Stratigraphic and Paleotectonic Studies of the Middle Paleozoic Sicker Group and Contained VMS Occurrences, Vancouver Island, British Columbia[1]

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INTRODUCTION

Volcanic strata of the mid-Paleozoic Sicker Group on Vancouver Island (Fig. 1) host the Myra Falls volcanogenic massive sulphide (VMS) deposit. With combined production and proven and probable reserves in excess of 30 million tonnes of Zn-Cu-(Au-Ag) ore, this is currently the largest and most productive VMS mine in western Canada. Other VMS deposits and occurrences are known elsewhere within the Sicker, and deposits in the Mt. Sicker area (Mt. Sicker, Lenora and Twin J; MINFILE (2005) occurrences 092B 001, 002, 003; Fig. 1) have been mined on a relatively small scale. Exploration for additional VMS deposits within the Sicker Group, however, has met with only limited success outside the immediate area of the Myra Falls deposit. Despite the considerable potential for such deposits in the Sicker and the current high base-metal prices, VMS exploration within the group has been at a low level for the past decade. A significant impediment to VMS exploration within the Sicker Group is the relatively poor overall understanding of the geology of this assemblage, which makes it difficult to develop a sound regional exploration strategy based on typical stratigraphic and volcanological criteria. Detailed studies of the group in the past have been hampered by generally poor exposure and limited access, except in the immediate vicinity of the Myra Falls deposit (e.g., Juras, 1987; Barrett and Sherlock, 1996; Robinson *et al.*, 1996). New logging-road construction in the 1980s and 1990s greatly improved access to and exposure of the Sicker Group in central Vancouver Island, and regional mapping studies of this area were carried out by personnel of the BC Geological Survey (e.g., Massey and Friday, 1987, 1989; Massey, 1995a, b, c; see also Yorath *et al.*, 1999). These studies did not include all of the exposed Sicker Group, however, and available data are still insufficient to produce a comprehensive analysis of the stratigraphy and evolution of the group.

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A new integrated geological, geochemical and geochronological study of the Sicker Group on Vancouver Island, funded by Geoscience BC, was begun in 2005. This study has the following main goals:

- develop a model for the physical volcanology and eruptive history of the Sicker Group
- constrain the paleotectonic evolution of this portion of Wrangellia
- evaluate the nature and stratigraphic position(s) of VMS deposits and occurrences within the Sicker Group

Results of the study will provide a much improved framework for VMS exploration within the Sicker Group. Two weeks of reconnaissance work were carried out by the author in September of 2005, and a new Ph.D. level graduate student will begin work on the project in the summer of 2006.

REGIONAL GEOLOGY OF THE SICKER GROUP AND REVIEW OF PREVIOUS WORK

The mid-Paleozoic Sicker Group and correlative Skolai Group in Alaska represent the oldest exposed rocks in Wrangellia (e.g., Monger and Nokleberg, 1996). The Sicker Group and the Late Paleozoic Buttle Lake Group that overlies it on Vancouver Island and the Canadian Gulf Islands are exposed in four major structural uplifts: the Buttle Lake, Bedingfield, Nanoose and Cowichan Lake uplifts (Fig. 1).

Most previous investigations of the Sicker and overlying Buttle Lake groups have focused on the Buttle Lake and Cowichan Lake uplifts. This work concentrated mainly on the stratigraphy of the two groups; however. a limited amount of geochronology has also been carried out, as well as detailed biostratigraphic and lithogeochemical studies of a few localities. Stratigraphic nomenclature for the Sicker and Buttle Lake groups has changed substantially over time (Fig. 2), and this complicates comparison between data produced by the different generations of work in the different regions.

Muller (1977, 1980) subdivided volcanic-dominated Paleozoic successions on Vancouver Island into two formations, the lower Nitinat and the upper Myra Formation. He also introduced the informally named ‘sediment sill unit’ (thin-bedded sedimentary rocks intruded by diabase sills), which stratigraphically separates the Myra and overlying Buttle Lake formations. The most recent revision of Sicker and Buttle Lake nomenclature (Massey, 1995a, b, c; Yorath *et al.*, 1999) divides the original Sicker Group into two groups: the Sicker Group (revised), comprising the Nitinat and underlying Duck Lake formations (previously the lower Nitinat Formation), as well as the McLaughlin Ridge Formation; and the overlying Buttle Lake Group (Fig. 2). From base to top, the Buttle Lake Group comprises the Fourth Lake and the Mount Mark formations, as well as the newly identified St. Mary Lake Formation. In this stratigraphic arrangement, the McLaughlin Ridge Formation is equivalent to all of Muller's Myra Formation. This revised stratigraphic nomenclature is presently only considered valid for the Cowichan Lake uplift (Yorath *et al.*, 1999).

Juras (1987) reinterpreted the stratigraphy of the Sicker Group specifically within the Buttle Lake uplift. He retained the Sicker and Buttle Lake group divisions; however, new terminology was proposed for the subdivisions of the Sicker. According to Juras, the lowermost unit in the Sicker Group in the Buttle Lake uplift is the Price Formation (which Yorath *et al.* (1999) correlate with all of the Duck Lake Formation and the lower Nitinat Formation). Above the Price Formation is the Myra Formation, which corresponds to the upper Nitinat and lower McLaughlin Ridge formations (and is therefore not equivalent to Muller's Myra Formation; Yorath *et al.*, 1999). Juras' Thelwood and Flower Ridge formations approximately correlate with the upper McLaughlin Ridge Formation of Yorath *et al.* (1999).

Collectively the Sicker Group comprises three successive volcanic and volcaniclastic formations that are thought to record the evolution of an oceanic magmatic arc. The following synthesis of Sicker Group evolution is summarized from Massey (1995a). The lowermost Duck Lake Formation consists of dominantly tholeiitic basalts, which pass upward into calcalkaline lavas. The Duck Lake Formation is interpreted to represent the oceanic crust basement and possibly the earliest stage of Sicker arc magmatism. The Duck Lake is overlain by mafic, submarine, volcanic and volcaniclastic rocks of the Nitinat Formation, which 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 occurred from several widely scattered centres, whereas the McLaughlin Ridge Formation is thought to represent eruption from one or more major volcanic edifices. One such magmatic centre is located in the Cowichan Lake uplift in the Duncan and Saltspring Island area (Fig. 1), and is defined by voluminous comagmatic felsic intrusions (Saltspring intrusions). Plant material and trace fossils indicate that at least some the McLaughlin Ridge volcanism was subaerial. Deposition of the Fourth Lake Formation of the Buttle Lake Group on top of the McLaughlin Ridge represents the end 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.

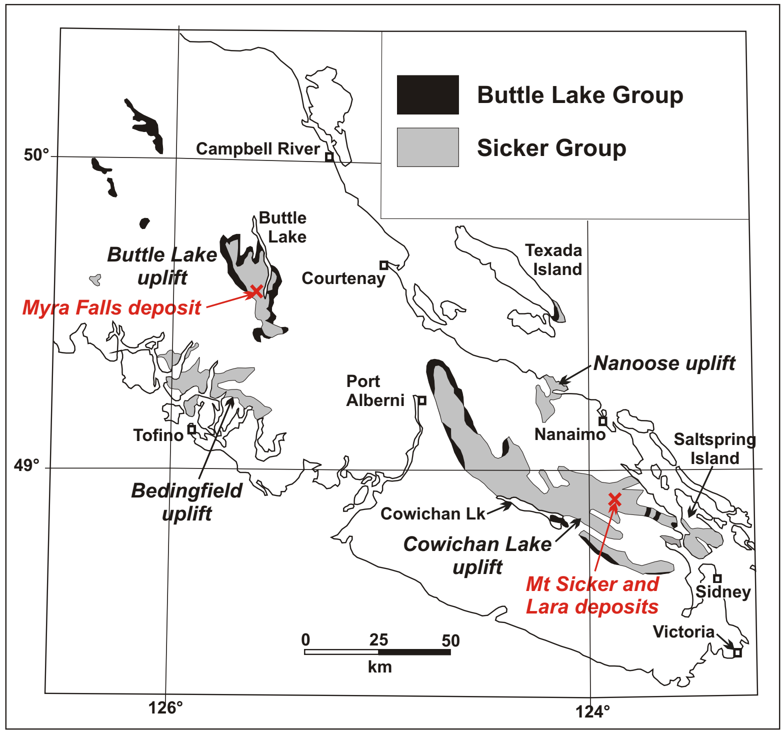

Figure 1. Distribution of Paleozoic strata of the Sicker and Buttle Lake groups on Vancouver Island and the Gulf Islands.

The most recent study of the Sicker and Buttle Lake groups was undertaken by Sluggett (2003) as part of a B.Sc. thesis at the University of British Columbia (UBC) under the author's supervision. The study included detailed petrographic and geochemical investigation of the Sicker Group and, to a lesser extent, the Buttle Lake Group on southern Saltspring Island, as well as detailed U-Pb dating of several key rock units. Although this study focused on a very small geographic area, the results underscore the fact that substantial problems remain in our understanding of the evolution of the Paleozoic portion of southern Wrangellia. Major results of the work by Sluggett (2003) and Sluggett and Mortensen (2003) include the following:

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	Sicker Gp	McLaughlin Ridge Fm
			Thelwood Fm		
			Myra Fm		
	Nitinat Fm		Price Fm		Nitinat Fm
					Duck Lk Fm

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

- U-Pb zircon dating indicates that two distinct episodes of felsic magmatism are represented in this portion of the Cowichan Lake uplift. Felsic volcanic rocks of the McLaughlin Ridge Formation and most of the geochemically similar and presumably genetically related Saltspring intrusions yield U-Pb ages in the range 356.5–359.1 Ma. However, a somewhat older phase of magmatism is indicated by a U-Pb age of 369.7 Ma for a separate body of Saltspring intrusion at Burgoyne Bay on southern Saltspring Island. The extent of this older magmatic episode is unknown; however, most previous U-Pb dating studies of felsic rocks in the Sicker Group (see later discussion) have produced imprecise ages of ~370 Ma, suggesting that the bulk of the McLaughlin Ridge Formation regionally, including the host rocks for the Myra Falls deposit, may correlate with the older magmatic event recognized on Saltspring Island.
- A minor component of inherited zircon with ages up to 420 Ma occurs within the Sicker Group. This is inconsistent with the dominantly intraoceanic-arc setting that has previously been suggested for the Sicker Group. In addition, all of the Saltspring intrusions that were sampled yield weakly peraluminous compositions and two are garnet bearing; these observations are also inconsistent with an oceanic-arc setting.
- Detrital zircons recovered from a grit unit that contains felsic volcanic lapilli, in the lower portion of the Fourth Lake Formation, yield consistent U-Pb ages of ~320 Ma. This indicates that this portion of the Fourth Lake Formation is at least 40 m.y. younger than the McLaughlin Ridge Formation that it is interpreted to directly overlie. This suggests the possibility of substantial unconformities within the Sicker Group.
- Mafic sills that intrude the Fourth Lake Formation and form part of the 'sediment sill unit' of Muller (1980) yield Late Triassic U-Pb baddeleyite ages and are thus unrelated to the sedimentary rocks into which they have been emplaced. The mafic sills represent subvolcanic feeders to basalts of the overlying Karmutsen Group (e.g., Greene et al., 2005).

VMS MINERALIZATION IN THE SICKER GROUP

In a review of potential for VMS mineralization in BC, Massey (1999) identified definite or potential VMS occurrences within three of the four uplifts of Sicker Group on Vancouver Island (Buttle Lake, Cowichan Lake and Bedingfield; Fig. 1). Most known VMS occurrences are of the Kuroko type and are hosted by felsic volcanic or volcaniclastic rocks of the McLaughlin Ridge Formation or equivalents. However, examples of manganiferous and/or sulphidic chert horizons that may be exhalitive in origin are also locally present in the upper Duck Lake Formation and the lowermost Fourth Lake Formation (e.g., Massey and Friday, 1989). Occurrences such as the Mt. Sicker and Lara in the southeastern and central part of the Cowichan Lake uplift (MINFILE occurrences 092B 001-003 and -129, respectively; Fig. 1) consist of baritic laminated base metal sulphide accumulations within felsic tuffaceous units of the McLaughlin Ridge Formation, and are clearly syngenetic in origin. Descriptions of some of the other occurrences taken from BC MINFILE, however, suggest that the identification of some of these occurrences as being syngenetic in origin is somewhat more equivocal, and at least some are more likely epigenetic occurrences associated with a later mineralizing event in the region, possibly related to the emplacement of the Early to Middle Jurassic Island intrusions. However, Massey's review serves to highlight the incompletely tested VMS potential remaining within the Sicker Group. Previous studies by Godwin et al. (1988) and Andrew and Godwin (1989) indicate that it is possible to confidently discriminate between syngenetic Paleozoic mineral occurrences and younger epigenetic occurrences within the Sicker using sulphide Pb isotopes (Fig. 3).

GOALS OF THE NEW PROJECT

A review of available data regarding the nature of the Sicker Group in the various uplifts on Vancouver Island suggests that significant problems exist in terms of how individual rock units correlate from one uplift to another and at what exact stratigraphic level known VMS mineralization occurs. Volcanic and volcaniclastic assemblages in an arc setting such as the Sicker typically show rapid lateral and vertical facies changes, and it is therefore difficult to establish confident correlations between widely separated exposures. Detailed correlations within and between the various uplifts must therefore be based largely on precise

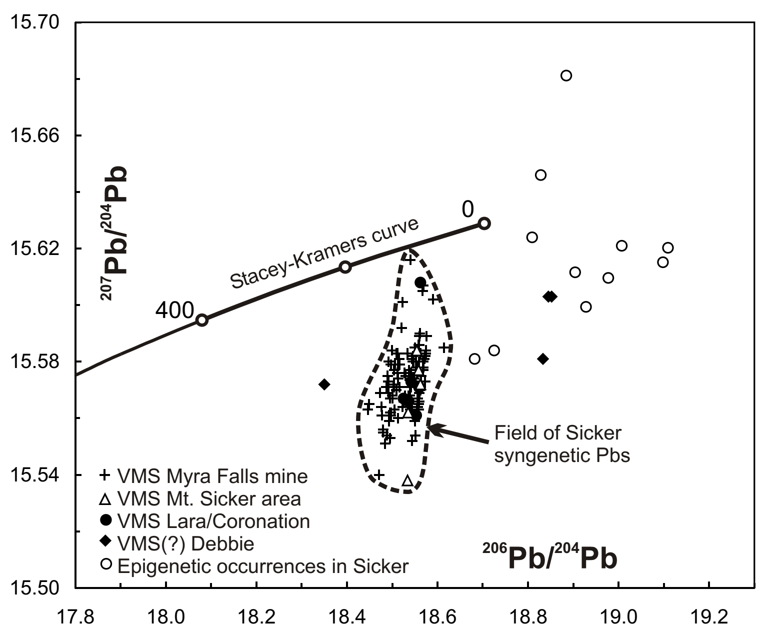

Figure 3. Lead isotopic compositions of sulphide minerals from syngenetic and epigenetic deposits and occurrences hosted within the Sicker Group. Data from Godwin *et al.* (1988) and this study.

age determinations. Existing age constraints for Sicker rock units, however, are generally very poor. Only one of the numerous published U-Pb age determinations from the Sicker Group, as reported by Juras (1987), Brandon *et al.* (1986) and Parrish and McNicoll (1992), is considered reliable (an age of 362 ±2 Ma for a quartz-feldspar porphyry body on the east side of Mt. Sicker). There are at present no reliable or precise age determinations at all from within the Buttle Lake uplift. Recent advances in U-Pb zircon dating methods have made it possible to produce much more reliable ages for Sicker samples (as evidenced by the four new ages reported by Sluggett (2003) for the McLaughlin Ridge Formation and Saltspring intrusions on Saltspring Island), with the high precision (±<2 m.y.) that is required to resolve the timing of individual magmatic events within the Sicker Group.

The most critical need in understanding the evolution of the Sicker arc is therefore to establish timelines throughout the Sicker Group that will allow direct chronological correlations to be made within and between various exposures of these units. Conodont biochronology may provide additional temporal constraints in some parts of the section, although carbonate units are rare within the Sicker Group. This temporal framework will constrain facies reconstructions of the Sicker arc and its immediately underlying basement and, together with complete geochemical and isotopic studies from throughout each section, will provide a basis for interpreting the paleotectonic evolution of the arc. It will also help constrain the metallogenic evolution of the Sicker and, in particular, establish the stratigraphic position of the Myra Falls deposit and other syngenetic base-metal occurrences in the Sicker (as identified through Pb isotopic analyses of sulphide minerals).

WORK COMPLETED AND IN PROGRESS

A two-week field program was carried out by the author in September of 2005. This work was aimed at gaining a better regional understanding of the geology of the Sicker Group, especially in the Cowichan Lake uplift, and also assessing the access to and exposure of the units in this region. As a result of recent and current logging activity, access and exposure are much improved since Massey (1995a, b, c) did his work in the area. In particular, several days were spent examining the geology and mineralization within the southeastern portion of the Cowichan Lake uplift in the vicinity of the Mt. Sicker and Lara deposits (Fig. 1). Forty-two samples were collected and have been analyzed for complete major, trace and rare earth elements at ALS Chemex Ltd. to more completely constrain the geochemical characteristics of the main Sicker rock types. These results are currently being compiled with existing lithogeochemical data from the Cowichan Lake uplift from Massey (1995a, b, c) and Sluggett (2003), and data from the Sicker Group in the Buttle Lake uplift from Barrett and Sherlock (1996). In addition, 15 samples were collected from throughout the Cowichan Lake uplift for U-Pb zircon dating using the laser-ablation inductively coupled plasma – mass spectrometry (ICP-MS) U-Pb dating technique that has recently been established at the Pacific Centre for Isotopic and Geochemical Research laboratory at UBC. This method makes it possible to generate reliable and precise U-Pb zircon ages much more quickly and at considerably lower cost than using conventional thermal ionization mass spectrometry methods. An additional five(+) U-Pb zircon dating samples will be collected later in the fall from the immediate mine stratigraphy at the Myra Falls mine in the Buttle Lake uplift. These data are critical to establish a comparative chronostratigraphy between the Buttle Lake and Cowichan Lake uplifts.

Existing Pb isotopic data from VMS and epigenetic mineral occurrences hosted by the Sicker Group on Vancouver Island are shown in Figure 3, together with several new Pb isotopic analyses of sulphide minerals from epigenetic vein occurrences in the Cameron River area, southeast of Port Alberni, that have been generated during the present study. Sulphide Pb compositions in VMS occurrences within the McLaughlin Ridge Formation form a well-defined cluster that differs markedly from Pb analyses from epigenetic occurrences within the Sicker (Fig. 3). This demonstrates that Pb isotopes provide an effective tool for discriminating between syngenetic and younger mineralization in the Sicker. Three analyses reported by Godwin *et al.* (1988) from the Debbie (Mineral Creek) occurrence (MINFILE 092F 079) in the northwestern portion of the Cowichan Lake uplift are identified on the plot. The Debbie occurrence is hosted within the Duck Lake Formation and comprises a variety of styles mineralization. Most previous and current work has focused on Au-bearing veins and shear zones; however sulphide-bearing cherty horizons are also present within the Duck Lake basalt on the property. There are no descriptions of the three sulphide samples that were analyzed for Pb isotopes; however, two fall within the broad array of analyses from other epigenetic occurrences in the Sicker, but one gives a Pb isotopic composition that is slightly less radiogenic than sulphide minerals from syngenetic occurrences hosted by the McLaughlin Ridge Formation. This would be consistent with this sample being syngenetic in origin with a somewhat older depositional age than the other VMS occurrences in the Sicker. The age of the Duck Lake Formation is not well constrained at this point, but it is certainly older than the McLaughlin Ridge Formation. Additional sampling for Pb isotopes is planned in the Debbie area to further investigate the range of styles of mineralization present and, in particular, the potential for VMS mineralization within the Duck Lake Formation.

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