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STUDIES IN THE SEAL LAKE GROUP, CENTRAL LABRADOR, PART I: DESCRIPTION OF COPPER OCCURRENCES

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ABSTRACT

The Seal Lake Group, the youngest supracrustal sequence in the Labrador Central Mineral Belt, is a dominantly continental assemblage of red shale, siltstone, and quartzite, associated with basalt flows and numerous diabasic to gabbroic sills. The middle three formations and sills contain over 250 copper occurrences, ranging from malachite stains to significant chalcocite–bornite deposits. In general, native copper-bearing quartz–carbonate veins occur in red slate and/or strongly hematized basalt units, whereas, chalcocite and/or bornite stringers and quartz–carbonate veins occur in diabase, basalt, or grey to black shales and phyllite; the copper mineralogy being dependant upon the valency state of iron in the host rock. All occurrences appear to be epigenetic and are interpreted as the products of a single mineralizing event.

INTRODUCTION

The field studies reported here are the 1987 results of a larger five-year Canada–Newfoundland Mineral Development Agreement (CNMDA) project on the 'Metallogeny of the Central Mineral Belt, Labrador'. Preliminary field results from the 1987 study have been described elsewhere (Wilton and Brace, 1988).

The Central Mineral Belt (CMB) is a 260 by 75 km area, within central to coastal Labrador that is underlain by six Proterozic supracrustal sequences, *viz.*, the Moran Lake, Lower Aillik, Upper Aillik, Bruce River, Letitia Lake and Seal Lake groups, ranging in age from *circa* 2000 Ma to *circa* 1300 Ma (Ryan, 1984). The Seal Lake Group, the youngest supracrustal sequence, hosts epigenetic copper occurrences ranging from native copper in slate and basalt, to chalcocite and bornite in slate, diabase sills and basalt flows.

The main objectives of the Seal Lake study were to, 1) document the numerous copper occurrences in the area *(this report)*, and 2) to sample the gabbro and diabase sills for petrogenetic modelling and definition of their Platinum-Group Element potential (Wilton, *this volume)*.

THE SEAL LAKE GROUP

Introduction

The Seal Lake Group (after Baragar, 1981, and Ryan, 1984) is a 1323 $\pm$ 92 Ma (Wanless and Loveridge, 1978) old unit that consists of six formations (see Figure 1) *viz.*; the Bessie Lake–Majoqua Lake Formation (quartzite or arkosic sandstone, and basalt); the Wuchusk Lake Formation (red to black shale, and minor quartzite and limestone); the Whiskey Lake and Salmon Lake formations (red shale, basalt and minor quartzite); the Adeline Island Formation (red to grey shale and quartzite with minor basalt), and the Upper Red Quartzite Formation. The middle sedimentary sequences (i.e., Wuchusk Lake, Whiskey Lake and Salmon Lake formations) contain numerous diabasic to gabbroic sills of the Naskaupi sills unit (Baragar, 1981). Throughout these six lithologic units, the group is host to over 250 Cu occurrences in quartz veins and/or shear zones (Brummer and Mann, 1961).

Previous Work

Most of the information available on the Seal Lake copper occurrences is in the form of unpublished mining company reports. Evans (1952) produced the first geological map of the Seal Lake Group, defined the stratigraphy of the group, and outlined the synclinal form of the unit. He also reported that the first discovery of native copper in the area was made in 1946 by geologists with Norancon Exploration Limited, south of Adeline Lake.

Robinson (1956) described briefly the geology of the Seal Lake Group and suggested that the group belonged within the Grenville geological province. Fahrig (1957) described the regional context and lithostratigraphy of the Seal Lake Group in greater detail and later (Fahrig, 1959) produced a 1:250,000 scale map of the regional geology.

Geologists from Frobisher Limited undertook extensive exploration and evaluation programs in the Seal Lake area during the years between 1950 and 1955 (Evans, 1951a,b; Robinson, 1953, 1954, 1955), which led to the discovery of numerous copper occurrences throughout the area. Their

This project is a contribution to the Canada–Newfoundland Mineral Development Agreement, 1984–1989

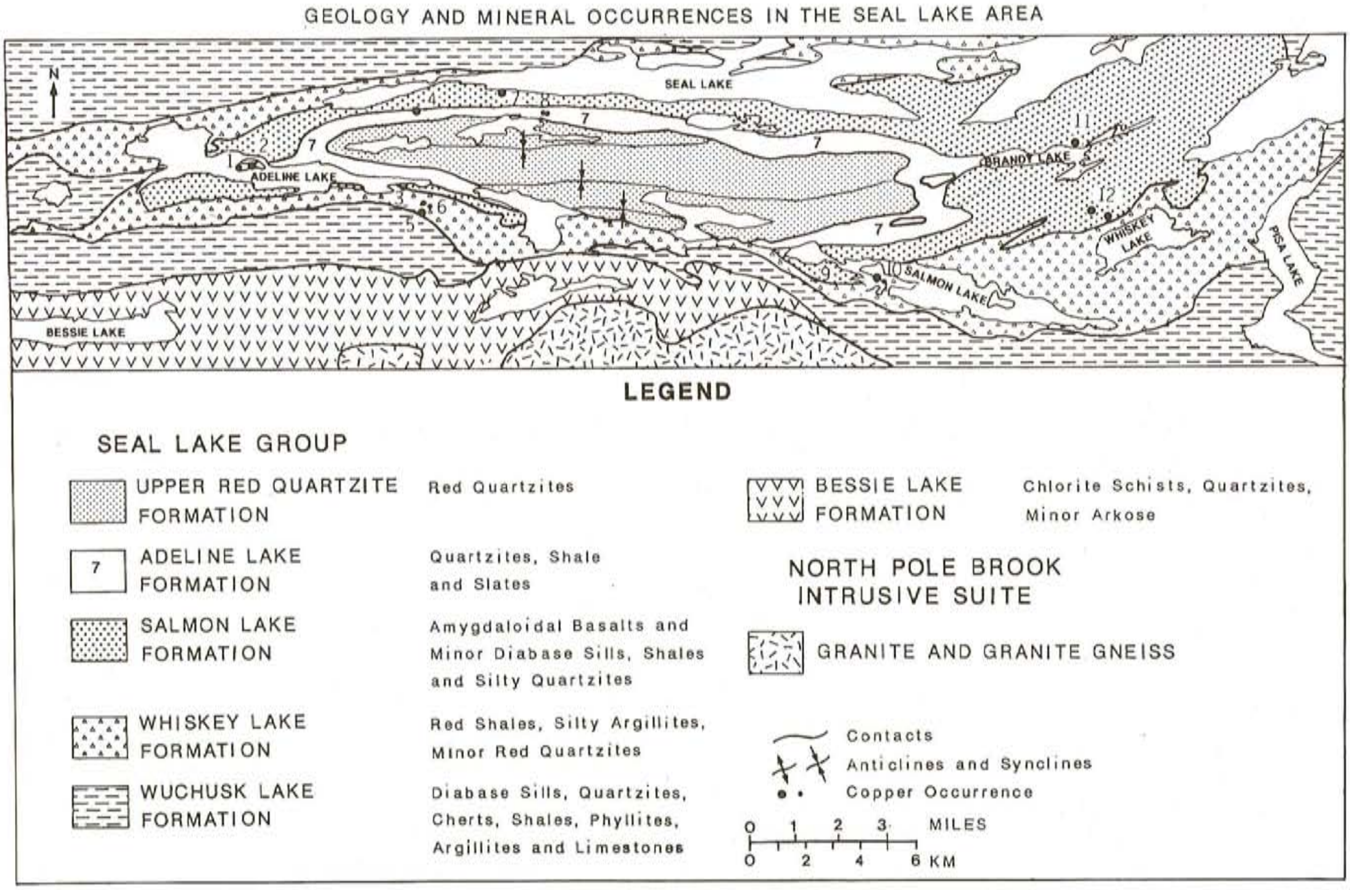

Figure 1. *Geology of the Seal Lake Group and the Seal Lake Syncline (after Brummer and Mann, 1961). Copper occurrences are denoted by black circles; the larger black circles indicate showings that have been evaluated in detail by mineral exploration companies. The location of the various copper occurrences discussed in the report are shown as follows: 1) Adeline Island West Occurrence; 2) Adeline Island Showing; 3) NMI 13K/5 Cu018; 4) Ellis Showing; 5) South Adeline Mountain Showing; 6) NMI 13K/15 Cu187; 7) Seal Lake Main Showing; 8) Brian Prospects; 9) Showing No. 36; 10) Salmon Lake Main Showing; 11) Brandy Lake Showing; and 12) Whiskey Lake Showings.*

evaluations included data collected from trench-blasting, diamond-drilling, and electromagnetic and scintillometer surveys.

Kennco Explorations (Canada) Limited optioned the concession area from Frobisher Limited in 1956 and undertook a further extensive property evaluation program during the 1956 field season. The 1956 program involved detailed examination of the Seal Lake Main Showing, the Adeline Island Prospect, the North Adeline Lake Prospects, the South Adeline Mountain Prospect, and the North Whiskey Lake Prospects. These investigations included mapping, geophysical surveys and diamond drilling. A pioneering stream-sediment geochemical survey was also completed in this area as reported in Brummer (1960). As a result of the 1956 field work, Brummer (1957) recommended that no further work be carried out in the area as he felt the potential for ore-grade concentrations of copper did not exist in the syncline.

Brummer and Mann (1961) produced the definitive work to date on the stratigraphy, nomenclature and geological distributions of both lithologies and mineral occurrences within the Seal Lake Group. They also described four showings in detail (*viz.*, the Adeline Island, Ellis, and North Whiskey Lake prospects, and the Seal Lake Main Showing).

Baragar (1969) completed two chain and compass stratigraphic section lines across the Seal Lake Group. These lines provided a complete section through the stratigraphy of the Seal Lake Group on the northern limb of the syncline. Baragar (1974, 1981) used the analytical data to define the sills as transitional between alkaline and subalkaline tholeiites and the basalts as olivine normative plateau basalts.

Commencing in 1970, geologists from BRINEX Limited mounted an exploration program in the basin (Gandhi, 1970). The main impetus for the exploration was the postulated geological similarity of a sulphide-bearing grey-black slate unit, within the Adeline Island Formation, and the Nonesuch Shale Formation in the White Pine Copper Deposit of Michigan (Gandhi, 1972a). Evans (1952) had previously suggested that the Seal Lake copper deposits were similar to those of the Keweenawan Peninsula of Michigan. Brown (1971) completed a mineralographical study of samples from the Ellis and Adeline Island showings in order to ascertain more fully their similarities with the White Pine Deposit. He suggested that, although some features were very much alike, a definite correlation could not be made due to deformation.

The exploratory program undertaken by BRINEX Limited from 1970 to 1972 involved detailed geological mapping (to define the stratigraphy of the Adeline Island Formation throughout the Seal Lake Basin), geophysical surveys and diamond drilling (Gandhi, 1970, 1971, 1972a,b; Murthy and Gandhi, 1972). The final conclusion from the evaluation of the basin was that, though there were, 'several small pockets of disseminated copper–silver mineralization in grey shales, ... none of them is of size and grade to be of economic interest' (Gandhi, 1972a, p. 13). Exploration activity by BRINEX Limited personnel ceased following the 1972 field season and there has been no further mineral exploration in the area.

The most recent report on the copper occurrences was by Gandhi and Brown (1975), who described in detail five showings (*viz.*, the Ellis, Brian, Duck Lake South, Duck Lake North and Brandy Lake prospects; the main BRINEX Limited targets) that they defined as occurring solely within the shale and quartzite of the Adeline Island Formation. They modelled this formational unit as an analogue to the Nonesuch Shale and associated mineralization at White Pine, Michigan.

Description of copper occurrences examined in 1987. During the field program of 1987, over thirty-six copper occurrences were examined; ranging from malachite-stained quartz–carbonate veins to larger prospects that had been extensively drilled by the mineral exploration companies. The six prospects (copper occurrences numbered 2, 4, 7, 8, 11 and 12 on Figure 1) described by Brummer and Mann (1961) and Gandhi and Brown (1975) occur within the northern limb of the Seal Lake syncline in the Salmon Lake (the Seal Lake Main Showing) and Adeline Island formations. Thus, to date, there has been no single complete compilation of all the copper occurrences in the Seal Lake Group and in this report, the more significant of the other occurrences in the southern limb of the syncline (discovered in the early 1950's) will be described (occurrences numbered 3, 5, 6, 9 and 10 on Figure 1). The alpha-numeric designation, of copper occurrences described in the text, refers to that used on Map 83-27 (O'Driscoll and Noel, 1983).

Adeline Island West

This occurrence, at the western end of Adeline Island, is on the same stratigraphic level as the Adeline Island Showing. It is a small (20 by 2 m), trenched, copper showing, consisting of quartz veins up to 0.3-m thick, having associated chalcopyrite, pyrite, bornite and molybdenite. The veins occur in a grey quartzite unit, between the contact zone with a 2-m-thick black slate bed. Molybdenite was discovered at this site during the 1987 field season.

Adeline Island Showing

At this showing, bornite and chalcocite occur within quartz veins in the contact zone between a phyllitic grey-black siltstone and massive red to grey quartzite (Adeline Island Formation). The siltstone layer has an irregular distribution and thickness (ranging from $\leq$ 3 m to $<$ 5 cm) due to infolding within the quartzite. The siltstone itself has infolded red slate layers (3- to 5-cm thick), which are cross-cut by quartz veins. The whole sequence dips to the south, and red quartzite and shale immediately underlie the ore zone. Stratigraphically below the mineralization is red slate and basalt of the Salmon Lake Formation.

There were two periods of folding; an earlier isoclinal folding episode, which produced folds with vertical to subvertical fold axes, and the later episode, which produced the larger folds (isoclinal and overturned with axial planes dipping to the south) described by Brummer and Mann (1961). Axial-planar foliation associated with the D_1 isoclinal folding has, in places, completely transposed bedding into a parallel secondary fabric.

There are at least two generations of quartz veining at the showing. The copper sulphides are hosted by the first generation (folded and boudinaged) set, thus the mineralization was syn- or slightly post-D_1. The second generation, undeformed, quartz vein set often brecciates the host rocks.

Where quartzite layers have been isoclinally folded (as visible at Adeline Falls), the ductility contrast between quartzite and enclosing phyllite produced dilatant zones in the quartzite, which were subsequently filled with quartz (Plate 1). Quartz veins in similar zones contain bornite at the showings (Plate 2). In other parts of the showing, where the quartzite–phyllite contacts are more linear, the sulphide-bearing quartz veins are also linear, although sheared.

Parts of the quartzite, which host the most intense copper mineralization, often have a grey 'washed out' colour, suggesting that the copper-bearing hydrothermal fluids reacted with the host rocks removing Fe to form bornite.

This showing is currently being studied by P. Ivany as the basis of a CNMDA-supported B.Sc. (Hons.) dissertation at Memorial University of Newfoundland.

Seal Lake Showing No. 1– NMI [13K/5 Cu018]

This is Robinson's (1954) Showing No. 1, at the eastern end of Adeline Lake, which consists of a single, 28-m-long trench through south-dipping (75°/45S) metabasalt. Within the trench is a podiform quartz–carbonate–epidote vein(158°/63E), which contains hackly native copper, and

Plate 1. *Isoclinally folded quartzite (white) within green phyllitic schist (black). The quartzite here occurs in a fold nose. Note the quartz vein and phyllite-filled fractures cutting the more competant quartzite.*

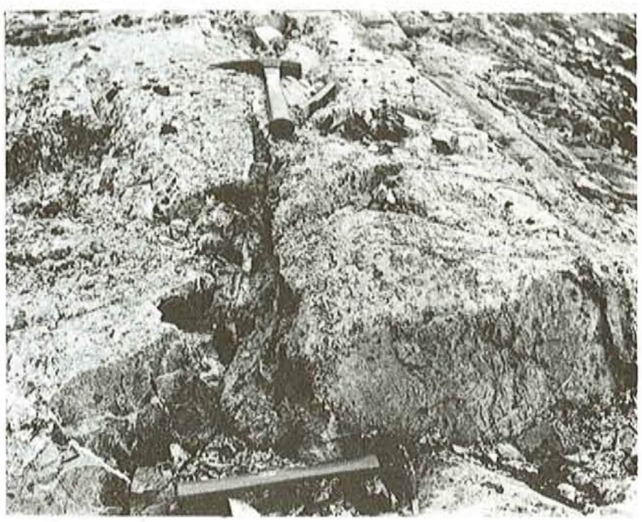

Plate 2. *Quartzite (massive grey rock in background) cut by black phyllite (parallel to the upper hammer handle) containing a bornite-bearing quartz vein at the Adeline Island Showing.*

associated malachite, azurite and cuprite. The vein appears to fill a fault–fracture system and is significant because it is the only example seen by this author in the Seal Lake area, wherein the vein system cuts the host rock at a high angle (i.e., in all other occurrences the vein systems are usually parallel or subparallel to the main S-fabric of the host rocks).

The Ellis Showing No. 26–NMI [13K/5 Cu002]

There are a number of different lithologies at this showing, and generally, mineralization seems to be contact-related. The main rock type is a grey quartzite (having visible, clear 1- to 2-m quartz grains interbedded with green siltstone, sandstone and minor fine-grained conglomerate. At one interval, the quartzite has an erosional contact (having a very thin basal conglomerate) indicating the units are upright. Stratigraphically above the quartzite (i.e., to the south), black slate and phyllite contain quartz–carbonate veins (up to 10-cm thick) having chalcopyrite, bornite and malachite (Plate 3). The quartzite contains bornite, chalcopyrite and/or pyrite stringers, which can account for up to 10 and 20 percent of the host rock (Plate 4).

Plate 3. *Chalcopyrite (+ bornite) in quartz–carbonate vein (white in centre of photo) cutting green phyllitic schist at the stratigraphic top of the Ellis Showing.*

Stratigraphically below the quartzite, small limestone pods are interbedded with the green sandstone–siltstone, which ultimately pass downward into red slate.

This showing was reported (Robinson, 1954) to have grab sample assays of 2.86 percent Cu and 3.66 oz/t Ag from quartzite and 3.54 percent Cu and 2.8 oz/t Ag from slate. From one of the six blasted trenches, Robinson (1955) reported an assay of 2.5 percent Cu and 2.71 oz/t Ag over 4.5 m and an average grade of 1.35 Cu and 1.6 oz/t Ag across 4.2 m over a length of 60 m.

Based on the 1987 examinations, the mineralization is epigenetic with respect to the host rocks, the depositional site is a somewhat sheared sedimentary contact zone and the quartzite lenses are true sedimentary horizons. There is no dissemination of sulphide in the host rock, just stringers.

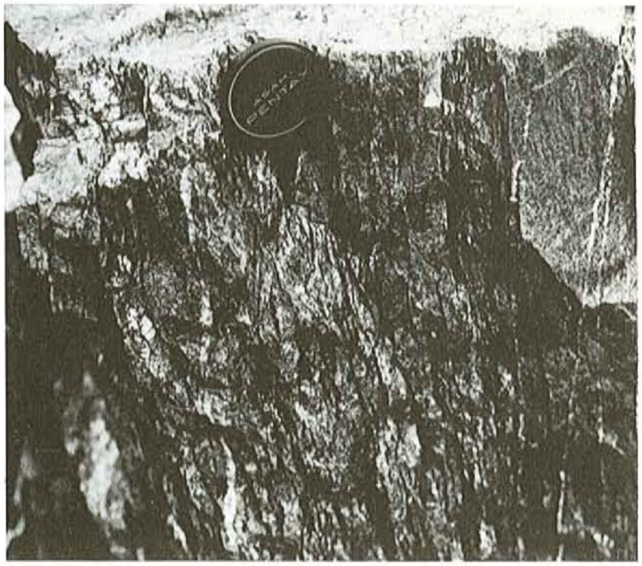

Plate 4. *Greenish-white quartzite (medium-grey massive rock) cut by stringers of bornite and chalcocite (black lines cutting quartzite) and quartz–carbonate veins (white) at the Ellis Showing.*

South Adeline Mountain Showing–NMI [13K/5 Cu019]

Robinson (1954) reported that his Showing No. 2 consisted of diabase underlain by hornfelsed argillite; shears along the contact contain quartz–carbonate veins, and pods and seams of bornite, chalcocite and chalcopyrite. According to Robinson (1955), the ore zone averages 1 percent Cu across a 5.1-m thickness over a 30-m length. Drilling by Kennco Limited (Brummer, 1957) revealed that the contact-related mineralization had a very erratic distribution.

This showing is exposed as two large blasted trenches and four channel-sample lengths along a north-facing cliff face (Figure 2). The cliff consists of a diabase sill overlying red sandstone and siltstone. The sill hornfelsed the Whiskey Lake Formation sedimentary rocks near the contact to the extent that they are dark green with flesh-coloured calc-silicate alteration patches. The mineralization consists of quartz–carbonate pods and disrupted veins, mainly within the metadiabase near the sedimentary contact, which contain impressive amounts of intergrown bornite and chalcocite. The widest pod is about 20 cm across (Plate 5).

South Adeline Lake No. 209A–NMI [13K/5 Cu187]

This showing occurs along the contact between the diabase cap of Adeline Mountain and the underlying hornfelsed shale of the Salmon Lake (or Whiskey Lake) Formation. Along the contact zone, the diabase is sheared and epidotized, often having malachite staining. The most intense malachite staining is associated with quartz–carbonate (± epidote) veins that contain chalcopyrite and pyrite (and minor bornite). Rare molybdenite was also found during this study, associated with copper minerals.

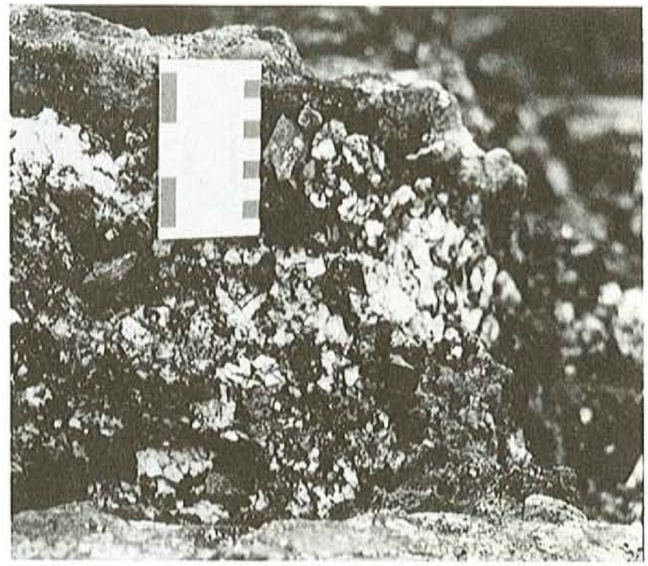

Plate 5. *Twenty-centimetre-wide quartz–carbonate vein (white) having abundant intergrown bornite-chalcocite (black in vein) from the South Adeline Mountain Showing; this particular vein occurs within the metadiabase.*

The Seal Lake Main Showing–NMI [13K/5 Cu001]

This showing consists of a 6- to 8-m-high cliff, 30 m from the south shore of Seal Lake, which is over 450-m long and has been trenched parallel to the cliff face for most of its length. Diabase occurs along the upper part of the cliff and is underlain by red slate, and in turn by the amygdaloidal basalt of the Salmon Lake Formation. At the contact, the diabase has hornfelsed the slate into a black slate. Within the red slate, quartz (+ carbonate) veins contain masses of native copper that form 'nuggets' up to 25-cm across. The veins trend parallel to the cliff face and are podiform within the cleavage planes of the slate. The slate wall rock is often brecciated and cemented by the veining. Quartz–epidote (± carbonate) veins within the diabase contain chalcocite and bornite, and rare native copper-bearing quartz–carbonate veins.

The showing resulted from a single mineralizing episode in which Cu-rich hydrothermal fluids migrated through the slate and diabase along fracture systems near their mutual contact. The oxidized nature of the slates (as indicated by their red colour) led to the precipitation of native copper. The more reduced nature of the diabase (magnetite-bearing and disseminated pyrite) led to precipitation of chalcocite and bornite.

The Brian Prospects–NMI [13K/5 Cu190 and 191]

There are two prospects, tentatively called the South and North zones (Gandhi and Brown's (1975) Brian Prospects 3a and 3b, respectively). The North Zone occurs in a 10-m-high cliff face, which has red slate at its base, grading upward into black and grey phyllite. The occurrence consists of

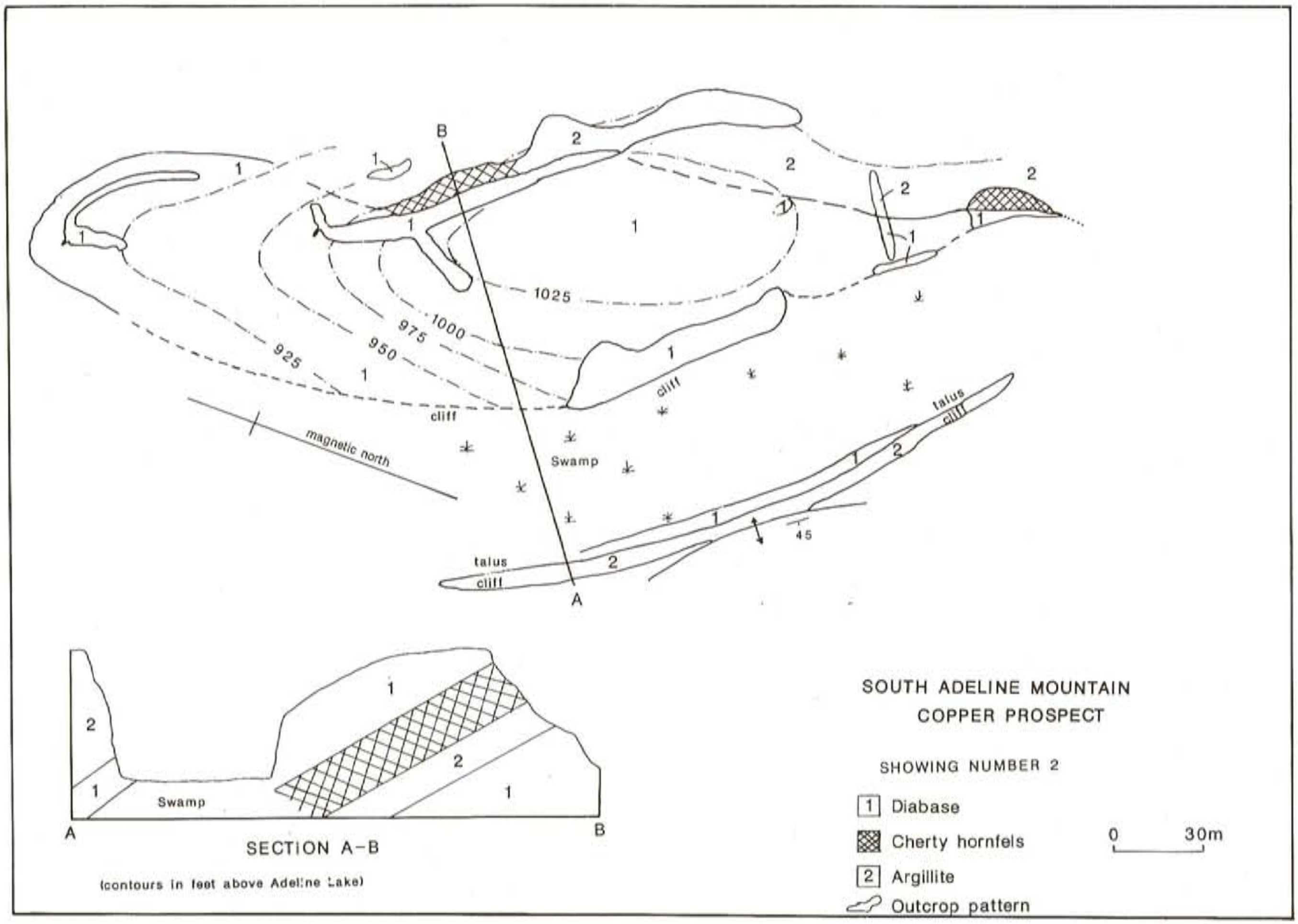

Figure 2. *Geological map of the South Adeline Mountain Showing (after Robinson, 1954). Podiform quartz–carbonate veins having bornite and chalcocite occur in the contact zone of the diabase and argillite; herein designated as cherty hornfels.*

(folded and/or boudinaged) quartz–carbonate veins within a 0.5-m-wide shear zone in green–grey phyllitic slate. The veins are up to 1.5-cm thick and contain chalcopyrite, bornite and pyrite.

At the South Zone, a 20-cm-wide quartz–carbonate vein occurs in grey–green quartzite, 0.6 m from a contact between the quartzite and black slate. The vein contains spectacular intergrowths of bornite and chalcopyrite. Pyrite stringers and cubes are present in both the slate and quartzite near the contact and there is minor malachite staining along the contact. Sedimentary facing directions are difficult to discern but it appears that the quartzite underlies the slate, and the mineralized zone is above the contact zone. In a more easterly trench (120 m from the main part of the zone) the quartzite is cut by quartz–carbonate veins containing bornite–chalcopyrite–pyrite (there is no slate in contact with the quartzite; i.e., the quartzite is the only rock in the trench).

West Salmon Lake No. 36–NMI [13K/5 Cu022]

This showing was discovered and described by Robinson (1954). It consists of a single 16-m-long stripped, and in places blasted, outcrop, along with smaller stripped outcrops extending for over 75 m west of the showing. This showing resembles the Adeline Island Showing in that it consists of quartz (+ carbonate) veins (up to 5-cm wide) along the lithological contact between a grey arkosic sandstone and chloritic schist. The veins contain bornite and malachite, and where veins are not present, intense malachite staining is present along the 75 m exposed contact zone. In the more western outcrops, veins contain pyrite. Robinson (1954) noted that channel samples across 0.75 m and 30 cm contained 0.83 percent Cu and 1.24 oz/t Ag, and 1.93 percent Cu and 0.22 oz/t Ag, respectively. During this study, minor amounts of molybdenite were found in the contact veins approximately 60 m west of the showing.

Salmon Lake Main Showing–NMI [13K/5 Cu017]

The showing occurs in an outcrop along the shore of Salmon Lake as a small blasted trench and has received relatively minimal evaluation. At this showing (Figure 3), epidotized and hematized basalt is cut by a native copper-bearing quartz–carbonate vein up to 0.3-m wide and over 20-m long. There is a smaller trench with native copper in

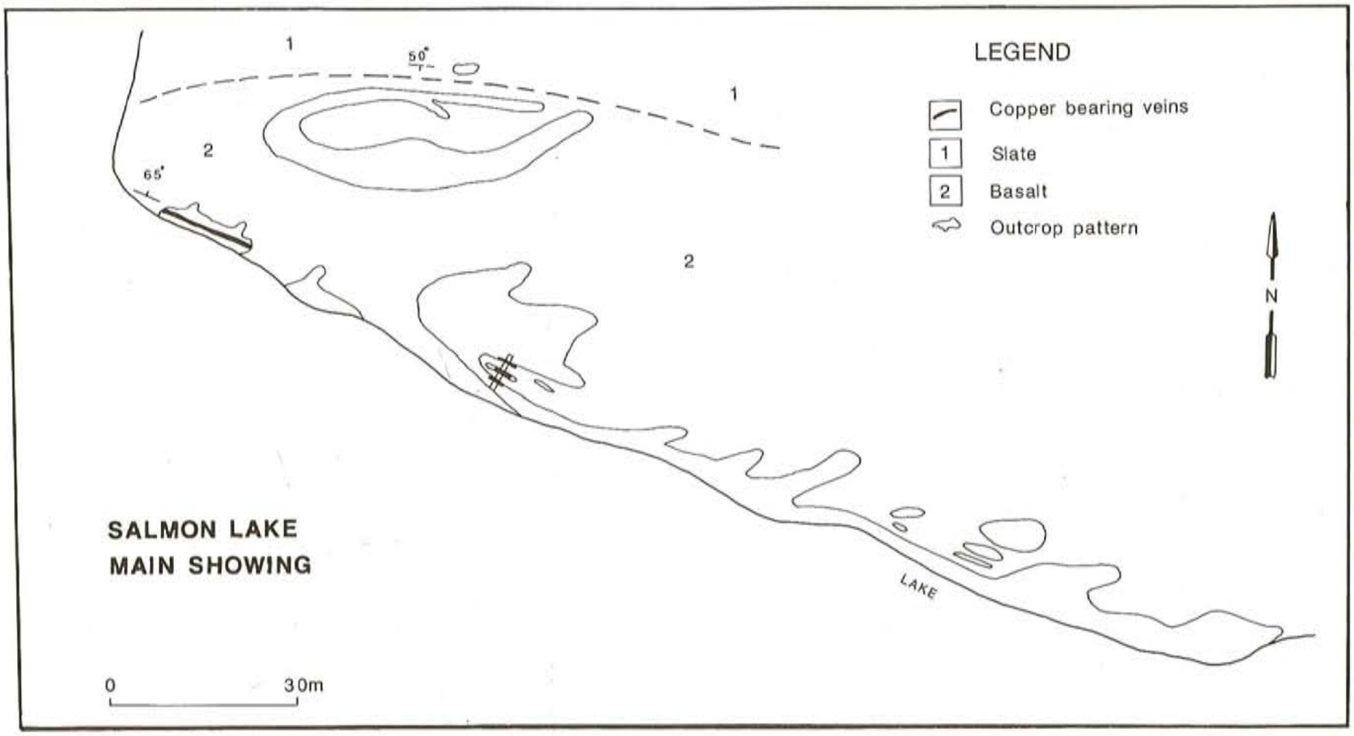

Figure 3. *Geology of the Salmon Lake Main Showing (after Robinson, 1953)*

quartz–carbonate veins, 40 m to the east. Robinson (1953) reported that grab sample from a 25-cm-thick section of the main vein contained 0.44 oz/t Ag and 16.72 percent Cu, and a chip sample across the eastern trench contained 0.07 oz/t Ag and 1.22 percent Cu.

There is another small occurrence 1 km to the west, which is seemingly an extension of the Salmon Lake Main vein system (Robinson, 1953). At this other occurrence, epidotized zones within chloritized and hematized basalt are cut by quartz–carbonate veins (up to 6-cm thick) that contain native copper and are malachite-stained. Robinson (1953) reported that two assays from this occurrence indicated 1.44 and 0.48 percent Cu across 0.8 and 1.2 m.

Brandy Lake Showings–NMI [13K/5 Cu029–032]

These showings are a series of small trenches spread over a 450 by 900 m area. The best mineralization occurs at the Brandy Main Showing and consists of a short trench and 3 by 5 m of blasted outcrop. There are a range of lithologies at this showing ranging from quartzite, to sandstone, and conglomeritic sandstone. Extensive chalcocite and bornite are associated with a sheared conglomeratic sandstone that has red (hematized) patches. Murthy and Gandhi (1972) describe the mineralization as a 0.6-m-thick, 1.5-m-long zone of chalcocite in grey slate at the contact with diabase and lava. They report grab sample assays of 7.5 and 10 percent Cu, and 0.17 oz/t and 0.26 oz/t Ag.

Approximately 195 m north-northeast of the main showing, red to pink quartzite contains small quartz veins associated with minor bornite. One hundred and thirty-five metres northeast of the main showing, diabase contains epidote veins having chalcopyrite, and quartz–carbonate (± epidote) veinlets containing bornite. Three hundred and ninety metres east of the main showing, quartz veins were found containing chalcocite and malachite in flesh-coloured phyllitic schist that are overlain by red slate, which in turn is overlain by quartzite.

Approximately 660 m northeast of the main showing, quartz–carbonate veins having chalcocite and malachite occur along the contact between diabase and underlying green phyllitic schist.

One hundred and twenty metres northwest of the main showing in an outcrop that contains the contact between two, somewhat schistose, basaltic lava flows (one hematized, the other chloritized with numerous amygdules), chalcocite and malachite containing specular hematite occur in carbonate–epidote patches and veins along the contact zone.

From the 1987 field survey, there is no evidence of copper sulphide minerals present in grey shales other than as epigenetic veins. Furthermore, the vein mineralization is found in all rock types and occurs in zones of structural weakness such as lithological contacts and hence it would appear that the copper mineralization in the Brandy Lake Showings was epigenetic.

North Whiskey Lake Showings–NMI [13K/5 Cu003]

There are two occurrences at this location, *viz.*, Mineral Occurrence (M.O.) 64 (after Brummer, 1957) to the south, and M.O. 150 to the north. Mineral Occurrence 64 consists

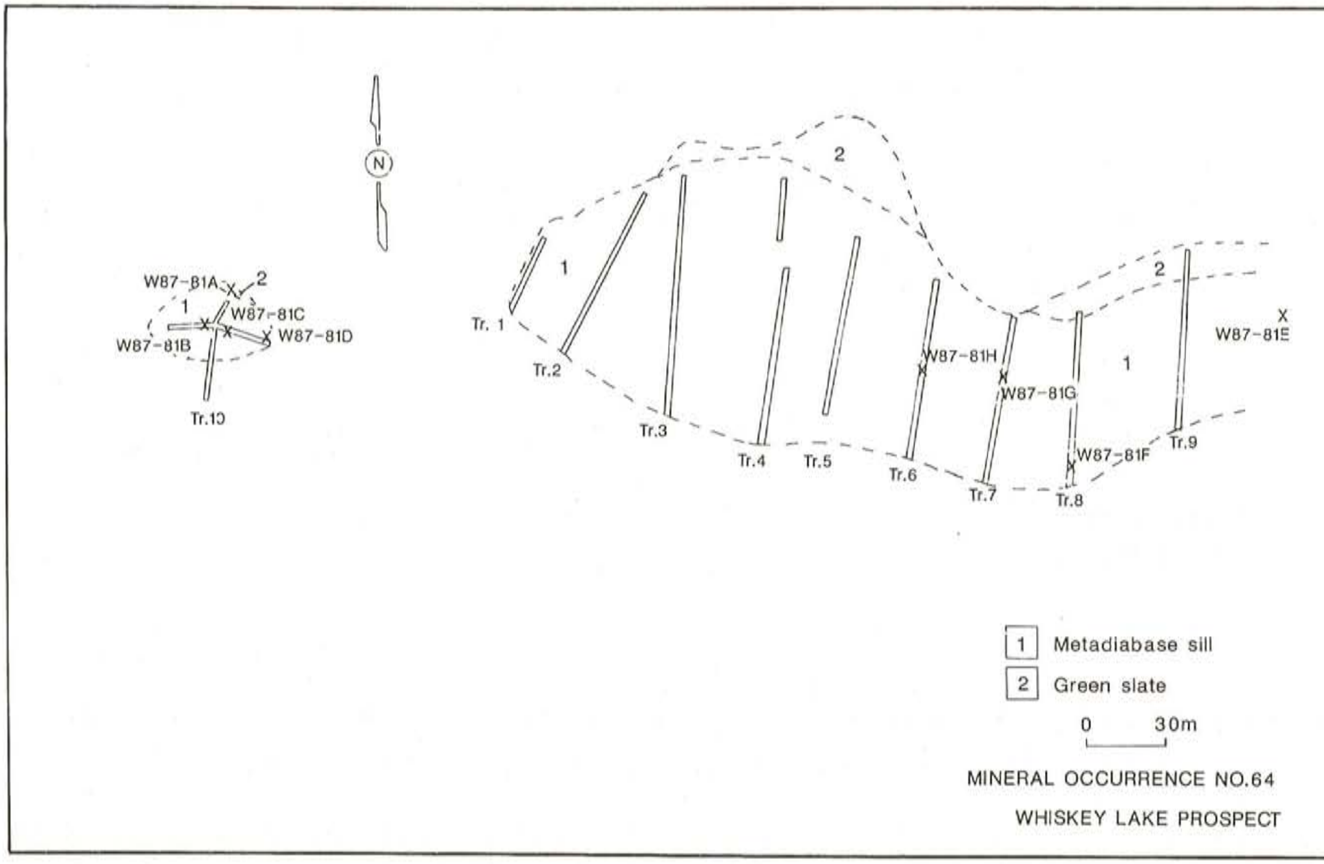

Figure 4. *Geology and sample location map of Mineral Occurrence No. 64, Whiskey Lake Showings (after Brummer, 1957).*

of eleven trenches across a diabase sill (Figure 4), which is underlain by grey slate–phyllite. There are a series of different vein systems cutting through the sill, including epidote veins and chalcopyrite and quartz–carbonate veins and bornite. The best mineralization occurs in trenches 10 and 11, where there are at least two generations of copper-bearing veins. The earlier set consists of epidote–quartz–carbonate veins containing chalcopyrite, and quartz veins having bornite, both of which are irregular and generally discontinous, and are associated with strong epidote alteration of the host diabase. The second set is a series of well-crystallized quartz–carbonate veins (up to 12-cm thick) containing chalcopyrite and chlorite.

On the northeastern edge of the outcrop grey slate–phyllite underlies the diabase (W87-81A, Figure 4). Close to the contact, the slate contains thin (≤ 1-cm thick) carbonate veinlets having chalcopyrite–pyrite and malachite staining.

In the remaining trenches, the diabase contains scattered, erratic, and thinner epidote–quartz–carbonate veins having bornite, chalcopyrite and pyrite. Molybdenite occurs in a 15-cm-thick epidote vein in trench six (sample W87-81H, Figure 4).

Robinson (1955) called this occurrence Whiskey Lake No. 1 and described average assay values across the trenches as ranging from 0.08 percent Cu over 9 m to 1.6 percent Cu across 18 m.

Mineral Occurrence 150 is located approximately 300 m northwest of Mineral Occurrence 64. There are eight trenches at this showing. In some trenches, the rock looks like a chloritized sedimentary lithology (small quartz grains are visible, similar to those seen in quartzite at the Ellis Showing). This rock type is interbedded with purple-red slate. Mineralization consists of chalcocite disseminations and stringers within shear zones cutting the chloritized host rock. There are also minor quartz–carbonate veins having specular hematite, which seem unrelated to the copper mineralization. The best assay value from this occurrence yielded 7.11 percent Cu and 2.92 oz/t Ag over 1.5 m (Brummer, 1957).

Conclusions on the Mode of Origin of the Copper Occurrences

Host rocks to the copper occurrences in the Seal Lake Group include slate and phyllite of the Whiskey Lake Formation, red and green slate, shale, amygdaloidal basalts and diabase of the Salmon Lake Formation, the mixed sedimentary (slate, shale, phyllite and argillite) units of the Adeline Island Formation, black-grey shale of the Wuchusk Formation, and coarse to medium-grained diabase of the Naskaupi sills. In all cases, the copper mineralization is demonstrably epigenetic with respect to host rocks.

In general, native copper in quartz vein systems occur within red slate and hematized basalt units (although there are some examples in diabase). Bornite, and lesser chalcocite, occur in those vein systems within diabase, basalt or green to black phyllitic schist. Deposition was, therefore, seemingly related to the oxidation state of the host rock (or was predicated on the presence or absence of iron sulphide); in the oxidized (red) slates and basalts, copper precipitated from solution in its native (or oxidized form). In those units that contain primary sulphide, however, copper precipitated as a sulphide. The association of native copper with hematized basalt, further indicates the epigenetic nature of the mineralizing events as the hematization was obviously a result of post-depositional alteration.

Some units, such as slate in the Wuchusk Formation, phyllites in the Adeline Island Formation, and diabase in the Naskaupi sills, contain primary, syngenetic sulphides in the form of disseminated pyrite. Copper sulphide mineralization usually developed in proximity to these Fe sulphide-bearing units, thus, the fluids were essentially Cu-rich and oxidized. The fluids were focussed along zones of structural weakness, especially contact zones. As visible at the well exposed Adeline Island Showing, the mineralization appears to be syntectonic to slightly posttectonic with respect to D_1 isoclinal folding and shearing.

There are no substantial differences between copper mineralization in the Salmon Lake and Adeline Island formations, except the presence of native copper in the Salmon Lake rocks, which is apparently dependant on the oxidation state of the host rock (not on stratigraphic position). Both units host chalcocite, bornite, and chalcopyrite in diabase and sedimentary rocks.

Brummer and Mann (1961) suggested that copper mineralization was restricted to the upper portions of the Seal Lake Group because only the uppermost lava flows and sills contained sufficient copper to be concentrated epigenetically into shears and veins during later folding. Baragar (1981), though, reported lower copper contents within the stratigraphically higher Salmon Lake Formation when compared to lower volcanic units.

Gandhi and Brown (1975) examined the Adeline Island Formation and stated that the copper therein was derived from underlying volcanic rocks and transported to pyrite-bearing shales of the formation along 'red bed aquifers'. The copper-bearing fluids subsequently reacted with, and replaced, the pyrite, and precipitated copper sulphides in these shales (presumably syn-to slightly post-diagenetically). To support this model, these authors redefined the stratigraphy at the Adeline Island, Ellis and Whiskey Lake prospects (from that of Brummer and Mann (1961) and earlier workers) such that the host rocks to the mineralization were specified to be a single shale unit overlying a quartzite (the proposed aquifer) member of the Adeline Island Formation (i.e., stressing the singular ore bed comparison with the Nonesuch Shale).

Field observations during 1987 suggest that none of the red sedimentary units within the Whiskey Lake, Salmon Lake, or Adeline Island formations possessed sufficient porosities to have acted as 'red bed aquifers' (i.e., the units are not conglomeratic but impermeable shale or quartzite). Certainly, there is nothing distinctive about the middle quartzite member (Gandhi and Brown, 1975) of the Adeline Island Formation compared to other quartzite units in the upper parts of the Seal Lake Group. Furthermore, ore-fluid flow was demonstrably deformation-related, as mineralization only occurs in sheared rock along lithological contacts.

Determination of the actual source(s) of the copper and hydrothermal fluids awaits more detailed geochemical, isotopic and fluid inclusion studies (in progress). One interesting phenomenon that may reflect on the origin of the mineralizing components is the presence of molybdenite in at least four occurrences. Molybdenite would suggest magmatic involvement (i.e., a deeper seated granitic system) in the origin of the ore fluids. A similar model has also been suggested by Richards and Spooner (1986) for some of the native copper occurrences in the Keweenawan Peninsula, which they postulate (on the basis of fluid inclusion and carbon isotope evidence) to have been produced by the mixing of magmatic (high temperature and high salinity) fluids with cooler dilute meteoric waters.

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REFERENCES

Baragar, W.R.A.
1969: Volcanic studies in the Seal Lake area, Labrador (13 K, L). Geological Survey of Canada, Paper 69-1A, pages 142-146.

1974: The Seal Lake and Croteau volcanic rocks of Labrador. Geological Association of Canada, Program with Abstracts, St. John's 1974, page 5.

1981: Tectonic and regional relationships of the Seal Lake and Bruce River magmatic provinces. Geological Survey of Canada, Bulletin 314, 72 pages.

Brown, A.C.
1971: A special mineralographic study of the Ellis and Adeline Island copper occurrences, Seal Lake Concession, Labrador. BRINEX Limited, Unpublished report, 64 pages.

Brummer, J.J.
1957: Report on operations in Frobisher's Seal Lake concession, central Labrador, Newfoundland. Kennco Explorations Limited. Unpublished report, 82 pages.

1960: A reconnaissance geochemical survey in the Seal Lake area, Labrador. Canadian Institute of Mining and Metallurgy Bulletin, Volume 63, pages 1-8.

Brummer, J.J. and Mann, E.L.
1961: Geology of the Seal Lake area, Labrador. Geological Society of America Bulletin, Volume 72, pages 1361-1382.

Evans, E.L.
1951a: Exploration in the Seal Lake area, Labrador, 1950. Frobisher Limited. Unpublished report, 19 pages.

1951b: Copper deposits in the Seal Lake area, Labrador. Frobisher Limited. Unpublished report, 19 pages.

1952: Native copper discoveries in the Seal Lake area, Labrador. Proceedings Geological Association of Canada, Volume 5, pages 111-116.

Fahrig, W.F.
1957: Geology of certain Proterozoic rocks in Quebec and Labrador. *In* The Proterozoic in Canada. *Edited by* J.E. Gill. Royal Society of Canada Special Publication, pages 112-123.

1959: Snegamook Lake, west half. Geological Survey of Canada, Map 1079A.

Gandhi, S.S.
1970: Seal Lake copper area, Labrador. BRINEX Limited. Unpublished report, 30 pages.

1971: Proposed exploration for 1972 in the Seal Lake area, Labrador. BRINEX Limited. Unpublished report, 5 pages.

1972a: Summary report on exploration during 1972 in the Seal Lake Joint Venture Area. BRINEX Limited. Unpublished report, 15 pages.

1972b: Geology of the Adeline Island Formation in the central part of the Seal Lake Synclinorium, Labrador. BRINEX Limited. Unpublished report, 20 pages.

Gandhi, S.S. and Brown, A.C.
1975: Cupriferous shales of the Adeline Island Formation, Seal Lake Group, Labrador. Economic Geology, Volume 70, pages 145-163

Murthy, T.N. and Gandhi, S.S.
1972: Geological report on the Adeline Island Formation in the eastern part of the Seal Lake Basin. BRINEX Limited. Unpublished report, 19 pages.

O'Driscoll, C.F. and Noel, S.
1983: Mineral Occurrence Map, Wuchusk Lake, Labrador North District. Department of Mines and Energy, Mineral Development Division, Map 83-37.

Richards, J.P. and Spooner, E.T.C.
1986: Native copper deposition by mixing of high temperature, high salinity fluids of possible magmatic association, with cool dilute groundwaters, Keweenaw Peninsula, Michigan. Geological Society of America. Abstracts with Program, Volume 18, page 730.

Robinson, W.G.
1953: Exploration on the Seal Lake Concession, Labrador during 1952. Frobisher Limited. Unpublished report, 17 pages.

1954: Exploration of the Seal Lake Concession, Labrador during 1954. Frobisher Limited. Unpublished report, 14 pages.

1955: Exploration on the Seal Lake Concessions, Labrador during 1955. Frobisher Limited. Unpublished report, 12 pages.

1956: The Grenville of New Quebec. *In* The Grenville Problem. *Edited by* J.E. Thomson. Royal Society of Canada Special Publication, Number 1, pages 14-19.

Ryan, A.B.
1984: Regional geology of the central part of the Central Mineral Belt, Labrador. Newfoundland Department of Mines and Energy, Memoir 3, 185 pages.

Wanless, R.K. and Loveridge, W.D.
1978: Rubidium–strontium isotopic age studies, Report 2 (Canadian Shield). Geological Survey of Canada, Paper 77-14.

Wilton, D.H.C.
This volume: Studies in the Seal Lake Basin, central Labrador, Part II: Geochemistry of diabase sills.

Wilton, D.H.C. and Brace, T.D.
1988: Final report of field work in the Florence Lake and Seal Lake areas, Central Mineral Belt of Labrador. Unpublished report (Contract 23233-7-0704/01-SS) to the Geological Survey of Canada, 102 pages.