rich ore consisting mainly of quartz and chalcopyrite. Ore at the Lenora deposit forms two lenticular orebodies that are contained within folded sedimentary strata.

Several other mineral occurrences that are interpreted to be syngenetic in origin have also been explored historically through adits, trenching and limited drilling in the Big Sicker Mountain area. These include the Key City (MINFILE occurrence 092B 087), immediately north-northwest of the Lenora adit; the Queen Bee (MINFILE occurrence 092B 088), approximately 1 km north of the Lenora adit; and the Northeast Copper (MINFILE occurrence 092B 099), approximately 2 km east-northeast of the Lenora adit (Fig 2). Sulphide mineralization in these occurrences comprises mainly disseminated pyrite (±pyrrhotite), chalcopyrite and locally sphalerite in schistose andesitic to rhyolitic volcanic rocks and/or associated carbonaceous sedimentary rocks, or in bands of cherty tuff.

The Lara deposit (MINFILE occurrence 092B-129) is a polymetallic VMS deposit hosted within the same package of Sicker Group stratigraphy and located approximately 10 km along strike to the northwest from Big Sicker Mountain. The main hostrocks are steeply dipping, intermediate to felsic volcanic and volcaniclastic strata of the McLaughlin Ridge Formation. A resource of approximately 500 000 t averaging 1.0% Cu, 1.2% Pb, 5.9% Zn, 4.3 g/t Au and 90 g/t Ag in two separate mineralized bodies has been reported (George Cross News Letter Ltd., 1992; Laramide Resources Ltd., 2006). Three distinct styles of mineralization are recognized at the Lara: a massive sulphide facies, a banded and laminated facies and a stringer facies. Mineralization occurs in three main bodies, and has been traced for a total strike length of at least 2 km and a down-dip extent of at least 440 m.

The Sharon occurrence (MINFILE occurrence 092B 040), located approximately 3.5 km northwest of Big Sicker Mountain (between the Mount Sicker and Lara deposits), has also been tested by three short adits as well as drilling and trenching. Hostrocks in the area comprise pyritic quartz-muscovite and chlorite-muscovite schists that locally preserve textures indicating a mainly lapilli tuff protolith. Small bodies of weakly foliated quartz-feldspar porphyry are also present. The Sharon is mainly a copper occurrence, with zones of disseminated to semimassive recrystallized pyrite and minor chalcopyrite in bands of strongly foliated and transposed metavolcanic rocks.

The authors are using Pb isotopic analyses of sulphide minerals from various deposits and showings within the Sicker Group in the Cowichan Lake uplift to differentiate between syngenetic mineralization and younger epigenetic mineralization. Previous studies by Godwin *et al.* (1988) and Andrew and Godwin (1989) provide an excellent compositional database for both VMS and epigenetic occurrences hosted by Sicker Group strata on southern and central Vancouver Island, including data from the Mount Sicker and Lara deposits (Fig 3). Lead isotope analyses are presently being carrying out on sulphide minerals from a suite of mineralized samples from throughout the southeastern Cowichan Lake uplift, including banded sulphide minerals at the Sharon occurrence (MINFILE occurrence 092B 040), pyrite from thin conformable bands of pyrite (with minor base metal enrichment; A. Francis, pers comm, 2005) within quartz-feldspar-phyric lapilli tuff in the Hidden Hills subdivision, and several new, possibly syngenetic occurrences that were discovered during the 2006 field work. The aim of this part of the study is to evaluate the total extent of syngenetic mineralization in the Big Sicker Mountain area and to distinguish which, if any, of the occurrences are younger and unrelated to submarine VMS processes. These new data will make it possible to fit all of the definite syngenetic occurrences in the Big Sicker Mountain area into their correct stratigraphic context and evaluate the true lateral and vertical extent of VMS mineralization in the area. This approach will subsequently be extended to cover the entire Cowichan Lake uplift.

IMPLICATIONS FOR VMS POTENTIAL IN THE BIG SICKER MOUNTAIN AREA

Evaluating the remaining potential within the vicinity of the existing Lenora, Tyee and Richard III mines, and potential for new, as yet undiscovered mineralization elsewhere in the Big Sicker Mountain area, is complicated by the difficulty in correlating stratigraphy from one area to another due to the lack of good marker horizons, and also by complexity imposed by postmineral folding and faulting. In addition, the three-dimensional extent of the Triassic gabbro bodies must be ascertained in order to determine the volume of prospective McLaughlin Ridge Formation that exists in the subsurface. Furthermore, the presence of numerous proven or probable syngenetic mineral occurrences scattered throughout the study area, including the Key City, Queen Bee and Northeast Copper occurrences (MINFILE occurrences 092B 087, 088 and 099, respectively), together with unnamed stratiform sulphide minerals in the Hidden Hills subdivision and newly discovered occurrences in the northern and eastern parts of the map area, demonstrate that VMS mineralization is widely developed within this package of Sicker Group strata. The authors have not yet been able to establish definitively the direction of stratigraphic younging within the McLaughlin Ridge Formation in the Big Sicker Mountain area. This is critical, because some of the styles of mineralization, especially the quartz-copper ores, could be interpreted to represent stringer or vent zone mineralization beneath as yet undiscovered stratiform ore lenses.

PLANNED FUTURE WORK

Work planned for the 2007 field season in the immediate Big Sicker Mountain area will focus on unravelling the structural and stratigraphic complexity through ongoing surface mapping, as well as integration of all available surface and subsurface information from previous exploration and mining activity in that area into a detailed three-dimensional model for the area. In particular, an attempt will be made to place all known stratiform and/or stratabound mineralization in the area into a volcanological framework for this part of the Cowichan Lake uplift. Studies will also be extended farther to the northwest in the Cowichan Lake uplift, as far as Rheinhart Lake, to encompass the other main areas of known VMS mineralization. In parallel with the geological mapping and synthesis work, the authors will also carry out additional lithogeochemical studies and U-Pb dating, as well as focused geological mapping in key areas elsewhere in the Cowichan Lake uplift.

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