

VOLCANOGENIC MASSIVE SULPHIDES OF THE NORTHERN TULKS VOLCANIC BELT, CENTRAL NEWFOUNDLAND: PRELIMINARY FINDINGS, OVERVIEW OF DEPOSIT RECLASSIFICATIONS AND MINERALIZING ENVIRONMENTS

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ABSTRACT

The Tulks Volcanic Belt, part of the Victoria Lake supergroup of central Newfoundland, is dominated by felsic volcanic and volcanoclastic rocks and lesser amounts of mafic volcanic rocks and intercalated sedimentary rocks. These rocks developed in volcano-sedimentary basins within active volcanic arcs on the peri-Gondwanan margin of the Iapetus Ocean.

The northern portion of the belt is host to the important Daniels Pond and Bobbys Pond volcanogenic massive sulphide (VMS) deposits, as well as numerous smaller, base-metal prospects. The major VMS deposits are hosted by felsic volcanic, pyroclastic and volcanoclastic rocks. Mineralizing styles vary from "classic" exhalative-type mineralization developed on the seafloor, to possible "replacement"-style mineralization developed in a sub-seafloor environment. There are also mineralized debris-flow breccias, suggesting potential for transported ores.

The Tulks Volcanic Belt has traditionally been viewed as a single stratigraphic sequence, but recent studies dictate that it is composite, consisting of several distinct tectonically juxtaposed groups ranging in age from at least 498 Ma to 453 Ma. Geochronological studies to further constrain the age of mineralization in the northern part of belt are under way; results of these studies may have stratigraphic and exploration implications.

Volcanic massive sulphide deposits in the northern Tulks Volcanic Belt are interpreted to have formed in volcanic, volcanoclastic and sediment-rich basins as tectonic conditions changed from convergent (e.g., active-arc environment) to extensional (e.g., back-arc or arc-rift) environments. The deposits display mineralization, alteration, and textural characteristics indicative of both "classic" VMS-type deposits and epithermal-style mineralization of the type generally associated with sub-aerial volcanism. As such, these deposits likely represent a "hybrid bimodal felsic VMS-epithermal" deposit style. They differ from the bimodal-siliciclastic type deposits that characterize the southern part of the belt. It is suggested that VMS deposits in the northern part of the belt formed in a higher standing portion of the basin in relatively shallow-water conditions, proximal to vents and active magmatic systems that may have supplied fluid input. This setting differs from the deeper water, more distal environment envisioned for the deposits in the southern part of the belt.

INTRODUCTION

OVERVIEW

The Tulks Volcanic Belt (TVB) is situated within the Victoria Lake supergroup of Newfoundland. It is comprised of felsic volcanic rocks and volcanoclastic rocks with lesser mafic and sedimentary rocks which formed in volcano-sedimentary basins associated with volcanic arcs in the peri-Gondwanan margin of the Iapetus Ocean. The entire TVB (Figure 1) is a major focus for base-metal exploration in

central Newfoundland, with the northern portion of the belt hosting the Daniels Pond and Bobbys Pond deposits as well as numerous other prospects.

Field work in 2007 focused on the northern TVB, emphasising the well-defined volcanogenic massive sulphide (VMS) deposits and several smaller prospects that may have future exploration potential. The field work extends examination of VMS environments in the southern part of the TVB (Hinchey, 2007). This study relies heavily on the examination of both archived drill core, and recently

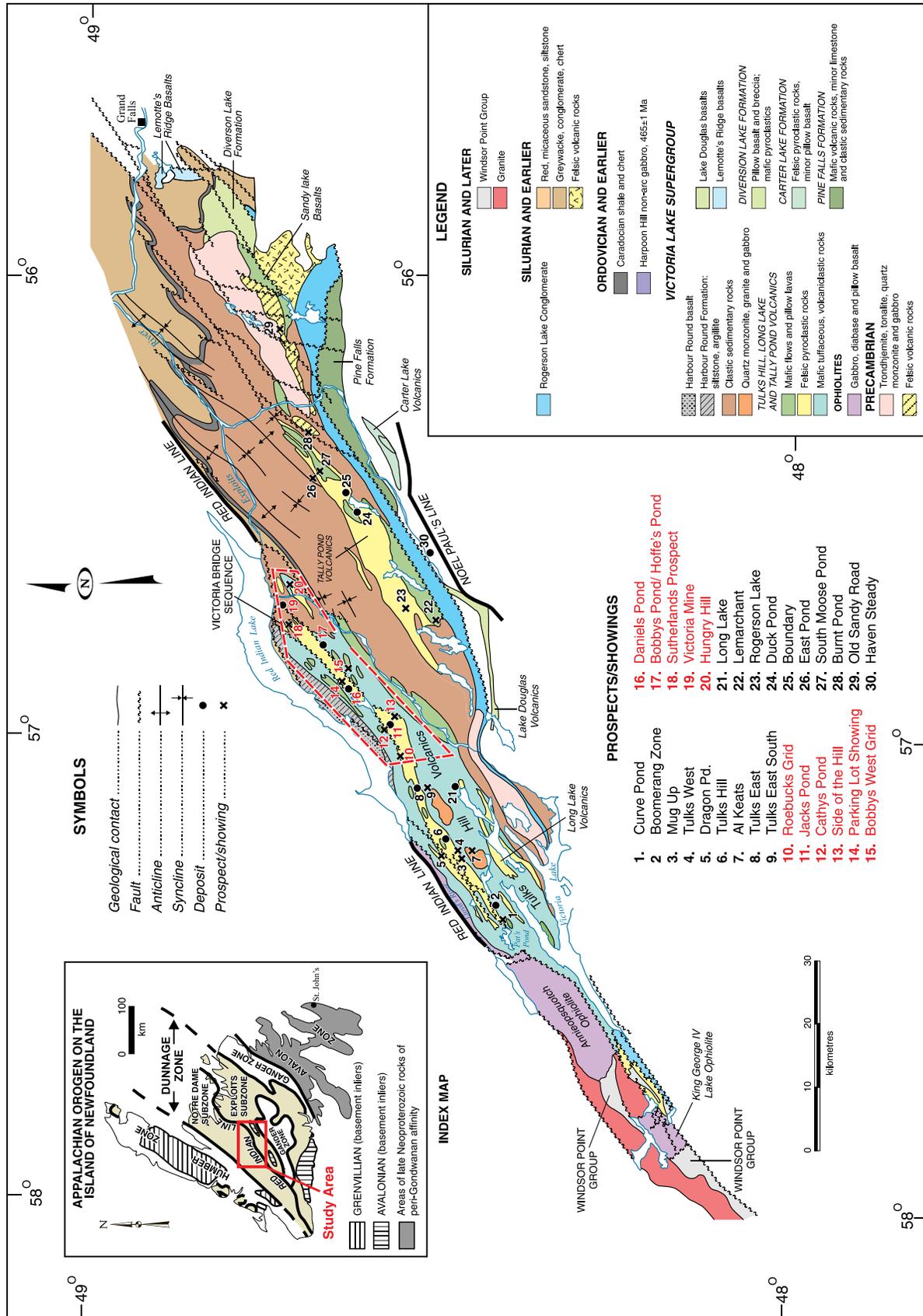


Figure 1. Simplified geology map of the Victoria Lake supergroup showing the location of the Tulks Volcanic Belt and associated volcanogenic massive sulphide occurrences. Note the northern TVB and its mineral occurrences outlined in red (modified after Evans and Kean, 2002).

acquired drill core from ongoing exploration programs. Field work in the immediate vicinity of VMS prospects was conducted where outcrops are available.

The main goals of this activity are to document the stratigraphy, styles of mineralization and alteration associated with VMS deposits and prospect's within the TVB of the Victoria Lake supergroup (VLSG; Figure 1). The 2007 program focused on the area from the southern tip of Red Indian Lake north to the Victoria River area (Figure 1). This portion of the belt hosts two significant VMS deposits (Daniels Pond and Bobbys Pond) and numerous smaller VMS occurrences of varied character.

This paper provides a review of VMS mineralization and presents initial thoughts regarding the styles of alteration, deposit classifications, and environments of formation. It is based on visual examination of drill core and outcrops, coupled with a compilation of previous data, mostly from earlier exploration programs. Petrographic, geochemical and other aspects of research are ongoing, and should provide further insights into these issues.

PREVIOUS WORK

The first regional mapping in the TVB area was conducted by Riley (1957), followed by Williams (1970) for the Geological Survey of Canada. More detailed mapping by the Newfoundland Department of Mines and Energy followed this work (Kean, 1977, 1979a, b, 1982, 1983; Kean and Jayasinghe, 1980, 1982; Kean and Mercer, 1981; Evans *et al.*, 1994a, b, c). The name Victoria Lake Group was proposed from the early work of Kean (1977). A recent summary of the geology, geochemistry, tectonic setting, and VMS mineralization of the VLSG by Evans and Kean (2002) provides a regional synthesis and is a valuable source of information for this report. Evans and Kean (2002) also provide a detailed review of all previous work conducted in the area.

There have been numerous exploration projects in the area, many of which were brought to an advanced exploration stage with diamond-drilling programs. As much of the area of the TVB was within the "AND Charter" established in 1905, effectively granting the Anglo Newfoundland Development Company a 99 year lease on exclusive timber, water and mineral rights to the area, the TVB was not under competitive staking. The earliest known exploration in the area occurred in 1905 at the Victoria Mine, where three shallow exploration development shafts were sunk on high-grade chalcopyrite-pyrite outcrops. Several small stockpiles of massive chalcopyrite-pyrite were extracted; portions of which remain on site. It was not until the 1930s that the

prospect was drilled, resulting in the discovery of ore-grade material. However, tonnages proved to be low and the ore had poor continuity. Another early exploration program, by ASARCO, consisting of prospecting, stream and soil sampling, led to the discovery of the Tulks Hill deposit in 1961. ASARCO conducted detailed evaluation work on the prospect, eventually outlining a geological resource. Abitibi-Price commenced exploration in the area surrounding the southern end of Red Indian Lake in the 1970s. During follow-up work associated with the Tulks Hill discovery, they discovered the Tulks East prospect and the Jacks Pond prospect in 1977 and 1980, respectively. In 1985, BP Resources Canada Ltd. acquired the mineral rights to the area (excluding the area around the Bobbys Pond deposit) and began systematic compilations, geophysical and geochemical surveys, followed by drilling. This work led to the discovery of the Daniels Pond deposit in 1989. However, BP Resources Canada Ltd. suspended exploration activities in the area in 1991 and chose to put the property assets for sale. In 1985, the Canadian Nickel Company Ltd. (Canico; a subsidiary of INCO) optioned the "Victoria Property", consisting of the northern portion of the TVB including land between the AND Co. charter to the southwest and the Victoria River to the northeast; encompassing the area around Bobby's Pond. After a systematic exploration program, Canico defined the Bobbys Pond VMS deposit. Noranda Inc. acquired the mineral rights in 1992 and continued exploration until 1997. Litho-geochemical surveys, coupled with geophysical surveys, resulted in several new discoveries including the Roebucks, Cathys Pond, Parking Lot, Daniel's Pond extension, Bobby's Pond south and Sutherlands Pond prospects. In 1998, Noranda Inc. decided to put its central Newfoundland properties up for sale. Kelmet Resources Ltd. took over the property and began exploration activities. Royal Roads Corporation merged with Kelmet Resources in 2002 and took over the direction of the exploration program in the area. Royal Roads Corporation continues to explore the area and is focusing efforts on expanding the resource at the Daniels Pond deposit. The Bobbys Pond deposit was acquired by Mountain Lake Resources from INCO, and Mountain Lake Resources are currently conducting advanced exploration aimed at resource definition.

The numerous industry reports prepared over the years on the northern TVB were invaluable sources for preparation of this review. It should be noted that the reference to Noranda (1998) includes data derived from many of the earlier company assessment reports. A recent NI 43-101 technical report of the Bobbys Pond deposit also provides an overview of the geology and mineralization in that area (Agnerian, 2007).

REGIONAL GEOLOGICAL FRAMEWORK

Overview

The Dunnage Zone of the Newfoundland Appalachians (Figure 1) represents the vestiges of Cambro-Ordovician continental and intra-oceanic arcs, back-arcs, and ophiolites that formed in the Iapetus Ocean (Kean *et al.*, 1981; Williams *et al.*, 1988; Swinden, 1990; Williams, 1995). The Red Indian Line marks the fundamental Iapetus suture zone and separates the western peri-Laurentian rocks (Notre Dame and Dashwoods subzones) from the eastern peri-Gondwanan ones (Exploits Subzone) that includes the VLSG. The deformation associated with final closure of the Iapetus Ocean culminated during the Silurian (Colman-Sadd *et al.*, 1992), at which time, thrusting and folding juxtaposed these initially geographically distinct volcanic belts. The two main subzones of the Dunnage Zone are differentiated based on stratigraphic, structural, faunal, and isotopic characteristics (Williams *et al.*, 1988). Both the Buchans Group and the VLSG are composite entities that include rocks of different ages and settings. Recent work (*e.g.*, Rogers *et al.*, 2005; van Staal *et al.*, 2005; Zagorevski *et al.*, 2003) has outlined some of these complexities, but it is likely that unresolved complications remain.

The TVB (*see* Figures 1 and 2) forms part of the VLSG and represents the remnants of one of several bimodal Cambrian to Ordovician volcanic-arc sequences within this composite package of rocks. Evans and Kean (2002) subdivide the VLSG into the TVB (ca. 498 Ma), the Long Lake Volcanic Belt (ca. 505 Ma), and the Tally Pond Volcanic Belt (ca. 515 Ma). In addition to these age differences, litho-geochemical studies indicate that the VLSG is composed of distinct chemical groupings representing different tectonic environments (*e.g.*, active arc, arc-rift, back-arc, and mature arc, *see* Swinden *et al.*, 1989; Evans and Kean, 2002).

Evans and Kean (2002) divide the VLSG into two main terrains, separated by the Rogerson Lake Conglomerate, termed the northern and southern terrains. The TVB is part of the northern terrain, where it is bounded to the north by the Red Indian Line and the sedimentary and volcanoclastic rocks of the Harbour Round Belt, and to the south by a regionally extensive magnetic anomaly separating the Tulks Volcanics from the Long Lake Belt.

The TVB covers an area of approximately 65 by 8 km, trending from northeast to southwest. It is a bimodal belt dominated by felsic volcanic rocks and variable amounts of intermixed mafic volcanic rocks, felsic pyroclastic rocks, and volcanoclastic and sedimentary rocks. The age of the TVB is constrained by a U-Pb age of 498 \pm 6/-4 Ma on a

small subvolcanic porphyry near the Tulks Hill VMS deposit (Evans *et al.*, 1990). However, recent age dates provided by the Geological Survey of Canada (GSC) suggest that portions of the TVB are actually much younger (*see* below), and this may necessitate revision of stratigraphy.

The most common rock types of the TVB consists of light-grey to white, quartz=feldspar-porphyrific pyroclastic rocks, felsic ash tuffs through to tuffs and lapilli tuffs, massive to flow-banded rhyolite, breccias (locally bimodal), and local subvolcanic porphyries. Mafic volcanic rocks are subordinate and are dominated by tuffs, lapilli tuffs, breccias, and local pillow lavas.

The TVB hosts several significant VMS deposits and numerous other prospects and showings. The scope of this report is confined to the northern portion of the belt, as indicated in Figure 1. The geology of this area is shown in more detail in Figure 2.

Complications Arising from Lack of Outcrop

The northern part of the TVB has been the subject of numerous mapping programs, both by industry (*e.g.*, Noranda, 1998; Greene *et al.*, 2001) and by provincial and federal surveys (*e.g.*, Kean, 1977, 1979a and b, 1982, 1983; Kean and Jayasinghe, 1980, 1982; Kean and Mercer, 1981; Evans *et al.*, 1994a, b and c; Lissenberg *et al.*, 2005; Rogers *et al.*, 2005). The inherent lack of outcrop in the northern TVB has resulted in different interpretations of map patterns, leading to differences in the appearance of the geological maps produced. The lack of outcrop in the area demands a great deal of interpretation and interpolation and these variable map patterns reflect different individual interpretations of the same data.

Industry mapping was mostly conducted at a property grid scale and commonly incorporated local scale geophysical interpretations. As such, these maps (*e.g.*, Noranda, 1998) provide excellent lithological regional maps, effectively illustrating that the northern TVB is composed of a series of NE-SW-striking packages dominated by felsic, and lesser mafic, volcanic rocks, and variable amounts of intercalated graphitic sedimentary rocks. Electromagnetic geophysical surveys have proven to be very efficient for the delineation of graphitic sedimentary rocks in the belt; and their presence is confirmed through field mapping and/or diamond drilling. As such, industry maps serve as excellent detailed lithological maps for the area. However, they do not so readily portray the temporal relationships because the TVB is dominated by felsic volcanic rocks of essentially identical appearance, which can only be unravelled by detailed, systematic geochronological studies.

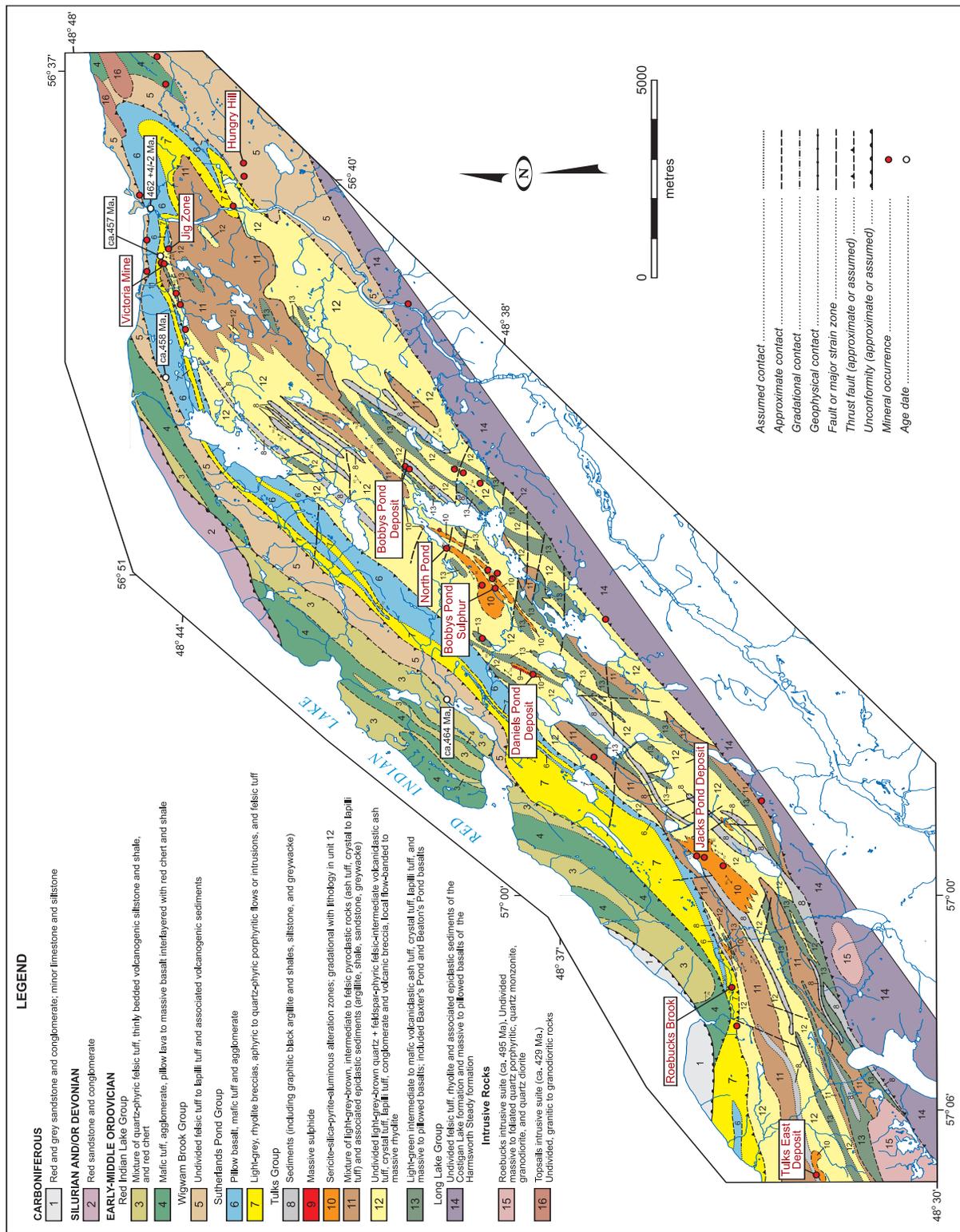


Figure 2. Geology map of the northern Tulks Volcanic Belt illustrating the locations of the VMS deposits, prospects, and showings. Note that for clarity purposes not all of the mineral occurrences are labelled. Partly modified and compiled from industry sources (e.g., Noranda, 1998; Celtic Minerals Ltd., 2001) and government publications (e.g., Kean, 1979a, b, c; Evans et al., 1994a, b; Evans and Kean, 2002; Rogers et al., 2005; Lissenberg et al., 2005).

Some of the earliest detailed regional mapping in the northern TVB was conducted through the Newfoundland Department of Mines and Energy by Kean (1977, 1979a and b, 1982, 1983), Kean and Jayasinghe (1980, 1982), and Kean and Mercer (1981), followed by Evans *et al.* (1994a, b and c). This mapping outlined the distribution of felsic, mafic and sedimentary rock types throughout the TVB. The results of this mapping have been commonly used as a starting point for industry surveys. Results indicated that the northern TVB was composite in nature, with much younger (ca. 463 Ma) rocks identified in the Victoria River area (*e.g.*, Dunning *et al.*, 1987; see below), compared to those of the Tulks Hill area (ca. 498 Ma; Evans *et al.*, 1990). Mapping suggested that the TVB is dominated by a series of NE–SW-trending units of felsic volcanic rocks intercalated with minor mafic volcanic rocks and sedimentary rocks.

The most recent detailed regional mapping in the area has been conducted by the GSC as part of the larger TGI program (*e.g.*, Lissenberg *et al.* (2005), Rogers *et al.* (2005), and van Staal *et al.* (2005)). This program was successful in identifying and outlining additional tectonostratigraphic packages within the TVB, based largely on U–Pb geochronological ages from the southern part of the TVB. Based upon these results, and in conjunction with geochemical correlations, this mapping has demonstrated that the TVB is composite and consists of a generally westward-younging series of volcanic packages (see below for details). This re-interpretation builds upon, and broadly agrees with, the distribution of rock types and groupings proposed by the earlier mapping. However, the interpreted map patterns vary significantly in detail, especially with respect to the indication of large-scale folds defined by mafic volcanic rocks throughout the belt (*e.g.*, Lissenberg *et al.* (2005), Rogers *et al.* (2005), and van Staal *et al.* (2005)). This interpretation differs from the simpler, more linear NE–SW map patterns commonly suggested for the TVB by earlier mapping. This variation in map patterns reflects the difficulty in extrapolating from the few isolated outcrops (especially in the case of the mafic volcanics) to a regional scale.

Figure 2 has been produced using field stations visited during this study, combined with a compilation of previous regional mapping and geophysical surveys in the area. From the perspective of tectonostratigraphic packages, the subdivisions defined by the recent GSC mapping have, for the most part, been adhered to. However, the distribution of rock types and local map patterns in the northern TVB are derived from the mapping of Kean (1977, 1979a and b, 1982, 1983), Kean and Jayasinghe (1980, 1982), and Kean and Mercer (1981), Evans *et al.* (1994a, b and c), and industry mapping. As such, this map is lithological in nature rather than formational, as this type of map is more useful

for this type of study. The most obvious differences between this map and those of Lissenberg *et al.* (2005) and Rogers *et al.* (2005) are that it indicates linear rather than folded map patterns for the mafic volcanics of the TVB, and indicates the graphitic sedimentary rocks as a separate unit. The latter were grouped with associated volcanic rocks by Lissenberg *et al.* (2005) and Rogers *et al.* (2005), but in the current context of VMS mineralization and exploration, they represent an important unit.

GEOLOGY AND MINERALIZATION

LOCAL GEOLOGY

The northern TVB contains a wide variety of rock types. These are dominated by various felsic, intermediate, and mafic pyroclastic rocks (ash tuffs through to lapillistone/agglomerates), and massive to flow-banded rhyolite and rhyolite breccias with locally amygdaloidal dykes and sills. There are also some sedimentary rocks, including black shales, graphitic argillites, greywackes, and thin iron formations. The region also includes some intrusive bodies that are generally interpreted as synvolcanic. The TVB has experienced moderate to strong deformation, and greenschist-facies metamorphism. Although small-scale structures are commonly observed, the lack of outcrop impedes identification of large-scale structures in the belt (*see* discussion below on Daniels Pond). Primary textures are usually obliterated by well-developed, bedding-parallel, foliations. Lithologic units typically strike steeply to the southwest and dip to the northwest, with a prominent regional foliation defined by the alignment of chlorite and sericite. The belt is transected by late shear zones and faults.

Although all rocks within the 2007-2008 study area were initially considered to be part of the TVB by Kean (1977, 1979a and b, 1982, 1983), it was recognized from an early stage that volcanic activity was diachronous, and spanned a time period between 498 \pm 6/-4 Ma to 462 \pm 4/-2 (Dunning *et al.*, 1987; Evans *et al.*, 1990). The relatively young ages from the "Victoria Bridge Sequence" (Dunning *et al.*, 1987) provide a clear indication that more than one volcanic package is present in the TVB, but the lithological similarities make map definition difficult. It was suggested that the variation in ages represented either a major structural or stratigraphic break in the area. Following up on this idea, more recent mapping and geochronological studies by the GSC have revised stratigraphic nomenclature to define a series of generally westward-younging tectonostratigraphic units in the area including the Tulks Group (ca. 498 Ma), the Sutherlands Pond Group (ca. 462 Ma; Dunning *et al.*, 1987), and the Wigwam Brook Group (ca. 453 Ma; Rogers *et al.*, 2005; van Staal *et al.*, 2005; Zagorevski *et al.*, 2003). There may yet be further complications amongst these monoto-

nous rods. From an exploration perspective, there is evidence that VMS mineralization can occur within any of these tectonostratigraphic subdivisions, although it is possible that the styles of mineralization may vary amongst them. For these reasons, geochronological studies aimed at defining the timing of VMS mineralization are an important priority.

VOLCANOGENIC MASSIVE SULPHIDE DEPOSITS

Introduction

Volcanogenic massive sulphide mineralization in the northern TVB is characteristically associated with felsic volcanic rocks (quartz \pm feldspar ash-crystal tuffs, rhyolites, rhyolitic breccias, and volcano-sedimentary debris flows) hosted within volcanoclastic sedimentary basin(s). The presence of abundant bimodal sills, locally amygdaloidal, and broadly synchronous volcanoclastic sedimentary rocks (argillite/wacke) within the mineralized sequences, suggests a possible arc-rift or back-arc basin tectonic environment. This interpretation is supported by ongoing litho geochemistry studies. Such an environment would likely be highly variable on a local scale, and this is reflected in the varied styles of mineralization (see below).

Two important VMS deposits occur within the study area, as well as numerous other prospects and zones of alteration. From south to north, the major VMS deposits are the Daniels Pond and Bobbys Pond deposits (Figures 1 and 2). Mineralization at these deposits is associated with intense sericite-silica-pyrite-aluminous alteration (*e.g.*, illite, halloysite, and pyrophyllite) and locally chloritic alteration. The mineralization is thought to have formed in both exhalative as well as sub-seafloor replacement environments (*see* discussion below). Excluding the mining lease surrounding the Bobbys Pond deposit, which is controlled by Mountain Lake Resources, and the claims in the far northern portion of the belt in the vicinity of the Victoria Mine, which are held by Celtic Minerals Ltd., mineral rights to the northern TVB are held by Royal Roads Corp.

Daniels Pond Deposit

The Daniels Pond deposit is hosted by a sequence of felsic tuffs and lapilli tuffs that exhibit sericite-silica-pyrite-aluminous alteration (*e.g.*, halloysite, illite, \pm pyrophyllite) and locally chlorite-carbonate alteration (Figure 3, Plate 1). These rocks are steeply dipping, and based on the observed grading of volcanoclastic and epiclastic sequences in drillcore, the sequence is interpreted to be overturned. The stratigraphic footwall rocks, sitting structurally above the ore horizon, consist of felsic tuffs to lapilli tuffs, and intermediate to mafic amygdaloidal sills. Massive sulphide mineralization is contained within two lenses,

i.e., a pyrite-rich, relatively weakly mineralized lens to the northeast and a base-metal rich, strongly mineralized lens to the southwest (Royal Roads Corp. website). The sulphides are structurally modified (Plate 1) and display tectonic layering and recrystallization of sphalerite-chalcopyrite-galena and pyrite. The immediate stratigraphic hanging wall, sitting structurally below the ore horizon, is composed of volcanoclastic debris flows containing quartz-phyric felsic volcanic clasts, fine-grained sedimentary (argillite) clasts, and massive sulphide clasts (Plate 1). The presence of sulphide clasts strongly suggests an exhalative origin for much of the mineralization. The remainder of the hanging-wall sequence consists of variably altered felsic to intermediate tuffs, lapilli tuffs, and associated volcanoclastic sedimentary rocks. The proportion of volcanoclastic sedimentary rocks (dominantly graphitic argillite and greywacke) increases substantially toward the pyrite-rich lens in the northeastern portion of the deposit. This suggests that the base-metal-rich and pyrite-rich portions of the deposit represent vent-proximal and vent-distal environments, respectively.

Unlike many of the deposits in the TVB, which are associated with large VMS-style alteration systems (*e.g.*, Tulks Hill, Jacks Pond), the Daniels Pond deposit has a relatively small alteration footprint. Although alteration is predominantly associated with the footwall rocks, minor sericite-carbonate-aluminous alteration is also locally present in the hanging-wall rocks. Footwall alteration is associated with intensely sheared felsic tuffs, and consists of variable amounts of sericite, silica, chlorite, carbonate and aluminous alteration, associated with pyrite and base-metal stringer sulphide. Locally, black chlorite, aluminous alteration (*e.g.*, clays), \pm sericite alteration is spatially associated in the immediate footwall of the deposit, implying a vent proximal acidic and oxidized mineralizing environment (Plate 1; *see* discussion below). The proportion and intensity of the aluminous alteration is greater in the area of the base-metal lens than in the area of the pyrite lens.

The massive sulphide lenses are confined to a narrow belt of highly strained rocks trending north-south. The base-metal-rich sulphides consist of tectonically banded sphalerite-galena-pyrite \pm chalcopyrite, in which steeply plunging isoclinal folds are observed (Plate 1). The presence of coarse-grained pyrite, which overprints banding, suggests that the ore has been extensively recrystallized. Gangue mineralogy is variable with a mixture of quartz-carbonate \pm barite distributed throughout the lenses (*see* also McKenzie *et al.*, 1993; Noranda, 1998). The ore in the northern lens is dominated by fine-grained pyrite with fine scale tectonic (?) layering. Quartz-carbonate veinlets commonly infill crosscutting fractures and locally contain minor remobilized copper mineralization in the form of chalcopyrite.

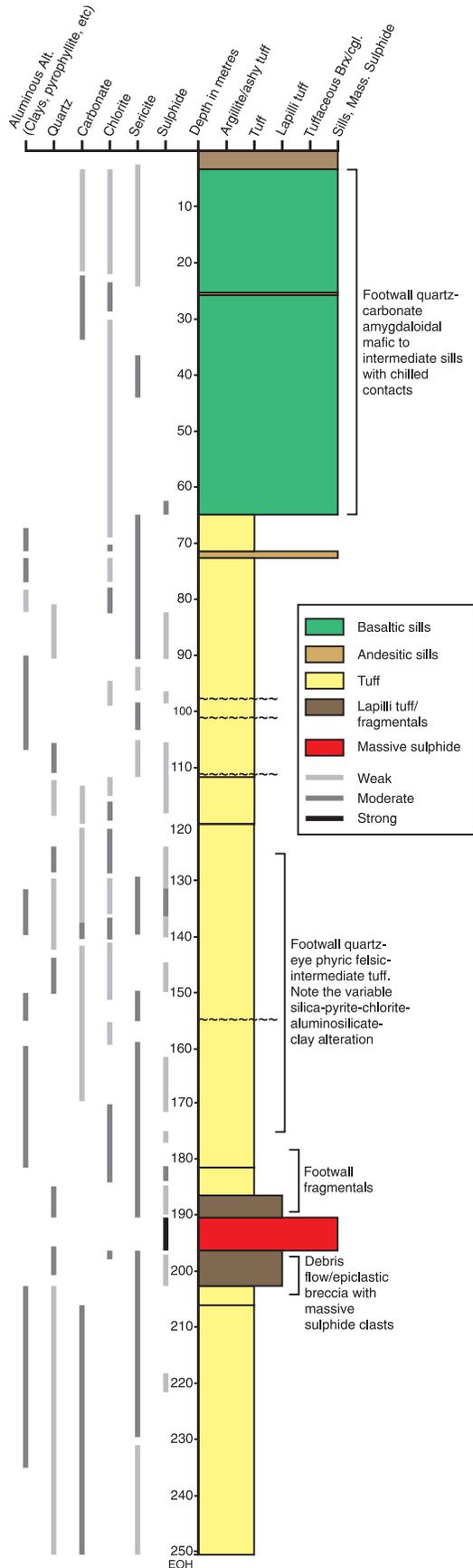


Figure 3. Schematic drillhole stratigraphic column for DDH DN-02-02 from the Daniels Pond deposit illustrating rock types and relations and alteration patterns. Note that stratigraphy is interpreted to be overturned. Note that the column is not necessarily intended to illustrate original stratigraphic order.

The exposures at Daniels Pond provide an excellent illustration of how sulphide zones and associated altered rocks experience intense deformation whilst surrounding, more competent units for the most part evade such effects. It is also illustrative in that the compositional banding is clearly tectonic, although it would likely be interpreted as primary if seen only in drill core. From a regional perspective, the extreme strain partitioning at Daniels Pond, and the localized nature of the folding, illustrates the pitfalls of extrapolating small-scale structural patterns to the scale of the TVB.

To date, the deposit contains a NI 43-101 compliant inferred resource of 1.69 million tonnes grading 8.37% Zn, 4.4% Pb, 0.57% Cu, 196.9 g/t Ag, and 0.68 g/t Au (Royal Roads Corp. Press Release, Nov. 7, 2006). Additionally, recent deep-exploration drilling by Royal Roads Corp. has extended the mineralization (*e.g.*, Royal Roads Corp. Press Release, Oct.7, 2007). This is supported by drill hole DN-07-92A, which intersected 7.9% combined base metals over 2.47 m at 75 m below the currently defined deposit. There is thus potential for expansion of the mineral resource at depth.

Bobbys Pond Deposit

The Bobbys Pond deposit appears to represent a similar stratigraphic horizon to the Daniels Pond deposit, but the two cannot be directly correlated. It is hosted by variably altered, bimodal, felsic-dominated volcanic sequences (aphyric to quartz porphyritic rhyolite, rhyolite breccias, and felsic tuff to lapilli tuff) that also contain intercalated epiclastic sedimentary rocks (graphitic argillite and greywacke) and mafic volcanic rocks (Figure 4, Plate 2). The preponderance of rhyolite in the sequence distinguishes it from the volcanoclastic dominated deposits farther south (*e.g.*, Daniels Pond, Tulks East, etc.), and may suggest a more vent proximal environment of formation. Strong sericite-carbonate-pyrite-silica alteration, and aluminous alteration are observed in proximity to the sulphide lenses (Plate 2, Figure 4). As with the Daniels Pond deposit, the sequence appears to be overturned. However, locally observed fining upward relations, as well as the presence of alteration both above and below the ore horizon, leave some ambiguity to this interpretation.

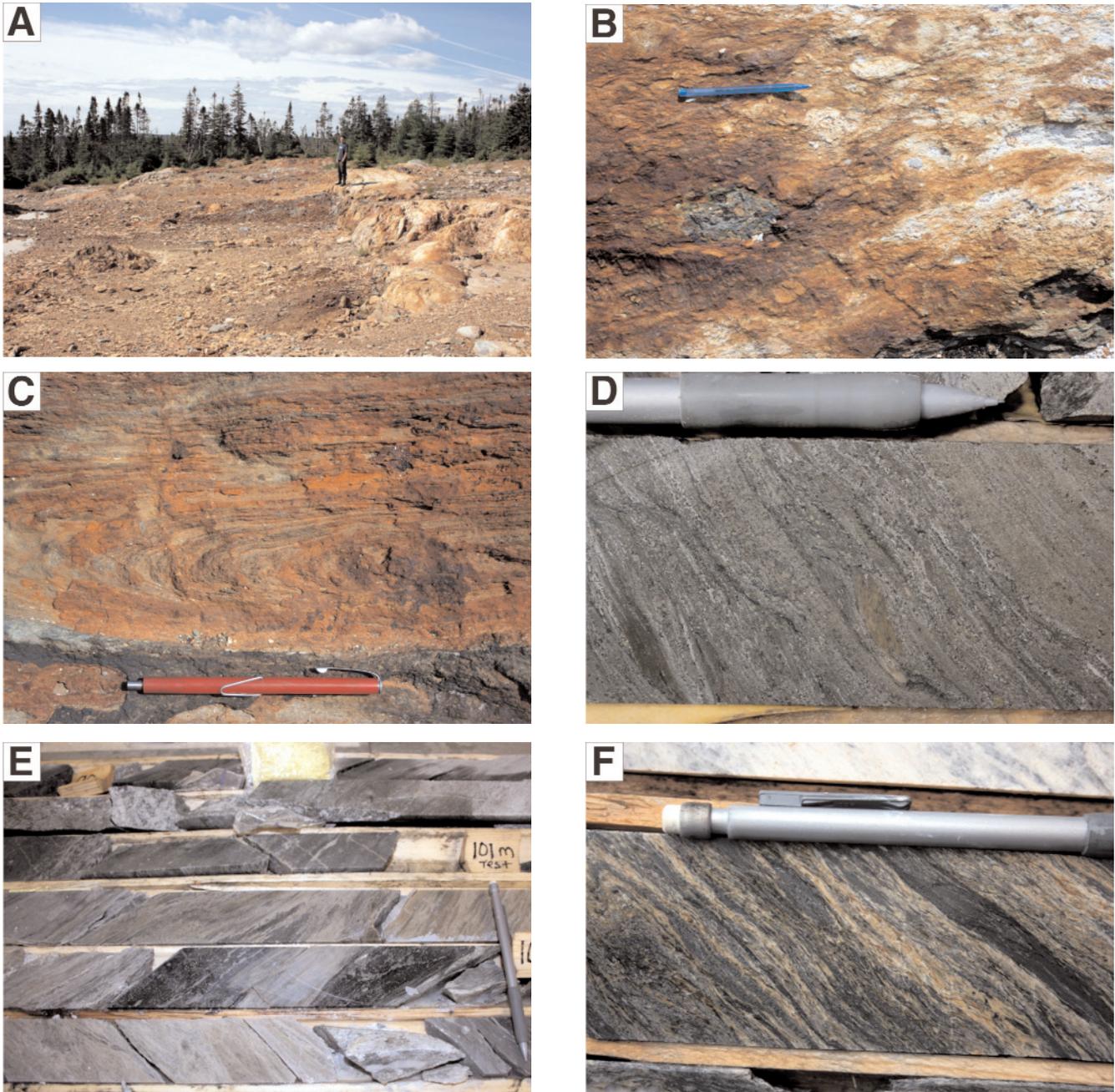


Plate 1. Photographs of Daniels Pond deposit stratigraphy, alteration, and mineralization: A) Daniels Pond massive sulphide deposit exposed in surface trench. Note massive sulphide in the centre of the photograph. B) Massive sulphide clast in the immediate hanging wall. The presence of sulphide clasts in the debris flow suggests that the mineralization is exhalative. C) Folded massive sulphides exposed by trenching. Note that the surrounding felsic volcanic rocks are not folded suggesting that folding occurs in the less competent host. D) Base-metal-rich massive sulphide. Note the altered felsic clasts. E) Intense chlorite-clay-aluminous alteration in the immediate footwall to the deposit. Intense chlorite suggests that the mineralization was vent proximal. F) Intense sericite-clay-aluminous alteration in a stringer zone to the deposit.

The footwall sequence, interpreted to sit structurally above the ore horizon, is dominated by aphyric to quartz-phyric rhyolite, associated with fining-upward felsic tuffs, lapilli tuffs, and associated epiclastic sediments. "Jig-saw-fit" rhyolitic breccias are also commonly observed in the

footwall sequence, interpreted to result from natural inflation processes associated with emplacement of felsic flows. It is noteworthy that very similar textures are observed associated with felsic domes at the Duck Pond deposit (e.g., Squires *et al.*, 2001). It was suggested by Stewart and Beis-

cher (1993) that some of the porphyritic rhyolite rocks may actually be intrusive. Footwall alteration is dominated by silica-sericite-carbonate alteration with local strong aluminous alteration. Carbonate alteration increases significantly in proximity to the massive sulphides, and is more intense than that observed at other deposits elsewhere in the TVB. The hanging-wall sequence, sitting structurally below the ore horizon, is dominated by variably altered rhyolite breccias with intercalated felsic tuff to lapilli tuff, and lesser amounts of siliceous sediments. The host rocks in both the stratigraphic hanging wall and footwall of the deposit are strongly deformed, and are locally converted to sericite schists. The deformation is typically more intense in the footwall sequence, perhaps reflecting originally more intense alteration.

The massive sulphide mineralization occurs within at least four sulphide lenses, all of which are contained in a ~100-m-thick zone of moderate to intense alteration. The intense shearing, coupled with the local presence of fault gouge in the immediate vicinity of the mineralization, imply that the ore horizon "stratigraphy" may actually represent a series of transposed slices, resulting in repetition of massive sulphide layers and associated alteration. However, some variations in sulphide compositions were observed between the lenses, and there are also small variations in their host rocks. The variations could be explained if there were originally lateral variations in sulphide lenses as those demonstrated at Daniels Pond. The lenses vary in thickness from less than a metre up to approximately 10 m, and generally display chemical zoning with a zinc-rich upper portion and a copper-rich lower portion. Sulphide mineralogy is dominated by pyrite with lesser amounts of yellow, honey-coloured sphalerite, chalcopyrite and galena. Locally, rhyolite appears to be pervasively replaced by sulphide mineralization, suggestive of a replacement style of mineralization, whereas elsewhere the presence of fine-grained, mineralized siliceous sedimentary rocks in the immediate stratigraphic hanging wall (sitting structurally below the ore horizon) suggests an exhalative style of mineralization.

As currently defined, the Bobbys Pond deposit contains a NI 43-101 compliant indicated resource of 860 000 tonnes of 6.30% Zn, 0.93% Cu, 0.53% Pb, and 20 g/t Ag, with an additional inferred resource of 480,000 tonnes of similar

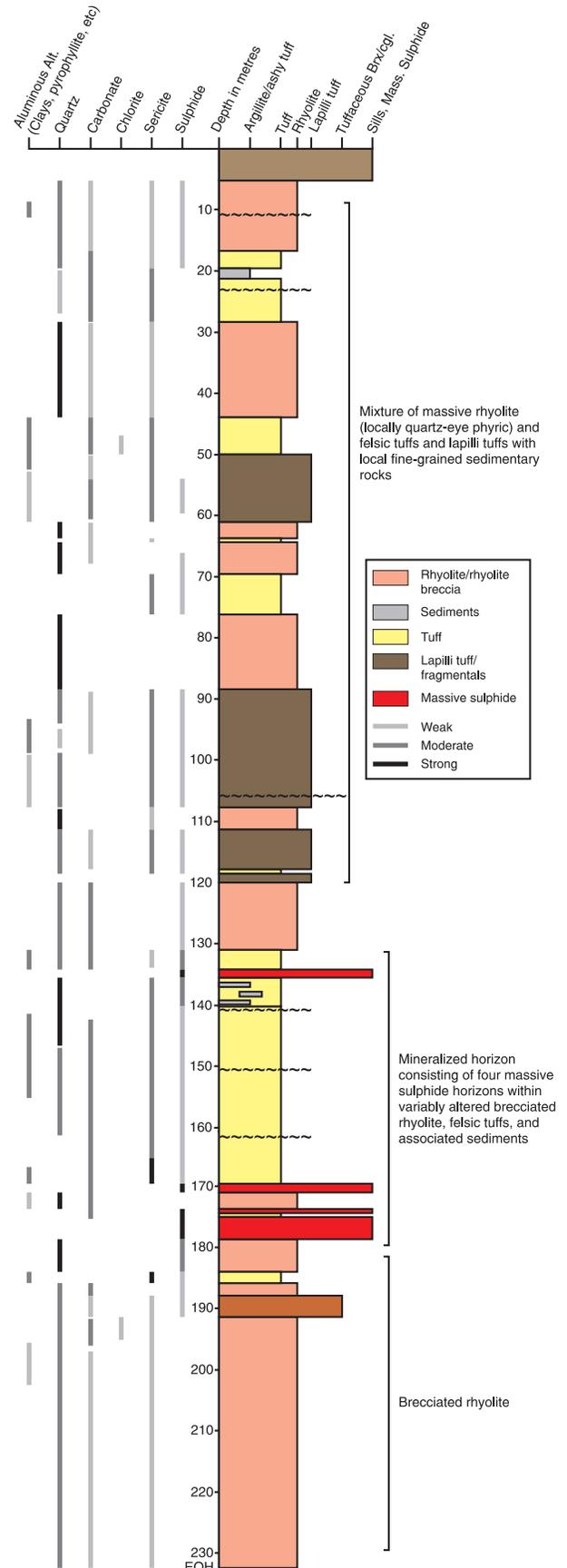


Figure 4. Schematic drillhole stratigraphic column for DDH 77537 from the Bobbys Pond deposit illustrating rock types and relations and alteration patterns. Note that stratigraphy is interpreted to be overturned. Note that the column is not necessarily intended to illustrate original stratigraphic order.

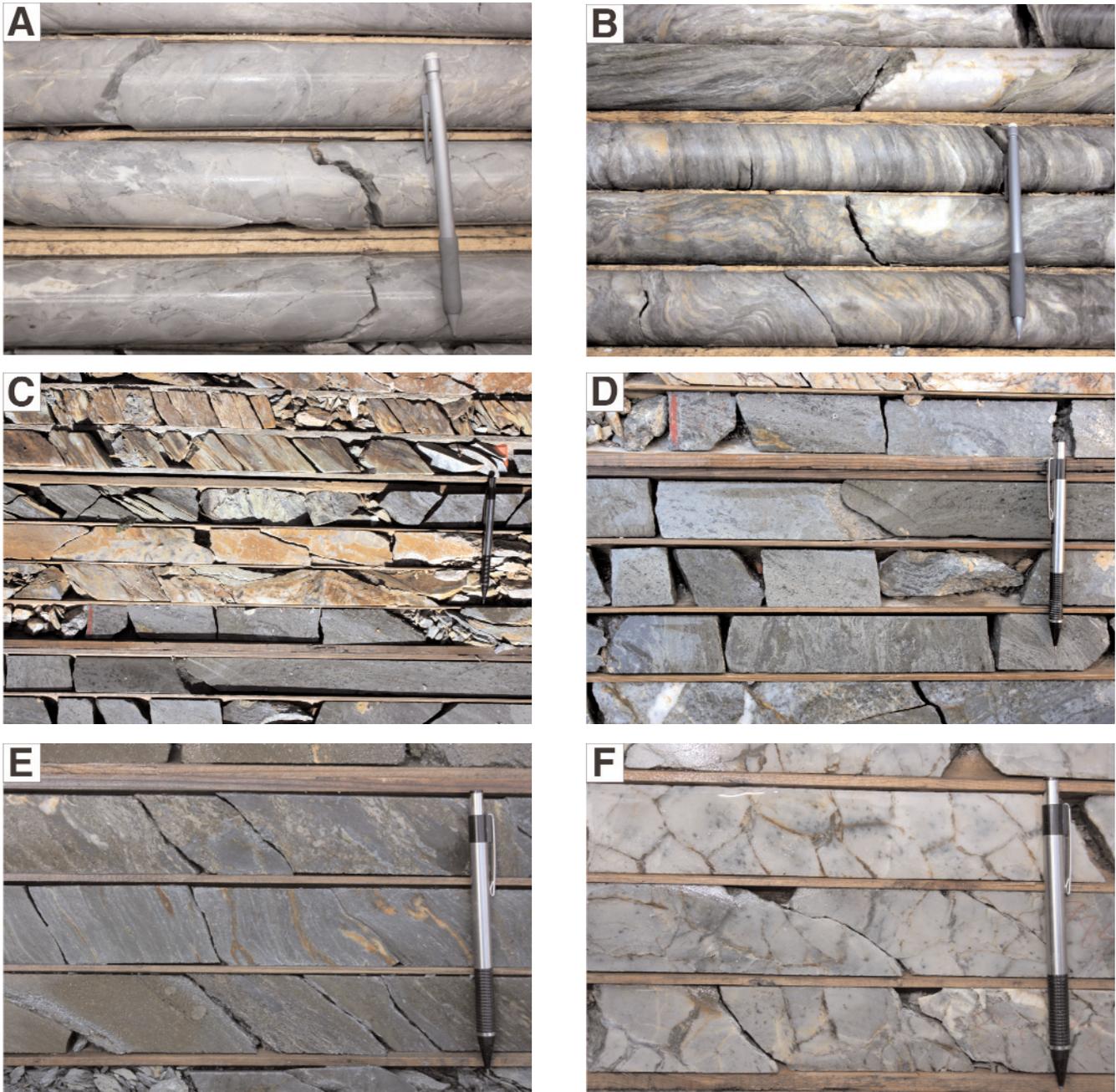


Plate 2. Photographs of Bobbys Pond deposit stratigraphy, alteration, and mineralization: A) Aphyric rhyolite. Note the local flow-banding textures. B) Intense sericite–carbonate–aluminous alteration in the footwall to the deposit. C) Massive sulphide lenses from the deposit. Note the intense carbonate alteration associated with the rhyolitic host in the middle of the photograph. D) Base-metal-rich massive sulphide. E) Mineralized very fine-grained ash-tuff to siliceous sediments from the mineralized horizon. F) Jig-saw-fit rhyolitic breccia with polygonal clasts indicative of a vent-proximal environment. Texture is interpreted to represent the rim of a blocky flow.

grade material (Mountain Lake Resources Inc. Press Release, Feb. 7, 2007). Mountain Lake Resources Inc. continues to define the resource and to explore for additional mineralization in the area.

Other VMS Deposits

There are several other VMS prospects and areas of favourable VMS-style, and hybrid VMS-epithermal type

alteration (see discussion below), in the northern TVB (Figure 2). These have not been described in as much detail as Daniels Pond and Bobbys Pond, but present data suggest that they fall into 5 broad groups:

Group 1

Coarse-grained, disseminated to semi-massive pyrite (with lesser base metals) associated with felsic to intermediate volcanic rocks that show zoned sericite–silica–chlorite alteration (e.g., Jacks Pond prospect, Roebucks Brook prospect): The zones of mineralization and alteration are developed in felsic to intermediate volcanic rocks that show intense sericite–silica–chlorite alteration. Semi-massive to massive, coarse- to fine-grained disseminated pyrite and lesser base-metal sulphides are associated with this alteration (Plate 3). The local stratigraphy is dominated by quartz-phyric felsic tuffs, coarse-grained felsic fragmental rocks (*i.e.*, volcanoclastic breccias), abundant epiclastic sediments (graphitic argillite), and minor mafic sills. Based upon the local presence of exotic granitic clasts (Plate 4), the coarse-grained volcanoclastic breccias may have developed in association with synvolcanic fault systems that exhumed basement (?) or subvolcanic intrusive rocks.

The Roebucks Brook prospect (Figure 2) is located between the Tulks East deposit and the Jacks Pond prospect; these two areas represent the largest sulphide accumulation and the largest alteration system in the TVB, respectively. Mineralization, discovered to date, is confined to stringer zones within sericite–silica-altered felsic tuff, but the base-metal-rich nature of the mineralization (*e.g.*, 2.29% Zn over 1.44 m in RB-01-02; Dadson, 2002), along with the general lack of diamond drilling in the vicinity, suggests that the area is still under-explored and holds potential for future discoveries.

The Jacks Pond prospect has been interpreted to represent the same stratigraphic horizon as the Tulks East and Tulks Hill deposits to the south (*e.g.*, Evans and Kean, 1986; McKenzie *et al.*, 1993). The prospect is associated with a very large (2.0 by 0.5 km) alteration envelope developed at the transition zone between felsic-dominated volcanoclastic rocks and clastic sediments that have minor mafic volcanics. The alteration is linked to at least four semi-massive to massive sulphide lenses dominated by pyrite (McKenzie *et al.*, 1993; Noranda, 1998). As elsewhere in the TVB, the Jacks Pond mineralization and alteration is hosted within dominantly felsic volcanic rocks (felsic tuffs, lapilli tuffs, felsic breccia, and local quartz phyric rhyolite) with minor mafic sills. The sulphides appear to be stratigraphically controlled and, based upon the observed zonation in alteration mineralogy, probably represent an alteration stockwork (see also discussion in Evans and Kean, 1986, 2002). Alteration is

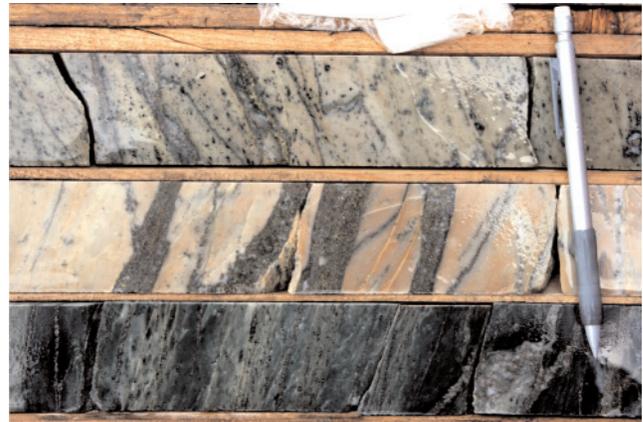


Plate 3. Variably altered and mineralized felsic tuff at the Jacks Pond deposit. Note the sericite–carbonate alteration at the top of the picture trending to chlorite alteration at the bottom.



Plate 4. Coarse-grained exotic granitic clasts in volcanoclastic breccia at the Jacks Pond deposit. The presence of such exotic clasts implies that the breccias represent fault breccias rather than true volcanoclastic debris-flow breccias.

broadly zoned, with an inner discordant core of Mg-rich chlorite–carbonate–sericite–silica alteration enveloped by a more silica–sericite-rich shell (Plate 3). Based on the local field relationships, and the classic zonation of the alteration package, it is postulated that the Jacks Pond prospect may actually represent a deep remnant of the hydrothermal conduit system to the nearby Cathys Pond exhalative horizon (see Group 2 discussion below). Exposure of the Jacks Pond alteration horizon is attributed to contrasts in erosion levels due to faulting and folding during later deformational events.

Group 2

Locally base-metal enriched sulphides associated with ferruginous, siliceous sediments interpreted to be of exhalative

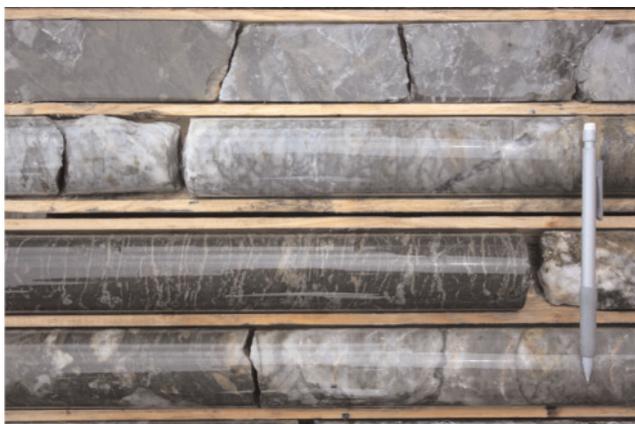


Plate 5. *Exhalative-type mineralization from the Cathys Pond prospect consisting of a silica- and pyrite-rich sedimentary (argillite) horizon associated with semi-massive to massive sulphides. Note the footwall (top of slide) stringer alteration.*

tive origin (e.g., Cathys Pond prospect): Cathys Pond prospect contrasts with most other deposits and prospects in the TVB in that it is dominated by silica and pyrite-rich sedimentary (argillite) horizons containing semi-massive to massive sulphides (Plate 5). The local stratigraphy consists of several conformable intercalated sericite–silica-altered felsic tuffaceous rocks, featureless grey siliceous rocks, and silica-rich and pyrite-rich argillite. The overall sequence is indicative of quiescent, low-energy conditions typically associated with waning volcanic activity. Based on the relatively weak alteration, and an increase in the proportion of detrital sedimentary rocks, it appears that the area in the northwest represents a more vent-distal facies (e.g., DDH JP-94-03 and JP-94-07) compared to that observed on the southern shore of Cathys Pond (e.g., JP-95-09). Based on the close proximity of the Jacks Pond alteration system to the southern shore of Cathys Pond, this observation provides indirect support for the notion introduced above that the Jacks Pond prospect may represent a deep feeder alteration zone to the exhalative mineralization observed at Cathys Pond.

Group 3

Felsic volcanic rocks showing local acidic, aluminous alteration (e.g., pyrophyllite, clays, and alunite group minerals), native sulphur, orpiment, possible stibnite and textures suggestive of an epithermal environment, in addition to typical VMS-style mineralization (e.g., Bobbys Pond native sulphur prospect, North Pond prospect (Plate 6)): When viewed in conjunction with the Daniels Pond and Bobbys Pond deposits, which also contain locally acidic, aluminous alteration (see above), this hybrid epithermal-VMS style of alteration and mineralization extends over approximately 4 to 5 km strike length in the TVB.

The Bobbys Pond native sulphur showing contains abundant argillic to advanced argillic alteration with intense silicification, natroalunite, and native sulphur on surface, with orpiment and possible stibnite in drill core, but it lacks any typical VMS-style alteration or mineralization. For this reason, the sulphur prospect has historically been viewed as a unique epithermal-style mineralizing event in the TVB, and interpreted to be superimposed on the older VMS mineralization. This interpretation is supported by the experimental work of Dill (2001) who suggested that aluminium phosphate and sulphate minerals of the alunite group are not stable at metamorphic conditions greater than lowermost greenschist-facies conditions. However, at the nearby North Pond prospect, intense silicification, alunite, and possible native sulphur occur with VMS-like massive pyrite in silica–sericite-altered felsic tuff. As alunite minerals are not uncommon within weakly metamorphosed VMS mineralized terrains (e.g., Morne Bossa deposit, stockwork deposits of the green tuff belt in Japan; see Hannington *et al.*, 1999 and references therein), the observed field relationships suggest that alunite may have been (meta?) stable within some of the northern TVB prospects, perhaps preserved due to the associated intense silicification. Vuggy quartz textures also point to an "epithermal-style" of mineralization, as they are potentially indicative of boiling and shallow depths. As such, the North Pond Prospect may serve as the "missing-link" connecting the acidic and aluminous alteration observed at the Daniels Pond and Bobbys Pond deposits to the characteristic epithermal-style alteration at the Bobbys Pond sulphur showing. As discussed below, this connection has implications for deposit classification schemes and exploration strategies.

Group 4

Massive, high-grade sulphide clasts within debris-flow breccias in resedimented volcanoclastic packages of uncertain affinity (e.g., Hungry Hill prospect): The assignment of these host rocks in stratigraphic terms is problematic as there are presently two different interpretations. According to the recent mapping conducted by the GSC, the prospect is situated within the Arenig–Cardoc Wigwam Brook Group (Rogers *et al.*, 2005), whereas earlier work placed this area within the northern extremity of the TVB (e.g., Evans and Kean, 2002). The prospect is located approximately 10 km northeast from the Bobbys Pond deposit. As with the Bobbys Pond deposit, it is hosted by a package of felsic rocks, dominated by massive rhyolitic flows, rhyolite breccias, and poly lithic debris-flow volcanic breccias. The latter locally contain massive sulphide clasts (Plate 7). In addition to this "transported" style of mineralization, the prospect also contains examples of stringer-type mineralization within massive rhyolite as well as sulphides forming the matrix to rhyolite breccias (Delaney *et al.*, 2001). Such features are reminiscent of textures described from Bobbys Pond.

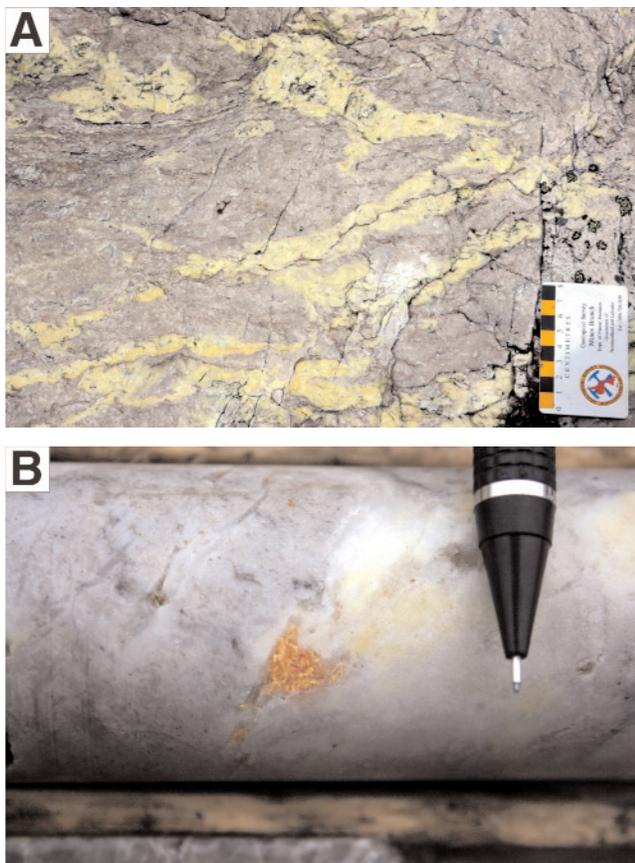


Plate 6. A) Native sulphur with silica–alunite alteration at the Bobbys Pond native sulphur showing. B) Orpiment crystals associated with the Bobbys Pond native sulphur showing. C) Massive pyrite mineralization associated with intense silicification and sericite ± alunite alteration at the North Pond prospect.



Plate 7. Base-metal-rich sulphide clasts in a polyolithic debris-flow breccia at the Hungry Hill prospect. Note that sulphide also locally forms stringers and breccia matrix.

Group 5

Copper-rich, VMS-style mineralization associated with intense black chlorite, carbonate, and quartz alteration (e.g., Victoria Mine and Jig Zone prospects): The stratigraphy in the Victoria Mine area consists of an east–west-striking, north-dipping sequence of volcanic and sedimentary rocks. In general, the stratigraphy can be broken into hanging wall aphyric felsic to intermediate lapilli tuffs, intensely altered and mineralized felsic tuffaceous rocks comprising the ore horizon, and footwall mafic volcanics and associated volcanoclastic sedimentary rocks. The mineralization occurs within altered felsic pyroclastics or breccias, which are currently grouped with the Tulks Hill volcanic rocks. The assignment of the host rocks is problematic, because the site lies very close to the proposed stratigraphic boundary between the Tulks Group and the Sutherlands Pond Group

(Rogers *et al.*, 2005). Uranium–lead zircon ages from rhyolites in the hanging-wall rocks give ages much younger than the ca. 498 Ma inferred age for the TVB (Evans *et al.*, 1990), but a recent lithogeochemical survey completed by Celtic Minerals Ltd. (Greene *et al.*, 2001) suggests the felsic volcanic rocks that host the mineralization resemble felsic volcanics elsewhere in the TVB. Evans and Kean (2002) also suggest this interpretation. The mineralization thus appears to be associated with a dipping structure that separates the TVB from younger rocks of the Sutherlands Pond Group. One possible explanation for the stratigraphic uncertainty in the area is that the mineralization represents structurally remobilized precursor sulphides (*e.g.*, Desnoyers, 1990) and occurs in both packages of rocks. Rocks in the ore horizon consist of strongly schistose, altered dacitic to rhyolitic tuff and tuff breccias. The above-mentioned structure appears to be the locus of intense black chlorite, sericite, carbonate and quartz alteration, with associated disseminated and stringer pyrite–chalcopyrite (Plate 8). Local examples of chaotic quartz–carbonate alteration closely resemble well-documented examples found at the Duck Pond deposit (Greene *et al.*, 2001). The intense chlorite and carbonate alteration differ from the typical sericite–silica-rich alteration associated with most of the VMS occurrences in the TVB.

The Jig Zone prospect is located approximately 250 m to the east of the main Victoria Mine. Mapping, in an exposed trench, suggests that the massive sulphide is associated with an asymmetrically folded thrust system, locally termed the Jig Zone fault. However, the exact relationship of the sulphide mineralization to the fault is uncertain. McKenzie *et al.* (1993) suggested that the mineralization and alteration overprinted the fault and was synchronous with the accretion of major tectonic belts in the region. The footwall stratigraphy consists of variably altered felsic volcanic rocks and coarse rhyolite breccias which most closely resemble the rhyolite breccias at the Hungry Hill prospect. However, the immediate hanging wall stratigraphy consists of very pristine and visually unaltered, green to maroon, felsic to intermediate tuffs; leading to the question of the relative timing of mineralization with respect to thrusting. The plunging massive sulphide lens, although not very well geometrically constrained, has been shown to contain interesting grades, indicated by a diamond-drill intersections of 11 m with an average grade of 2.9% Cu, 5.7% Zn in Vic-89-02 (*e.g.*, Greene *et al.*, 2001).

ALTERATION

The alteration associated with VMS mineralization in the northern TVB is quite variable from deposit to deposit but it can be subdivided into three main varieties. From south (*e.g.*, southern tip of Red Indian Lake) to north (*e.g.*,



Plate 8. *Chalcopyrite-rich, chloritized felsic pyroclastic rocks from the Victoria Mine prospect. Note that intense carbonate–silica–sericite alteration assemblages are also locally present in the ore horizon.*

in the vicinity of the Victoria River) these are: 1) stratabound sericite–silica–chlorite–carbonate–pyrite alteration assemblages, 2) sericite–silica–aluminous (illite–pyrophyllite–halloysite) and locally chlorite alteration assemblages, and 3) chlorite–carbonate–silica–sericite alteration assemblages. Alteration is widespread throughout the belt and is identifiable both in outcrop and in diamond-drill core. Silica and sericite alteration is easily identified in the field, whereas chlorite, carbonate, and especially the aluminous alteration types are much more subtle. These alteration minerals are, however, observed in drill core associated with the footwall alteration systems in some of the deposits.

Sericite–silica–pyrite, and to a lesser degree carbonate, alteration assemblages are ubiquitous for most of the VMS deposits and prospects in the TVB, but chlorite and aluminous alteration assemblages are only locally developed. The hydrothermal carbonate alteration generally occurs as overprinting spots in most of the deposits, and locally as semi-massive accumulations. Where present, chlorite alteration occurs either as part of the inner core of stringer mineralization in the footwall alteration sequences of deposits (*e.g.*, Jacks Pond deposit, Plate 3), associated with aluminous alteration in footwall alteration systems (*e.g.*, Daniels Pond deposit, Plate 1), or as the major alteration mineral associated with carbonate–silica alteration near Cu-rich mineralization (*e.g.*, Victoria Mine prospect, Plate 8). The aluminous alteration is currently defined over an approximately 4- to 5-km-strike length within the TVB, from the Daniels Pond deposit in the south to the Bobbys Pond deposit in the north. This aluminous alteration occurs in conjunction with sericite–silica–chlorite–carbonate alteration, but the most intense aluminous alteration is seen in proximity to sulphide-bearing horizons.

Most of the VMS deposits and prospects in the northern TVB are either hosted by originally porous and permeable felsic volcanoclastic rocks (*e.g.*, crystal-ash tuffs) or rock packages that are mechanically heterogeneous, such as debris flows with a permeable matrix, or brecciated rhyolites containing altered fractured networks. These host-rock characteristics most likely influenced the distribution and extent of hydrothermal fluid flow, and therefore the distribution of hydrothermal alteration and mineralization.

DISCUSSION

MINERALIZATION STYLES, DEPOSIT CLASSIFICATIONS, AND TECTONIC SETTINGS

Volcanogenic massive sulphide deposits are commonly interpreted to have formed via one of, or a combination of two, main processes. These are termed exhalative or supra-seafloor sulphide accumulation (*e.g.*, chimney-growth process or precipitation from a brine-pool), or sub-seafloor replacement of existing rocks by sulphides (*e.g.*, Doyle and Allen, 2003; Franklin *et al.*, 2005). As outlined by Squires *et al.* (2005), and Hinchey (2007), the recognition and understanding of the second process in Newfoundland is relatively new and it has implications for the deposits throughout the TVB. Criteria for diagnosis of a replacement-style VMS deposit can be found in Doyle and Allen (2003), and are summarized by Hinchey (2007).

The VMS prospect at Jacks Pond, and potentially the Bobbys Pond deposit (see additional discussion below), display many of the characteristics indicative of a replacement style of mineralization (see also McKenzie *et al.*, 1993). In both cases, hydrothermal fluids infiltrated favourable horizons of either unconsolidated tuffs (Jacks Pond) or mechanically heterogeneous (Bobbys Pond), felsic volcanic rocks that were variably porous. This process resulted in variable degrees of replacement of the original rock types and associated accumulation of massive sulphides. Both deposits locally show evidence of relict host-rock textures (felsic crystal-ash tuffs to rhyolite) within the ore, in the form of relict quartz crystals, and they display hydrothermal alteration in both the hanging wall and footwall sequences (*e.g.*, Figure 4). In addition, both deposits locally contain fine-grained siliceous sedimentary rocks either within the mineralized horizon (*e.g.*, Bobbys Pond), or spatially above it (*e.g.*, Cathys Pond horizon above the Jacks Pond deposit), which may have acted as a physical barrier to fluid migration and trapped the metalliferous fluids in underlying prospective horizons. The possible genetic link between the Cathys Pond exhalative horizon and the Jacks Pond prospect suggests that there may have been a large-scale upward migration of hydrothermal fluids. In this case, the system would have produced mostly replacement-style mineraliza-

tion at depth, that was accompanied by exhalative-type mineralization associated with those hydrothermal fluids that did reach the seafloor and vented into the water column.

At the Bobbys Pond deposit, local occurrences of very fine-grained, mineralized sedimentary rocks in the immediate hanging wall may suggest some minor exhalative mineralization. In contrast, the massive sulphide-clast-bearing debris-flow breccias in the immediate stratigraphic hanging wall to the Daniels Pond deposit suggest that the mineralization formed largely through exhalative processes. It seems that the TVB contains a spectrum of deposit styles, ranging from classic exhalative VMS deposits that formed on the seafloor through to replacement-style deposits that formed in the sub-seafloor, and combinations thereof.

Previous classification schemes of the VMS deposits in the TVB were largely based upon characteristics such as paleotectonic settings and metal contents (*e.g.*, Swinden, 1991), rather than variations in host rock types or associated alteration assemblages. Using the recent classification schemes of Barrie and Hannington (1999), Hannington *et al.* (1999) and Galley *et al.* (2007), the deposits in the northern part of the TVB (*e.g.*, Daniels Pond and Bobbys Pond) have characteristics suggestive of "hybrid bimodal felsic VMS-epithermal" deposits (Figure 5). In contrast, most of the deposits in the southern part of the TVB correspond to their

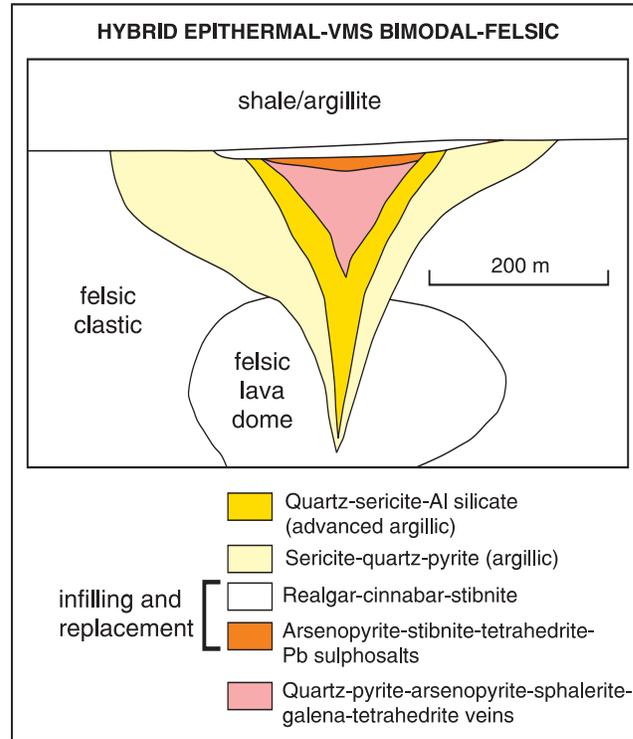


Figure 5. Graphic illustration of the lithological and alteration styles associated with the hybrid epithermal-VMS classification of VMS deposits (from Galley *et al.*, 2007).

"bimodal-siliciclastic" deposit type (Hinchey, 2007). The indications of a shallow-water, hybrid VMS-epithermal environment in the northern part of the belt include: 1) the presence of acidic aluminosilicate alteration in the immediate footwall, and locally in the hanging wall, of the Daniels Pond and Bobbys Pond deposits, 2) local occurrences of silica-alunite-native sulphur-pyrite-orpiment-stibnite alteration in the vicinity of these deposits, and 3) local vuggy silica textures in the vicinity of the deposits.

Aluminous alteration assemblages have been described from other VMS deposits and environments throughout the world, especially from the Kuroko deposits in Japan, Australian deposits, a small subset of Canadian deposits, and also from active seafloor systems (*e.g.*, see Sillitoe *et al.*, 1996, Hannington *et al.*, 1999, Dubé *et al.*, 2007, and references therein). The presence of these argillic and advanced argillic alteration assemblages suggests that the deposits formed under relatively oxidized, low-pH, acidic conditions compared to the typical reduced, near-neutral to weakly acidic conditions associated with typical VMS deposits in which the hydrothermal fluids are dominated by seawater circulation (*e.g.*, see Sillitoe *et al.*, 1996; Hannington *et al.*, 1999). For pyrophyllite and/or kaolinite minerals to be stable in typical VMS-type fluids, the pH of the fluid must be <3.5, much lower than the typical range of 5-6 for most VMS-related fluids (Gifkins *et al.*, 2005). As outlined by Gifkins *et al.* (2005), such acidic fluids could be generated in VMS systems by acidic fluid reactions associated with the introduction of magmatic volatiles into the hydrothermal system. Due to the buffering of the fluid pH by potassium-rich sericite and chlorite alteration assemblages within these deposits, this first process is likely not applicable to the TVB deposits. It is therefore suggested that magmatic fluids played a greater role in VMS hydrothermal systems in the northern TVB, and that fluid boiling may have been locally important. It is also postulated that mineralization formed in a shallow-marine environment, in some respects equivalent to a shallow-submarine version of the more typical subaerial high-sulphidation epithermal-type deposit environment. This provides a reasonable explanation for characteristics typical of both VMS- and epithermal-type deposits (see below, Figure 6).

Although the deposits in the northern TVB share many similarities with the deposits in the southern part of the belt (*e.g.*, styles of mineralization, felsic host rocks etc.), the general environment is different in that the stratigraphy contains a higher proportion of extrusive rhyolitic facies (*e.g.*, blocky rhyolite flows, rhyolite breccias, etc.) compared to felsic volcanoclastic and sedimentary facies. This is perhaps indicative of a vent-proximal environment in the north compared to the south (Figure 6). It is also suggested that the northern Tulks deposits likely formed in an area of relative-

ly "high-standing ground" within the basin, under relatively shallow-water conditions, compared to a deeper water, sediment-dominated distal environment in the southern TVB (see Hinchey, 2007). It is also possible that parts of the northern TVB were an emergent arc environment, although these rocks are less likely to be preserved. From south to north, the TVB is envisaged to record a transition from deep basin, classic VMS environment (*e.g.*, Tulks East deposit), to shallower water, vent-proximal bimodal VMS-epithermal-style deposits (*e.g.*, Daniels Pond deposit).

IMPLICATIONS FOR EXPLORATION

Based upon the observations discussed within this report, and those previously outlined by Hinchey (2007), exploration for VMS-style mineralization within the TVB should consider five main points when planning exploration activities:

1. Detailed geochronological studies by the GSC, in conjunction with previous work, illustrate that the TVB is composite in nature, ranging in age from at least 498 Ma to 453 Ma. To date, VMS-style mineralization within the TVB is known to occur within rocks of 498 \pm 6/-4 age at the Tulks Hill deposit (Evans *et al.*, 1990), and within rocks of 491 \pm 3 Ma at the Boomerang deposit (V. McNicoll, GSC, unpublished data, as part of this project). However, several of the other prospects in the belt have uncertain stratigraphic affinity (*e.g.*, Victoria Mine, Hungry Hill). Given the difficulties in discriminating rocks that look alike but may be of varied ages, the placement of boundaries between these components remains problematic. At least for the moment, all parts of the TVB should be viewed as prospective.
2. Graphitic sedimentary rocks associated with felsic volcanoclastic assemblages and bimodal sills are intimately associated with many of the deposits, particularly the bimodal felsic siliciclastic-type deposits in the southern portion of the TVB. The location of conductive horizons, potentially associated with such sediment rocks has been outlined by previous electromagnetic surveys. As such, targets should be assessed with respect to such relationships.
3. The reclassification of the TVB deposits into bimodal felsic siliciclastic and hybrid VMS-epithermal-style deposits highlights the importance of sediment-rich sequences and acidic, aluminous alteration assemblages respectively. The aluminous alteration is particularly difficult to identify in both

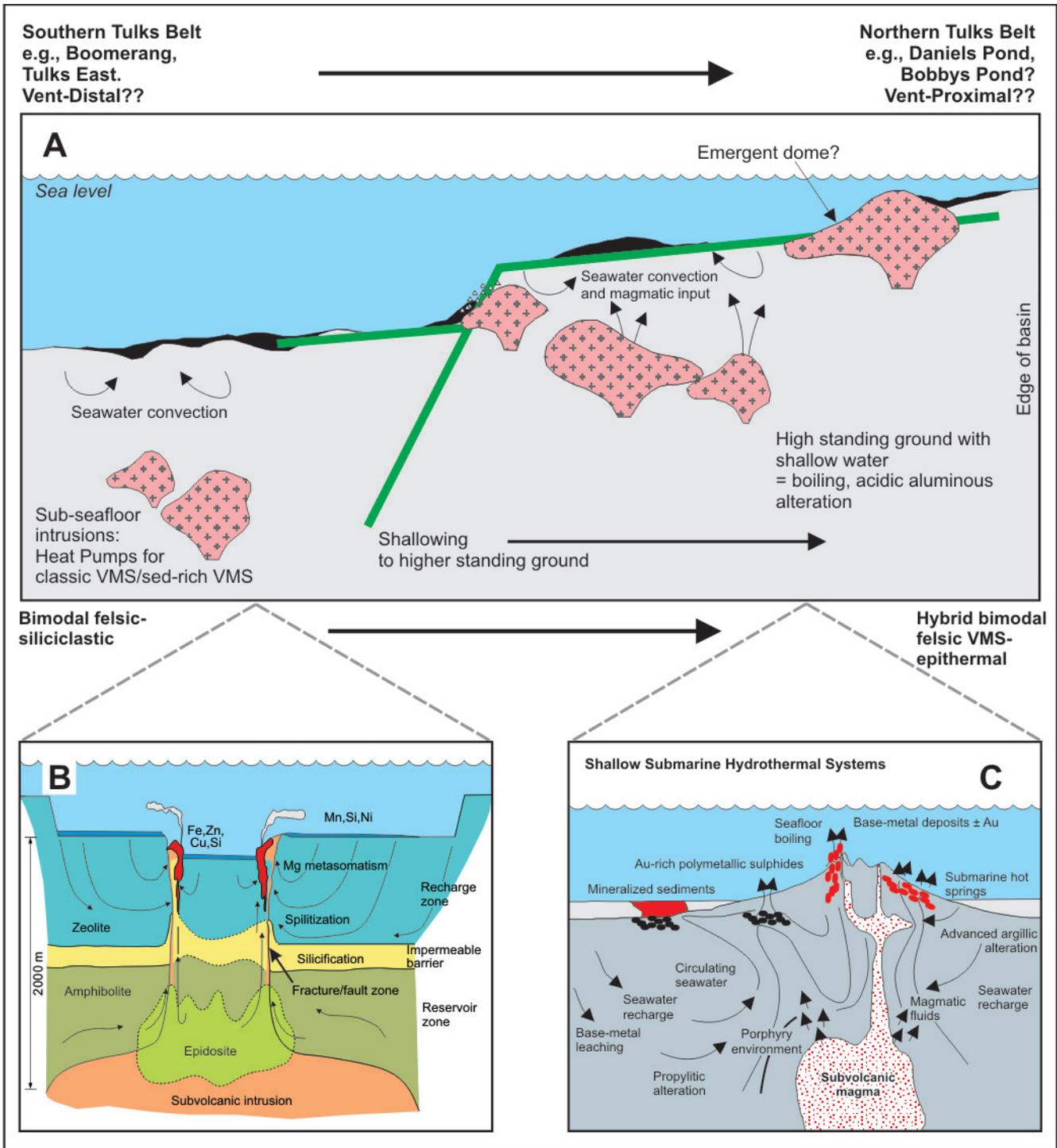


Figure 6. Schematic diagram illustrating the two types of VMS-forming environments observed in the Tulks Volcanic Belt. A) Cartoon depiction of the transition from the deep-water, typical VMS environment observed in the southern part of the TVB to the shallower water, VMS-epithermal type environment observed in the northern part of the TVB (inspired from Hannington et al., 1999); B) Blow up of the typical VMS environment illustrating distribution of alteration types and hydrothermal fluid flow (from Galley, 1993); C) Blow up of a shallow-marine, transitional VMS-epithermal environment illustrating distribution of alteration types as well as the input of both magmatic fluids and seawater to the hydrothermal convection system (from Hannington et al., 1999).

field and drill-core samples, and alternative identification methods (*e.g.*, PIMA spectrometry \pm geochemistry) may be beneficial for exploration.

4. Mineralization styles range from typical exhalative-style VMS mineralization to replacement-style deposits, although both may occur in some areas. In the former case, geochemical vectoring from exhalative horizons may be possible. However, lack of outcrop in the area may be significant enough to impede such methods. Furthermore, the replacement-style sulphide deposits may not always be responsive to EM geophysical techniques, even though commonly associated graphitic sediments are conductive over a wide area. A combination of EM and other methods (*e.g.*, gravity, or geochemical studies of alteration) may be required for successful delineation.
5. Although no "gold-rich" VMS deposits have yet been discovered in the TVB, it is important to note that from a global perspective, gold-rich VMS deposits commonly coexist with gold-poor VMS deposits (see Dubé *et al.*, 2007 and references therein). The particular physiochemical conditions and fluid chemistry required for gold deposition and concentration in the VMS environment may only thus be locally achieved throughout a given VMS district. The hybrid VMS-epithermal environment in the northern TVB may contain the right environmental conditions to host such gold-rich VMS deposits. From a North American perspective (Dubé *et al.*, 2007), possible targets for some of the gold-rich VMS deposits are large tonnage, medium-grade deposits (*e.g.*, LaRonde deposit with ~60 Mt grading ~5g/t Au, 76 g/t Ag), or low tonnage, extremely Au-rich deposits (*e.g.*, Eskay Creek deposit with 2.5 Mt grading 44.4 g/t Au). The latter could easily fit into numerous relatively untested portions of the northern TVB. Deposits of this type may provide viable exploration targets, and may require somewhat different strategies in exploration.

CONCLUSIONS AND FUTURE WORK

The main focus of the 2007 season was to extend 2006 fieldwork to include the known VMS deposits of the northern TVB, and to understand the regional and local stratigraphy, the alteration styles associated with mineralization, and the nature and style of the massive sulphide mineralization.

Volcanic lithofacies were investigated and classified to aid in ongoing lithogeochemical studies. Preliminary results suggest that there are a number of distinguishable volcanic facies amongst the variable felsic volcanic, pyroclastic and volcanoclastic rocks that host mineralization along the belt. Significantly, there are more vent-proximal rhyolitic facies in the northern part of the belt compared to the volcanoclastic dominated environments to the south. Results of geochemical studies may serve to provide additional facies variations throughout the TVB. Uranium-lead geochronological studies are also planned to date the rocks associated with the VMS deposits and see if there are further unresolved complexities in the TVB.

In contrast to the "bimodal felsic siliciclastic" deposits in the southern TVB (Hinchey, 2007), the deposits in the northern part of the belt are more akin to "hybrid VMS-epithermal" style deposits. As with the southern portion of the belt, two main styles of VMS mineralization occur within the northern Tulks Volcanic Belt. Replacement-style mineralization dominates at the Jacks Pond deposit and potentially the Bobbys Pond deposit, whereas exhalative-style mineralization dominates at the Daniels Pond deposit.

Several follow-up research studies have now been initiated. Lithogeochemical sampling has been completed on stratigraphic units within the TVB, using outcrops and diamond-drill core. Results will hopefully aid in identification and characterization of prospective VMS horizons for future exploration. Isotopic and geochronological studies have also been initiated to see if such data supports the observed variations in prospective VMS environments.

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