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# GEOLOGY OF THE SEAL LAKE GROUP, CENTRAL LABRADOR (PARTS OF NTS MAP AREAS 13K/5 AND 6)

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## ABSTRACT

*The Mesoproterozoic Seal Lake Group in central Labrador is the youngest of the six supracrustal sequences comprising the Central Mineral Belt. The Seal Lake Group consists of a succession of six formations of argillaceous and arenaceous sedimentary rocks, intercalated with basalt flows and intruded by gabbro sills. The entire group is folded into an east-trending syncline of which the southern limb has been overturned and thrust northward during Grenvillian deformation.*

*Gabbros, sedimentary rocks and mafic volcanic flows, from all six formations, are present within the map area and comprise the two limbs and hinge of the eastern part of the Seal Lake syncline. Two periods of deformation are recognized. The first regional event produced a dominant east-northeast-striking fabric, resulting in folding or tilting of the main syncline toward the north and possibly fault development along its eastern limbs and hinge area. A later deformation resulted in folding of the main fabric into small-scale folds and open warps. A dominant south-southeast plunge of mesoscopic, first-generation fold axes define the plunge of the main syncline. Prevalent south-plunging mineral lineations suggest a north-directed thrust component is present in the faults. The fault zones exhibit textures indicative of both brittle and ductile deformation. Metamorphic grade ranges from chlorite–tremolite assemblages in the southern map area to pumpellyite facies in the north.*

*Examination of known mineral occurrences in the eastern Seal Lake area confirm native copper, malachite and bornite mineralization hosted by quartz + carbonate veins associated with fractures and small-scale shear zones proximal to basalt–slate contacts. Minor chalcopyrite, bornite, chalcocite and Cu-carbonates are also hosted by basalt flows and gabbro sills. New mineral occurrences include trace native copper within basalt flows and slates, ilmenite and rare chalcopyrite in gabbroic rocks, and several minor pyrite indications hosted by all three rock types. Cursory prospecting of these areas did not reveal any further significant mineralization.*

## INTRODUCTION

During July and August of 2008, a 1:50 000-scale bedrock-mapping project of the Seal Lake Group in central Labrador began with the intent to compile a comprehensive geological map of the area, through systematic field mapping. A two-person field crew carried out ground, boat and helicopter traverses around the eastern end of Seal Lake, covering the southeast part of NTS 1:50 000 map area 13K/5 and the southwest corner of map area 13K/6. Ground traverses were carried out at 0.5 to 1.0 km spacings, where possible, and helicopter stops were utilized to fill in between ground-traversed areas and to investigate areas to the west and southwest.

### LOCATION AND ACCESS

The eastern Seal Lake region is located in central Labrador approximately 145 km northwest of Happy Valley–Goose Bay (Figure 1). Access to the area is by float plane or helicopter from Goose Bay or from Makkovik or Postville on the Labrador coast. Much of the map area can be accessed by boat *via* Seal Lake, Wuchusk Lake and the Naskaupi River. A combination of helicopter- and small float plane-supported ground traversing are effective means to cover much of the region.

### PHYSIOGRAPHY

The physiography of the area is dominated by the east-trending Seal Lake, which is approximately 35 km long by 1.5 km at its widest point, and is surrounded along its entirety by rugged, densely wooded hills and ridges to the north and east of the lake, and steep-sided north-facing escarpments to the south. Elevations in the map area range from a maximum of 590 m asl in the northern plateau to 212 m asl at Seal Lake. The generally narrow, east-trending intervening valleys are occupied by thick alder and spruce forests

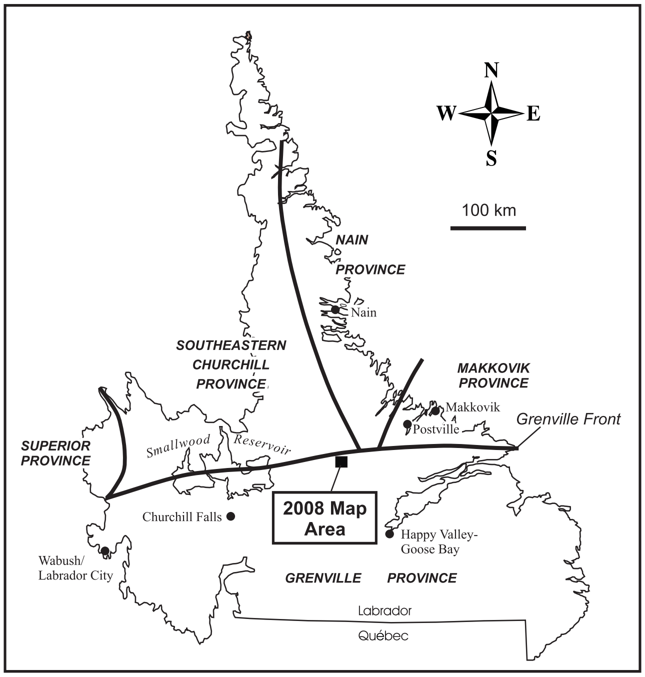



**Figure 1.** *Location of 2008 study area, approximate positions of major tectonic boundaries and communities in Labrador.*

and, rare, intermittent swamps. Bedrock exposure is generally poor, with the exception of some shoreline outcrops, barren hilltops and steep-sided escarpments.

A large sandy esker system, part of a wide preglacial valley, extends from west of Wuchusk Lake, along the east side of the Naskaupi River where it flows from Wuchusk Lake. The esker continues southeastward where it forms a long, very narrow peninsula that extends off the east end of Seal Lake and then trends eastward out of the map area (*see* Figure 3).

The major ice-flow direction was to the northeast, followed by a later northeast to east-southeast direction (McQuaig and Smith, 2005). A few examples of well-developed glacial striae were noted during the 2008 survey, particularly on smooth, exposed hilltops and on some of the better exposed shoreline outcrops. Two main striae directions were measured; a dominant northeast trend (060– 070) and a weaker east-northeast trend (080–090).

## PREVIOUS INVESTIGATIONS

The geology of the Seal Lake Group has been investigated extensively since the mid-1940s, in particular to determine its potential to host iron formation and copper deposits. More recent investigations have focused on its potential to host IOCG (Iron-oxide–Copper–Gold) type deposits and uranium mineralization.

Initial geological investigations of the Seal Lake area began when geologists from Dome Exploration (Canada) Limited carried out mapping and prospecting in the east-central Seal Lake area (Halet, 1946). The purpose of the survey was to explore for iron-ore deposits similar to those which had recently been discovered in western Labrador (Retty, 1937). Norancon Exploration also prospected for iron ore during 1946 in the Seal Lake area and reported an occurrence of native copper south of Adeline Lake (Smith, 1946). The first geological map of the area was produced by the Photographic Survey Corporation of Toronto (Scott and Conn, 1950), in which the rocks were designated, the Seal Lake series.

Throughout the 1950s, exploration geologists with Frobisher Limited, Kennco Limited and BRINEX Limited carried out extensive copper prospecting and mapping of the Seal Lake area (Evans, 1951, 1952; Brummer, 1957; Robinson, 1953, 1956). As a result of these activities, the 'Seal Lake series' was renamed the Seal Lake Group. Evans (1951, 1952) produced a geological map of the area, defined the stratigraphy, and was the first to outline the synclinal form of the rocks. The area was also mapped at 1:500 000 scale by the Geological Survey of Canada in 1952 (Christie *et al.*, 1953). Robinson (1956) briefly described the geology of the area and suggested that the Seal Lake Group belonged within the Grenville (geological) Province. Compilation of all this work from 1946 through to 1956 led to the recording of over 250 mineral occurrences in the area surrounding Seal Lake. Brummer and Mann (1961) produced a comprehensive compilation of the stratigraphy, nomenclature and mineral occurrences of the Seal Lake Group, based on their field work (carried out in 1956) and using data collected by Frobisher Limited (1950 to 1955).

Baragar (1969) undertook two chain-and-compass transects across the southern portion of the Seal Lake Group, and Baragar (1981) used the data from these sections to complete a petrochemical study of the volcanic rocks and gabbro sills. Gandhi (1971, 1972), Murthy and Gandhi (1972) and Gandhi and Brown (1975) carried out field studies of the more significant mineral occurrences, particularly those associated with the Adeline Island Formation. Knight (1972) completed a M.Sc. study of the stratigraphy and structure of an area north of Arkose Lake, approximately 15 km northwest of the present map area.

More recently, Marten and Smyth (1975) and Thomas (1981) carried out 1:50 000-scale mapping of the southern limit of the Seal Lake Group and rocks of the Letitia Lake Group and North Pole Brook Intrusive Suite. Hibbs (1980) and Calon and Hibbs (1980) completed detailed structural studies of an area included in the mapping of Thomas (1981). Ryan (1984) included the eastern limit of the Seal

Lake Group in a comprehensive regional compilation of the central part of the Central Mineral Belt. In a detailed review of the metallogeny of the Central Mineral Belt, Wilton (1996) described several of the major copper occurrences and suggested an epigenetic model for their origin. Nunn (1993) studied the western limit of the Seal Lake Group as part of a regional mapping project of the geology of the northeastern Smallwood Reservoir area. Cadman *et al.* (1993, 1994) carried out comparative geochemical and geochronological studies of the Harp dyke swarm and igneous rocks of the Seal Lake Group to determine genetic and magmatic relationships.

Exploration of the Seal Lake Group continued intermittently through the 1990s with Noranda Exploration (Graves,1992) and Black Pine Limited (Mitchell and Tallman, 1996) examining some of the well-known copper occurrences hosted within the Adeline Island Formation. In 2006, Silver Spruce Resources completed a helicopter-borne magnetic and radiometric survey (200-m line spacing) of their Seal Lake claims to target IOCG-type deposits and unconformity-style uranium mineralization along sedimentary contacts (Silver Spruce Resources Limited, press release, August 16, 2006). Currently, Silver Spruce Resources Limited (joint ventured with Crosshair Explorations Limited) and Tripple Uranium Resources Limited (a wholly owned subsidiary of Capella Resources Limited) hold mineral claim licenses in the Seal Lake area. Recently, Kilfoil (2008) released a shaded-relief, 1:250 000-scale airborne-magnetic compilation that includes the Seal Lake area.

Early age determinations of the Seal Lake Group comprise a number of K–Ar ages as follows: 960 ± 60 Ma for a basalt flow from the Salmon Lake Formation (Leech *et al.*, 1963); *ca.* 975 Ma (K–Ar, muscovite) for a Majoqua Lake Formation quartzite (Wanless *et al.*, 1965); *ca.* 865 Ma (K–Ar, whole rock) for a diabase (Wanless *et al.*, 1966) and, 843 ± 125 Ma (K–Ar) for a tuff from the lower part of the Seal Lake Group (Wanless *et al.*, 1967). More recent age determinations include: a 1323 ± 92 Ma Rb–Sr whole-rock isochron age for basalt flows and one diabase dyke (Wanless and Loveridge, 1978) and, Romer *et al.* (1995) reported combined U–Pb zircon–baddelyite ages of 1250 +15/-7 Ma and 1224 +6/-7 Ma for two crosscutting gabbros north of Bessie Lake, in the western part of the Seal Lake Group.

## REGIONAL SETTING

The Seal Lake Group is a sequence of Mesoproterozoic sedimentary, volcanic and mafic intrusive rocks covering an area of approximately 10 000 $km^2$ in central Labrador. The group lies near the junction of the Churchill, Nain and Grenville provinces, and straddles the Grenville Front Zone (Gower, 1980). The Seal Lake Group is the youngest of the volcano-sedimentary sequences comprising the Central Mineral Belt and unconformably overlies rocks of the Letitia Lake Group to the southwest, the Bruce River Group to the east, the Harp Lake Complex to the north and, Churchill Province gneisses to the west. To the south, it is in thrust contact with granitoids of the North Pole Brook Intrusive Suite, part of the Trans-Labrador batholith (Thomas, 1981; Wardle *et al.*, 1997; Figure 2). The southwestern margin of the Seal Lake Group is represented by clastic sedimentary rocks of the Bessie Lake Formation. The latter unconformably overlies volcanic rocks of the Letitia Lake Group, but the unconformity has been largely reworked by north-directed Grenvillian thrust faults.

The Grenville Front Zone (Gower *et al.*, 1980) has generally been considered to represent the northern limit of the effects of Grenvillian metamorphism between ca. 1080–970 Ma (Gower, 1996). This zone has traditionally been considered to transect the Seal Lake Group, reflecting penetrative Grenvillian effects in the southern half of the Seal Lake Group, and weak to minimal effects in its northern constituents. Thomas (1981) noted that, in keeping with the findings of Gower *et al.* (1980), a definitive Grenville Front Zone does not exist in the southern Seal Lake area, but rather is delineated by a series of folds and brittle thrust faults. The thrust faults, which bring granitoids of the North Pole Brook Intrusive Suite over basal Seal Lake Group rocks, form a series of structural breaks over which a gradual north–south transition from lower to upper greenschist-facies metamorphism is noted. More recent divisions of the Grenville Province have identified the Exterior Thrust Belt (Gower, 1996), a region of extensive north- and northwest-directed thrusting at the northern margin of the Grenville Province, part of which corresponds with the trace of the southern contact of the Seal Lake Group (Figure 2).

To the northwest, the Seal Lake Group unconformably overlies Archean gneisses of the Southeast Churchill Province in the Smallwood Reservoir area and, to the west, is bounded by a subvertical, post-Grenvillian fault system that developed a series of half-graben structures (Nunn, 1993). The Pocket Knife Lake Fault zone, located immediately east of the map area, generally separates rocks of the Seal Lake Group from volcanic and sedimentary rocks of the Bruce River Group to the east. This is a major north–south-trending fault system, which has been suggested to represent reactivated splays of the southward continuation of the Nain and Churchill provinces tectonic boundary (Marten and Smyth, 1975). The Seal Lake Group is, however, preserved east of the Pocket Knife Lake Fault zone in the Stormy Lake area (Figure 2) where several outliers of basal parts of the group sit unconformably on older rocks.

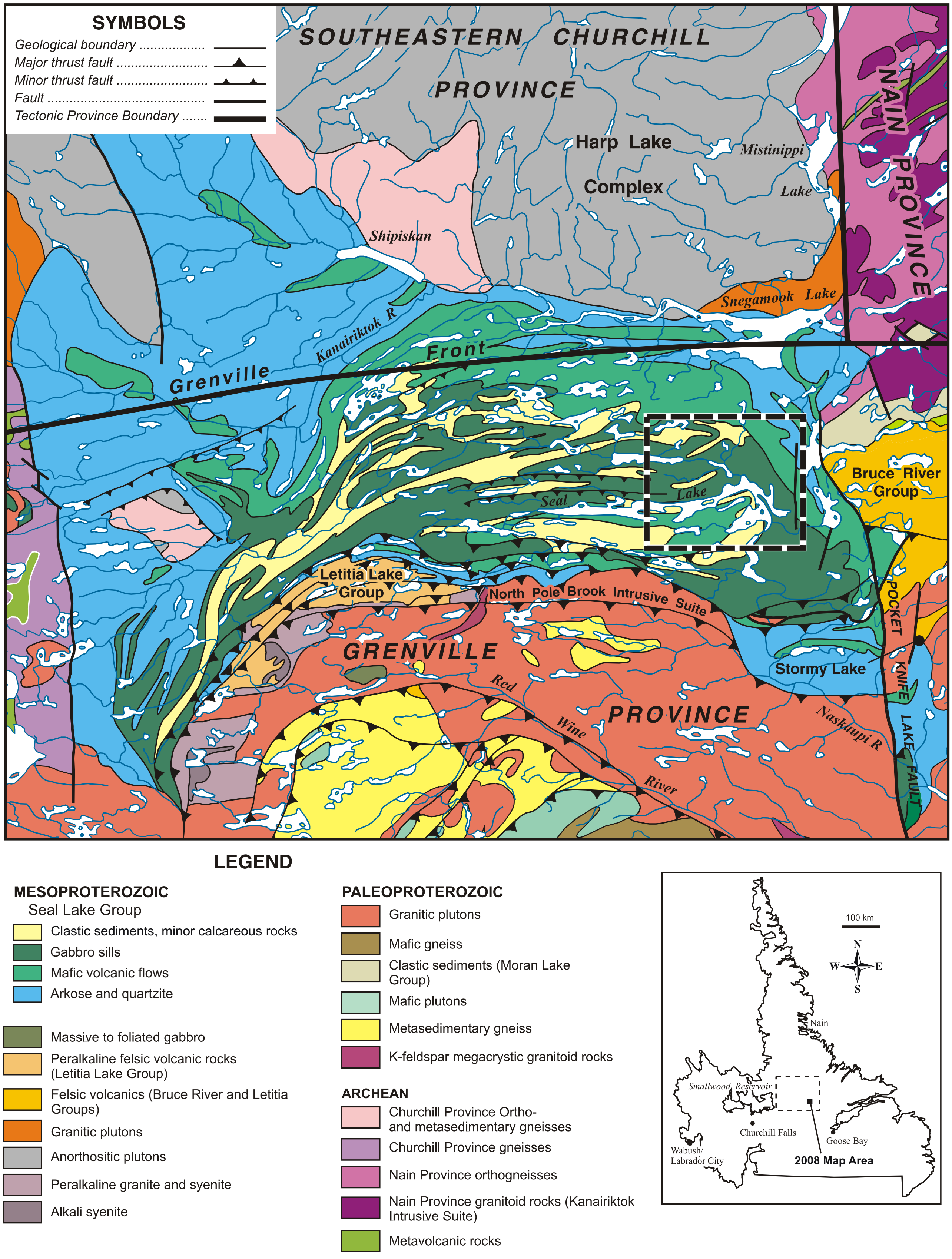



**Figure 2.** *Regional geology of the Seal Lake Group and surrounding area (after Wardle* et al., *1997).*

The northern margin of the Seal Lake Group is defined by flat-lying sedimentary rocks of the Majoqua Lake Formation,which form a thin veneer, sitting unconformably on the Harp Lake Complex (Emslie, 1980).

**SEAL LAKE GROUP**

The Seal Lake Group is divided into six formations (Evans, 1952; Brummer and Mann, 1961): 1) the stratigraphically equivalent, basal Bessie Lake–Majoqua Lake formations comprising clastic sedimentary rocks and basalts; 2) the Wuchusk Lake Formation containing shale, slate, sandstone and gabbro sills; 3) the Whiskey Lake Formation composed of slate, phyllite, siltstone, sandstone and chert; 4) the Salmon Lake Formation consisting of slate, shale, basalt and gabbro sills; 5) the Adeline Island Formation comprising clastic sedimentary rocks, basalts and gabbro, and 6) the Upper Red Quartzite Formation. The Majoqua Lake Formation and the Bessie Lake Formation are considered stratigraphic equivalents, however, the Majoqua Lake Formation, exposed along the northern limb of the regional syncline is weakly deformed whereas the southern, basal Bessie Lake Formation is strongly deformed (Brummer and Mann, 1961).

Estimates of the overall thickness of the Seal Lake Group vary considerably. Brummer and Mann (1961) reported a total thickness of 34 200 feet (10 500 m) but did not take into account the effects of deformation. Based on work in the Arkose Lake area, Knight (1972) suggested a significantly lesser thickness of 5280 m. Baragar (1974) estimated the thickness of the group to be about 9000 m but later suggested that, due to differential subsidence in the Seal Lake basin, the sequence may be, locally, up to 14 000 m thick (Baragar, 1981). It should be noted that accurate measurements of some units, particularly those of the lower formations, are hampered by the effects of folding and thrusting, which may have thickened, or in some cases, thinned, the units.

The Seal Lake Group is disposed as a major east–west-trending, doubly plunging synclinal structure, approximately 120 km long and 45 km wide. The southern limb of the fold is overturned and has been structurally buried beneath older granitoids that have been transported northward over the Seal Lake Group along Grenvillian thrusts (Brummer and Mann, 1961; Baragar, 1981). From west to east, the trend of the synclinal axis varies from southeast through to northeast, and folds exhibit a progression from tight to open. From north to south, sedimentary rocks of the group exhibit a general transition from subaerial to shallow marine and from coarser to finer grained. Metamorphism, attributed to Grenvillian deformation, is at greenschist grade (chlorite–tremolite assemblages) in the south of the group, but the northern limb of the syncline attained only pumpellyite facies (Baragar, 1981).

The middle and upper units of the southern part of the Seal Lake Group, along the south shore of Seal Lake, are host to more than 250 native copper and copper-sulphide occurrences, most of which are hosted within local shear zones and/or quartz + carbonate veins associated with rock contacts. Host rocks of the mineralization include: shale and gabbro of the Wuchusk Lake Formation; slate of the Whiskey Lake Formation; slate, shale, basalt and gabbro of the Salmon Lake Formation and, slate, shale, phyllite, sandstone and gabbro of the Adeline Island Formation. The latter two formations are host to most of the reported mineral occurrences. The only mineralization reported within the Bessie Lake Formation are minor, epigenetic uranium occurrences developed along the Seal Lake Group basal unconformity near Bessie Lake (Marten and Smyth, 1975), in conglomerate southeast of Snegamook Lake (Baragar, 1969) and in conglomerate and in basal conglomerates at the Stormy Lake showing, situated in the extreme southeast margin of the Seal Lake Group (Figure 2). Sparkes and Kerr (2008) suggest, however, that the rocks hosting the Stormy Lake mineralization more closely resemble the Bruce River Group rather than the Seal Lake Group. No mineralization is known from the Upper Red Quartzite Formation.

## GEOLOGY OF THE MAP AREA (PARTS OF NTS 13K/5 AND 6)

The 2008 survey area is broadly subdivided into three main zones (Figure 3). The north and east parts of the map area (north zone) are underlain mainly by gabbro sills and basaltic flows with thin intercalations of sedimentary rocks. The area between Seal Lake and Whiskey Lake (central zone) includes predominantly argillaceous sedimentary rocks and basalt flows and relatively minor gabbro sills. The area south and east of Whiskey Lake (south zone) comprises dominantly gabbro and sedimentary rocks. The three-fold subdivision, including rocks from all six formations, corresponds to the limbs and fold closure area of the eastern edge of the main Seal Lake syncline.

The rocks in the map area are subdivided using the statigraphic nomenclature of Brummer and Mann (1961) but subsequent modifications by other authors have been noted where applicable. Herein, the basal unit will be referred to as the Majoqua Lake Formation, as defined by Brummer and Mann (1961).

**UNITS 1a-b–MAJOQUA LAKE FORMATION**

**Unit 1a Mafic Volcanics**

The Majoqua Lake Formation (Units 1a-b) is represented by weakly metamorphosed and relatively undeformed basaltic rocks and subordinate sedimentary rocks, and underlies the north and northeast parts of the map area (Fig-

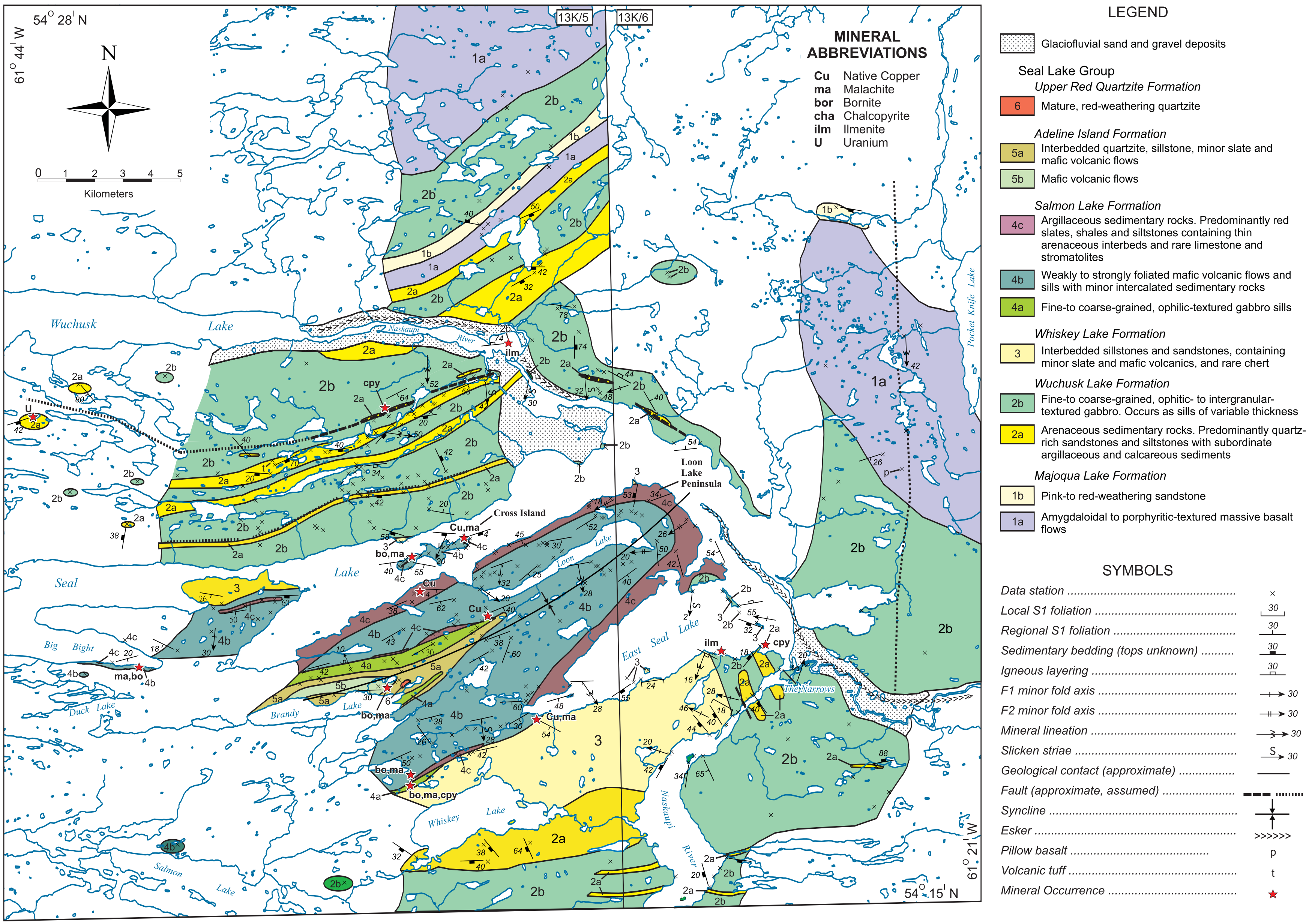



**Figure 3.** *Geology and structural features of the eastern Seal Lake area.*

ure 3). The volcanic rocks are typically best exposed on the bare tops of densely wooded hills on the upland plateau, and are characterized by smooth, gravel- and boulder-covered, glacially polished surfaces, locally exhibiting glacial striae.

The rocks consist predominantly of green- to grey-weathering, massive, homogeneous basalt although amygdaloidal and porphyritic varieties are locally present. Where observed, amygdules and phenocrysts comprise 5 to 15 percent and, in a few rare outcrops, the crystals show a very weak preferred alignment that may represent an igneous flow fabric. Amygdules consist mostly of quartz and calcite but epidote is locally dominant. Phenocrysts are unaltered to weakly saussuritized plagioclase feldspars.

Features interpreted as pillow structures were observed at only one locality in the east, situated on a hilltop 2.4 km southwest of Pocket Knife Lake ('p' on Figure 3). There, light green-weathering, subrounded to pillow-shaped features, ranging from 10 to 40 cm in diameter are loosely packed within green-grey-weathering, fine-grained, massive basalt 'matrix'. A 5-mm-wide, diffuse hematite-oxidation alteration halo occurs along the margins of some of these features. One appears unmodified and exhibits the classic basaltic pillow shape, although no obvious top can be defined as it appears to be symmetrical in having two vertices (Plate 1). The variable shapes and wide spacing of the features suggest that they may represent a pillow breccia. Previous workers have similarly noted the absence (Brummer and Mann, 1961) and rarity (Baragar, 1981) of pillow features. Baragar (1981) mapped a pillowed basalt flow within the southern Seal Lake Group, immediately west of the map area. There, a 5-m-thick sequence of close to loosely packed pillows, ranging from 0.5 to 1.5 m long, grades into a breccia and hyaloclastite at the top of the flow. Baragar (1981) suggested that the extrusion of pillows must have been short-lived, as only one flow seems to have developed these features. On the basis of the rarity of pillow basalts and the general oxidized nature of volcanic flows of the Seal Lake Group, Baragar (*op. cit.*) considered most of the volcanic rocks to be subaerial.

### Unit 1b–Sedimentary Rocks

Sedimentary rocks of the Majoqua Lake Formation are a minor occurrence within the map area, occurring in wide valleys between hills in the north and northeast, and comprise a few isolated outcrops of pink- to red-weathering, fine- to medium-grained, locally graded quartz-rich sandstone. Bedding in these rocks ranges from cm to tens of cm thicknesses and is defined by a thin, diffuse to sharply defined, heavy-mineral grading. No discernable crossbedding was observed, although a very weak 'tops up' grading of coarse- to medium-grained detritus was noted in one outcrop.

**Plate 1.** *Loosely packed, variably shaped features indicative of a pillow breccia developed in massive basalts of the Majoqua Lake Formation (Unit 1a). Some pillows exhibit partial, hematite-altered margins. Tops direction is unknown. Centre pillow has been outlined for clarity. (Station VN08-223, UTM coordinates 604933E/6023650N)*

## UNITS 2a-b–WUCHUSK LAKE FORMATION

### Unit 2a–Sedimentary Rocks

Unit 2a is generally poorly exposed and occurs as northeast-trending, 200–500-m-thick horizons, alternating with extensive gabbro sills and basalt flows north and east of Seal Lake, and east- to northwest-trending zones south of East Seal Lake. It should be noted that the distribution of this unit as depicted on Figure 3, is based on extrapolation between rare isolated outcrops, aerial-photograph interpretation and aeromagnetic data. Several isolated exposures of this unit, in the extreme southeast part of the map area, are depicted on Figure 3. However, Fahrig (1959) shows these bands of sedimentary rocks to be more extensive. Unit 2a rocks comprise primarily white- as well as pink- to red-weathering, fine- to medium-grained, variably recrystallized and hematized, quartz-rich sandstone, siltstone, rare black schist and volcanic tuff. Bedding in the clastic sedimentary rocks is defined by thin concentrations of fine-grained magnetite ± biotite and is accentuated by red alteration of magnetite to hematite. At one locality in the farthest southeast, sandstone exhibits well-defined, upward-facing crossbedding indicating an easterly (080°) paleocurrent direction (Plate 2). Siltstones are a minor component and are typically thinly bedded or finely laminated and occur as small isolated outcrops or locally as mm to cm scale laminae within the sandstone unit.

Rare, yet distinctive sedimentary rocks of the Wuchusk Lake Formation include black schist and a single outcrop of a basaltic tuff. Two closely spaced outcrops of schist occur


**Plate 2.** *Crossbedded, pink-weathering, quartz-rich sandstone of the Wuchusk Lake Formation (Unit 2a). Bedding defined by thin magnetite concentrations accentuated by iron-oxide staining. Note weak-graded bedding just to left of scale card, indicating beds are top side up. Implied current direction is to the east (080°). (Station VN08-220, UTM coordinates 604475E/6015832N)*

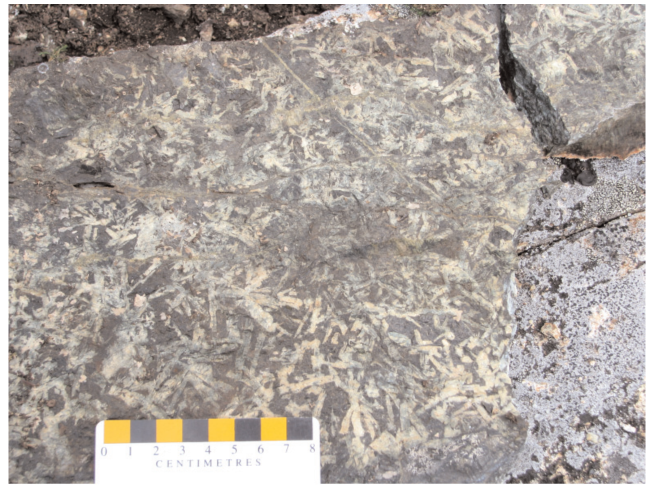



**Plate 3.** *Coarse-grained plagioclase–pyroxene–olivine–magnetite gabbro exhibiting well-developed ophitic texture. Wuchusk Lake sill, north of Seal Lake. (Station VN08-070, UTM coordinates 590755E/6022961N)*

between Wuchusk and Seal lakes, north of Seal Lake. These rocks are fine grained, black weathering, strongly foliated, schistose to shaly in texture and are composed almost entirely of mafic minerals including fine-grained biotite and minor magnetite.

A single exposure of brown-weathering, feldspar porphyritic tuff occurs between the two outcrops of black schist described above. The rock consists of 10 to 15 percent altered feldspar phenocrysts in a fine-grained, moderately foliated matrix. The tuff contains a small lens of the same black schist as noted previously, although other relationships between these rock types could not be found in the area. The apparent narrow extent, rarity and the distinctive nature of the black schist and basaltic tuff could serve as useful stratigraphic markers.

### Unit 2b–Gabbroic Rocks

Medium- to coarse-grained, ophitic to equigranular gabbro and leucogabbro sills are the dominant rock type within the Wuchusk Lake Formation. The rocks exhibit a wide range of grain size, igneous textures and compositions depending on their relative position within each sill. These gabbros can be remarkably monotonous over large areas, yet they can also exhibit local textural variations. Medium- to coarse-grained gabbro of the sill interiors exhibit well-developed ophitic to subophitic textures, in which subhedral to euhedral plagioclase is partially to wholly included, within coarse-grained pyroxene crystals and oikocrysts (Plate 3). Plagioclase content varies from 30 to 70 percent and pyroxene–olivine–ilmenite ± magnetite generally comprise 20 to 50 percent of the rock. Alteration is typically minor although plagioclase is, locally, partially saussuritized and pyroxene and olivine are, locally, altered to chlorite ± epidote. The general lack of alteration in gabbroic rocks north of Seal Lake is a characteristic that distinguishes sills of the Wuchusk Lake Formation from similar, but altered, gabbros of the Salmon Lake Formation (Unit 4a).

Pegmatitic gabbro occurs as a subordinate phase within medium- and coarse-grained varieties where it forms irregular metre-scale patches exhibiting gradational contacts with the host gabbro. In some examples, the margins of the pegmatite are sharp, and it appears to intrude the host medium-grained gabbro. The fine-grained margins of Wuchusk Lake Formation sills are generally poorly exposed north of Seal Lake. They are typically observed in small, lichen-covered outcrops on the slopes of wooded hills and in valleys; contacts with other sills or supracrustal units are rarely exposed. These fine-grained gabbros (< 1 mm grain size) are black-, dark-grey- or brown-weathering, massive, homogeneous and are equigranular to locally ophitic-textured and generally have a more consistent composition than the coarser grained varieties.

In their margins, some Wuchusk Lake sills exhibit a 'knobby' appearance on weathered surfaces, caused by raised 'knobs' ranging from 1 to 3 cm in diameter. These rocks are leucogabbros and the raised knob features and 'matrix' material appear to be of comparable composition. Thus, the features do not appear to be a variation in constituent minerals but may represent either quench textures, or possibly pyroxene oikocrysts. Another distinctive texture locally developed in the Wuchusk Lake sills is a 'spotted' or 'leopard' appearance, particularly in gabbros along the Naskaupi River and along the shoreline of East Seal Lake. The texture occurs as diffuse, irregular patches of slightly more mafic-rich composition than the 'background' rock.

The only example of a definitive crosscutting relationship within the gabbroic rocks observed in the entire map area occurs within a Wuchusk Lake Formation sill. The location of the mafic dyke is approximately 2 km north of Seal Lake, denoted as 'd' on Figure 3. There, a poorly exposed hilltop is underlain by medium- to coarse-grained, olivine-bearing gabbro, intruded by a 0.25- to 0.50-m-wide mafic dyke exhibiting a chilled margin against the host gabbro. Examples of such crosscutting relationships are very rare within the Seal Lake Group; Brummer and Mann (1961) noted a small basaltic dyke along the southern shore of Seal Lake near Big Bight, and Romer *et al.* (1995) dated two crosscutting gabbros in the western Seal Lake Group, north of Bessie Lake.

Mineralization associated with the Wuchusk Lake Formation sills is minor and is limited to less than one percent disseminated pyrite and local concentrations of ilmenite + magnetite. Rare chalcopyrite was observed in altered and sheared gabbro within a fault zone north of Seal Lake and in interbedded siltstone and sandstone on a small island in East Seal Lake (Figure 3). Sedimentary rocks near the contact with the Wuchusk Lake gabbro sills locally contain trace to minor pyrite.

## UNIT 3–WHISKEY LAKE FORMATION

### Interbedded Siltstone, Sandstone, Slate and Shale

The Whiskey Lake Formation (Unit 3) is characterized by an almost ubiquitous intercalation of thin beds, layers and laminae of several sediment types (sandstone, siltstone, shale and slate). Gradations from flaser, to lenticular, to wavy textures were noted in several exposures, their appearance dependent upon the proportions of argillite and arenite (Plate 4). Bedding in Unit 3 varies from mm- to cm-scale laminations of slate and siltstone to more competent fine-grained sandstone beds up to 1 m thick. Calcareous laminae and thin limy slate beds are locally present but no limestone was observed. Fine-grained chert is a rare rock type in this unit.

Rocks of the Whiskey Lake Formation are best exposed in the southeast, along the shoreline of East Seal Lake and along the western bank of the Naskaupi River where it flows out of Seal Lake (The Narrows, Figure 3). One outcrop along the East Seal Lake shoreline exhibits well-preserved examples of ripple marks and mudcracks. These features occur in well-bedded siltstone and fine-grained sandstone that are intercalated with subhorizontal, planar-bedded, quartz-rich sandstone. The ripple marks are developed on the northern part of the exposure and appear to be symmetrical over most of the outcrop; however, local asymmetric ripples suggest a northwesterly (310°) paleocurrent flow direction. The mudcracks, best developed on the southern end of the outcrop, are 0.5 to 1 cm wide and comprise a core of medium-grained arkose, having very fine-grained margins. The cracks connect fine-grained siltstone polygons that range from 5 to 15 cm in diameter (Plate 5).

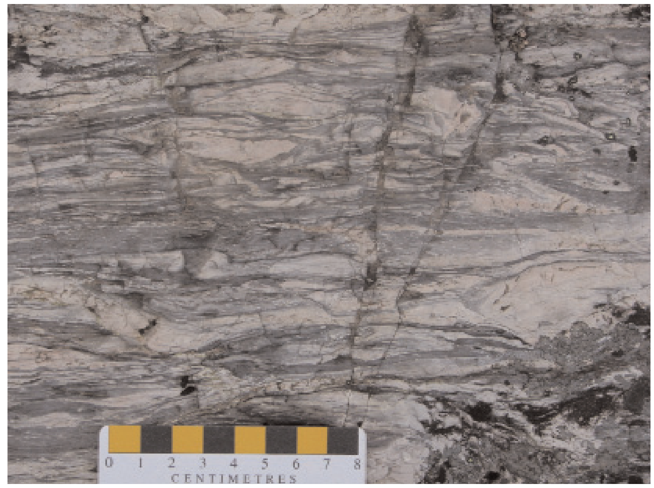



**Plate 4.** *Flaser to lenticular bedding defined by variable proportions of alternating arenaceous and argillaceous layers in the Whiskey Lake Formation (Unit 3). Naskaupi River, southeastern map area (Station VN08-286, UTM coordinates 600911E/6017627N).*

**Plate 5.** *Mudcracks developed in Whiskey Lake Formation sediments (Unit 3). Cracks are composed of quartz +/- feldspar, with very fine-grained margin adjacent to siltstone polygons. View looking down on subhorizontal bedding surface. Ripple marks within this same outcrop suggest bedding is right way up. Shoreline exposure, East Seal Lake. (Station VN08-108, UTM coordinates 601010E/6018821N)*

Rare exposures of the Whiskey Lake Formation also occur on the northern limb of the regional syncline. These include one outcrop on the northwest edge of the informally named Loon Lake peninsula; one outcrop on a large peninsula on the west edge of the map area and, two closely spaced outcrops of chert on the north shore of Seal Lake. The chert has cm-scale bedding defined by alternating green-grey, grey- and light-brown-weathering layers and is cut by numerous quartz + chlorite veins that form the loci of small-scale, localized offsetting shears. The limited extent of Whiskey Lake Formation on the north limb of the regional syncline, compared to the thick sequence preserved on the south limb, might indicate thinning by possible thrusting. This suggestion, however, has not been substantiated during the 2008 survey.

Mineralization within the Whiskey Lake Formation is limited to trace pyrite within some exposures of thin laminated siltstones and sandstones.

## UNITS 4a–c–SALMON LAKE FORMATION

### Unit 4a–Gabbro

Gabbro sills (Unit 4a), within the Salmon Lake Formation (Unit 4), unlike those of the Wuchusk Lake Formation (Unit 2b), are not as aerially extensive, are finer grained, generally exhibit higher degrees of alteration and, are associated with significant copper mineralization. The Salmon Lake sills occur as subhorizontal sheets intruding sedimentary and volcanic rocks within the east-trending ridges that dominate the topography south of Seal Lake. One of these ridges, the most prominent, trends east for approximately 8 km along the south shore of eastern Seal Lake (Plate 6). At the top of the eastern end of the ridge, northeast of Brandy Lake, a fine-grained marginal phase of a gabbro sill that has an exposed thickness of about 7 m, overlies a 10-m-wide quartzite layer. The contact is very sharp, strikes east and dips 10 to 20° to the south. The sill has a 1-m-wide, very fine-grained contact margin with a 10- to 20-cm-wide, brown- to grey-weathering, hornfels zone at the top of the quartzite layer (Plate 7). The quartzite is underlain by a 5-to10-m-wide, grey- to mauve-weathering, fine-grained, amygdaloidal basalt flow, although the contact is not exposed. Lower in the sequence, intercalated basalt flows, maroon-weathering slate and minor sandstone beds are exposed in the near-vertical cliff face. A 2- to 3-m-wide, partially exposed, fine-grained gabbro sill has intruded the volcanic flows and maroon slates, near the base of the sequence.

No mineralization was observed associated either with the sill contact or the mafic volcanic rocks in this area. Seven kilometres west of this locality, within the same ridge, Robinson (1953) and Wilton (1996) described malachite-

**Plate 6.** *East-striking, north-facing steep-sided ridge, south side of Seal Lake. Ridge runs along strike for approximately eight kms and consists of a gabbro sill cap, underlain by intercalated maroon slates, quartzites and mafic volcanic rocks. View looking west. Height from top of talus slope to ridge top is approximately 45 m.*

**Plate 7.** *Shallowly (10 to 15°) south-dipping, fine-grained gabbro sill overlying quartzite layer, at the eastern end of steep-sided ridge shown in Plate 6. Contact is very sharp and exhibits a 50-cm-wide chilled gabbro margin and 10- to 20-cm-wide zone of hornfels quartzite. Hammer is 50 cm long. (Station VN08-147, UTM coordinates 592625E/ 6019079N)*

and chalcocite-bearing shear zones associated with intercalated mafic volcanic rocks and maroon slate at the A-13 showing. The contact zones of the sills with volcanic and sedimentary rocks are locally the site of copper mineralization. The contacts are commonly altered, sheared, and exhibit extensive quartz ± carbonate veining. This is the case at the Brandy and Whiskey lakes occurrences, as with several other minor copper showings and indications south of

Seal Lake (*see* Mineralization, page 267). The mineralization at these occurrences consists of variable amounts of malachite, azurite, bornite, chalcocite, chalcopyrite, pyrite and, locally, native copper.

### Unit 4b–Mafic Volcanic Rocks

Mafic volcanic rocks within the Salmon Lake Formation are of two main types. One is a fine- to medium-grained, green- to grey-weathering, variably foliated, locally amygdaloidal metabasalt to chlorite schist and is the dominant mafic volcanic rock within the map area. It underlies much of the central part of the Loon Lake peninsula, where it is intercalated with maroon slates. A distinctive feature is the presence of hematite-altered ellipses and diffuse amygdules aligned with a moderate to locally strong fabric. In other areas, it is relatively homogeneous and variably foliated. A second, distinctive mafic volcanic rock within the formation is a dark-grey, mauve- to red-weathering, massive to strongly foliated, metamorphosed basalt. This rock contains red to mauve, hematite-altered vesicles and amygdules and discontinuous layers developed concordant to, and partially defining, the fabric. Where the amygdules are not completely altered, they comprise feldspar, quartz and minor epidote, and form 5 to 25 percent of the rock. These rocks occur as shallow-dipping to subhorizontal flows intercalated with slates along the steep-sided escarpment south of Seal Lake, in shoreline exposures on the cross-shaped island in the centre of the map area (informally named Cross island), and along the adjacent southern shore line of Seal Lake.

The variation in the weathering from green to red or mauve, in the formation basalts, has resulted from alteration and hematite enrichment rather than representing a primary feature (Fahrig, 1957; Baragar, 1981). This is generally a reasonable interpretation, although the variation from a weak alignment of amygdules and alteration layers in the red-weathering basalt, to a strong, almost schistose fabric in some of the green-weathering basalts, would suggest that there are compositional differences. Baragar (1981) and Wilton (1996) noted that vesicular and amygdaloidal basalts are representative of the upper portions of basalt flows, whereas more homogenous volcanic rocks occur in the lower portions; this was confirmed by the 2008 survey. The predominant minerals in these rocks include feldspar + chlorite ± olivine ± pyroxene ± epidote ± iron oxides. Although not yet confirmed by petrography, fine-grained quartz crystals were noted in the green-weathering basalts at a few localities.

### Unit 4c–Argillaceous Rocks and Subordinate Carbonate Rocks

Unit 4c mainly comprises a sequence of red-, maroon- to mauve-weathering, well-cleaved, argillaceous rocks and occurs only along the shoreline and south of Seal Lake. The slate is locally interbedded with sandstone, minor shale, siltstone and basalts. A single outcrop of limestone was found near the northern margin of the formation. The slate occurs as a relatively thin horizon (50 to 100 m thick) that envelopes the Loon Lake peninsula and also as intercalations within basalts in the core of the peninsula. The slate unit also occurs as extensive horizons within the steep-sloped ridge that runs parallel to the south shore of Seal Lake. Therein, the slates are intercalated with basalts, minor arenaceous sediments, and gabbro sills. In most areas, bedding within the slates is not preserved because it is typically transposed parallel to the regional fabric.

A common feature of the maroon slate is the presence of abundant, fine-grained, quartz eyes and lenses (0.5 to 2 mm in diameter), which in some areas, are flattened parallel to the cleavage. The presence of quartz eyes is most apparent along contact zones with the volcanic and gabbroic rocks. In these areas, quartz ± carbonate veining is extensive and is both concordant and discordant to the main fabric (Plate 8).

**Plate 8.** *Maroon-weathering slate (Unit 4c) containing abundant concordant and a few discordant quartz +/- carbonate veins at contact with overlying mafic volcanic flow; Salmon Lake Formation (Unit 4b). Bedding is almost always transposed concordant to the fabric in this unit. East shoreline of Cross Island in central map area. Hammer head is 15 cm long. (Station VN08-014, UTM coordinates 593601E/6021773N)*

Brown- to grey-weathering reduction spots are locally developed within the slate unit. In some areas, they are attenuated and have the appearance of bedding, but can be distinguished by their diffuse boundaries and the presence of adjacent, relatively undeformed, reduction spots.

Argillites constitute most of the rocks in this unit although intercalated calcareous zones, typically as cm-wide, fine-grained limy layers also occur locally within the slates on the Loon Lake peninsula. A single outcrop of laminated limestone and inferred stomatolitic limestone occurs on the east shore of Cross island (Figure 3). The limestone is grey weathering, fine to medium grained, thin bedded to laminated, and occurs as a 0.75-m-wide layer in contact with maroon slates. The subhorizontal bedding within the limestone is defined by medium-grained, resistant, possibly quartz-bearing layers, alternating with finer grained, less competent, partially weathered-out layers. Adjacent to the grey limestone, is a grey- to white-weathering, 40- to 50-cm-wide layer of fine-grained, calcareous rock that exhibits a very distinct wavy or 'scalloped' texture (Plate 9). The scalloped features consist of alternating white- and mauve-weathered, mm-scale laminations that vary from rounded to slightly elongate, and are composed entirely of carbonate. This texture is very similar to that discussed by Brummer and Mann (1961) who described it as "a deformed (?) algal structure in a sheared limestone"; this unit could not be traced inland from the shoreline and is the only occurrence of limestone and possible stromatolites found within the map area. The presence of the narrow limestone layer, in this part of the formation, attests to the shallow-marine environment within which many of the Seal Lake Group rocks have been deposited (Brummer and Mann, 1961; Baragar, 1981). Considering the narrow width (1.5 m) of the limestone and that basalts, immediately south along the shoreline section, do not show evidence of pillow features (*i.e.*, presumably subaerial deposition), the shallow-water, depositional environment may have been short-lived, at least in this section of the Salmon Lake Formation.

Brummer and Mann (1961) reported two stromatolite localities within the Seal Lake Group; 1) algal structures classified as general type *Collenia Walcott* are exposed in a 9-m-wide unit of grey limestone, about 5 km northwest of Wuchusk Lake, 2) a ridge of limestone north of Ten Mile Lake, in the western part of the Seal Lake Group, contains deformed algal structures and oolitic limestone. Baragar (1981) reported a zone of interlayered limestone, shale and quartzite in both of his geological sections of the Wuchusk Lake Formation to the north and northwest of Wuchusk Lake. He noted that the limestone contains scalloped and wavy bedding, which he suggested were stromatolitic structures, although these were not positively identified. Wilton (1996) also reported stromatolitic limestone in a ridge approximately 2.5 km northeast of Bessie Lake.

## UNITS 5a-b–ADELINE ISLAND FORMATION

Within the map area, rocks of the Adeline Island Formation are assigned to Unit 5a, comprising interbedded slate, sandstone and minor siltstone, and Unit 5b, consisting

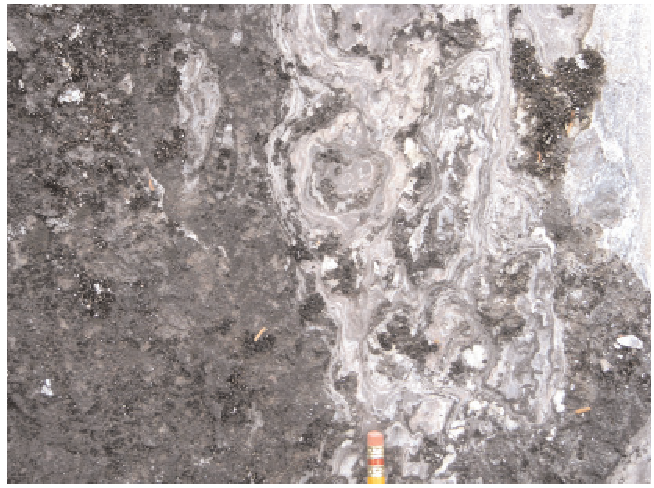


**Plate 9.** '*Scalloped-texture' in probable stromatolite layer adjacent to zone of bedded limestone; viewed looking down on bedding plane. Total thickness of stromatolite layer is approximately 50 cm, Salmon Lake Formation (Unit 4c). East side of Cross Island, central map area. Top of pencil (including eraser) is 1.5 cm long. (Station VN08-015, UTM coordinates 593637E/6021855N)*

of basalt flows. These rocks form part of the core of the northeast-trending syncline defined by the Loon Lake peninsula and are host to several copper sulphide occurrences (*see* Mineral Occurrences, page 263; Figure 3). The formation was the focus of several studies in the 1970s to compare mineralization in the Seal Lake Group with the Nonesuch Shale Formation of the White Pine Copper Deposit in Michigan (Gandhi, 1972a; Gandhi and Brown, 1975).

### Unit 5a–Interbedded Slate, Sandstone and Siltstone

Sedimentary rocks of the Adeline Island Formation exposed in the Brandy Lake area consist predominantly of white- to pink-weathering, diffusely bedded, medium-grained, quartz-rich sandstone having minor grey to green slate layers. A sandstone conglomerate was also documented by Wilton (1996). The quartz-rich sandstone contains 2 to 10 percent fine-grained magnetite and hematite, making the rocks distinctly pink, and also partially defining bedding. Locally, thin quartz veins contain minor, fine-grained chalcocite. Immediately north of the central shore of Brandy Lake, a grey-weathering slate in contact with basalts, has both been cut by discordant quartz ± calcite veinlets that contain very minor chalcocite.

### Unit 5b–Mafic Volcanic Flows

Only a few exposures of mafic volcanic flows were mapped within the Adeline Island Formation. These occur north of Brandy Lake and the rocks appear very similar to basalts of Unit 4b. The basalts range from green- to grey-weathering, locally amygdaloidal and vesicular, contain chlorite ± epidote, and exhibit alteration and veining near their contacts with other units. In one exploration trench, excavated at the contact between basalts and grey slate, chalcocite, bornite and malachite mineralization is hosted by quartz-carbonate veins and is also found as fracture coatings (*see* Mineral Occurrences, page 263, for further details).

### UNIT 6–UPPER RED QUARTZITE FORMATION

Rocks included in the Upper Red Quartzite Formation (Unit 6) are exposed north of Brandy Lake, overly slates, sandstones and basalts of the Adeline Island Formation, and are intruded by gabbro sills (Figure 3). In a detailed study of this area, Gandhi and Brown (1975) mapped several small exposures of red quartzite of the Upper Red Quartzite Formation. One of these, at the northeast end of Brandy Lake, forms the core of the main Seal Lake syncline, and was re-examined during the 2008 survey (Figure 3).

The mature character and dark-red-weathering of the quartzites of the Upper Red Quartzite Formation distinguish it from the quartzite of the Adeline Island Formation. Gandhi and Brown (1975) suggested that the boundary of this exposure of Upper Red Quartzite was a fault, but the nature of the contact could not be determined. The eastern boundary of the main occurrence of Upper Red Quartzite Formation is located about 4 km west of the Brandy Lake area. No mineralization has been reported from the formation.

## STRUCTURE

Detailed structural studies of parts of the Seal Lake Group (Calon and Hibbs, 1980) along the southern marginal zone, have demonstrated that the overall structure of the group is more complex than reported earlier by Brummer and Mann (1961). Mapping in areas to the north of Letitia Lake, led Calon and Hibbs (1980) and Thomas (1981) to conclude that two episodes of regional Grenvillian deformation, and a later thrusting and high-angle reverse faulting event, were evident in the rocks of the southern Seal Lake Group. There, Calon and Hibbs (1980) and Hibbs (1980) interpreted the main east–west trend to reflect regional, $D_2$ Grenvillian deformation, and that the large-scale folds, which delineate the regional trend, are $F_2$ structures. According to those authors, an earlier $D_1$ deformation resulted in tight to isoclinal folding of the basal Bessie Lake Formation. Similarly, Marten and Smyth (1975) defined recumbent $D_1$ structures that were folded by later upright folds. In a study of the basal unconformity of the Seal Lake and the Bruce River groups, near Stormy Lake, Kontak (1978) noted an early ($D_1$) deformation resulting in flat-lying folds and an east-trending cleavage. These are apparently the only areas where evidence of an earlier, pre-$D_2$, regional deformation event have been documented, and regional structures within the southern Seal Lake Group are attributed to $D_2$ or possibly late-stage $D_3$ events. Thus, the interpretation put forth by earlier workers (*e.g.*, Brummer and Mann, 1961) that the large-scale folds in the southern Seal Lake Group were $F_1$ folds has been subsequently revised by Calon and Hibbs (1980) and Hibbs (1980) to indicate that these large-scale folds are, in fact, regional $F_2$ fold structures.

The 2008 map area is characterized by northeast- to east-northeast-trending, penetrative fabrics in the central portion, and a weaker, northwest trend in the southeast area. These fabrics are generally subparallel to contacts, although deviations are, locally, evident. With the exception of those occurring in fault zones, the rocks north of Seal Lake generally do not exhibit a preferred deformation fabric. Instead, they display either massive textures or preserve original, generally diffuse structures with no obvious evidence of folding or cleavage development. In contrast, rocks south of Seal Lake contain a moderate to strong foliation and /or cleavage in sedimentary rocks, particularly in the fine-grained, maroon-weathering slates (Unit 4c) and the basalts (Unit 4b). Gabbros exposed south of Seal Lake, like those to the north, locally exhibit weak to moderate foliations, and moderate to strong, mineral lineations and slicken striae. No folds were observed in the gabbros, although a slight undulation of locally developed fabrics is evident in some exposures.

The shoreline section along the Naskaupi River and a few small islands northwest of The Narrows (Figure 3) is one of the few areas within the map area where macroscopic $F_1$ folds are well exposed. Sedimentary rocks of the Whiskey Lake and Wuchusk Lake formations exposed in these areas consistently exhibit southeast-bedding orientations that dip gently to moderately southwest. Foliations are rare and $F_1$ fold axes plunge moderately to the northwest. These trends abruptly deflect toward the northeast between the Naskaupi River and East Seal Lake and retain this general direction across much of the map area. The reason for the southeasterly strike of bedding and foliations and the northwest-trending fold axes, in the southeast of the map area, is unclear because these are perpendicular to the main north-northeast fabric. Fahrig (1959) and Gandhi and Brown (1975) placed an assumed, northeast-trending fault between Brandy Lake and Whiskey Lake. This feature could not be confirmed, however, if a fault is present and extends through the peninsula between East Seal Lake and the Naskaupi River, it may explain the deflection of fabrics toward the northwest. Alternatively, the fabrics may have been folded toward the northwest by a later ($D_3$) deformation.

On the Loon Lake peninsula and north of Seal Lake, bedding in quartz-rich sedimentary rocks, and penetrative fabrics in slates and basalts, strike consistently northeast and have a gentle to moderate, southeast dip. Fold axes and mineral lineations typically exhibit a consistent and moderate southerly plunge. Although significant deviations from the dominant northeast trend and southerly plunge are locally observed, particularly in the slates, some of these variations may reflect small-scale, second-generation folding or warping.

Approximately 1.5 km northeast of the eastern end of Big Bight (Figure 3), gneissic banding was noted in a single outcrop of strongly altered basalt. The banding comprises cm-scale, quartz + feldspar layers that alternate with fine-grained, chlorite and hematite-altered, green-weathering, mafic volcanic matrix. These felsic layers are locally folded and have a moderate developed mineral lineation. Within the same outcrop, this texture is gradational into non-banded basalt exhibiting a more foliated texture. The gneissic fabric in these volcanic rocks may indicate local zones of stronger deformation and metamorphism in the central part of the Seal Lake Group than previously recognized.

## FAULTS

Faults are delineated by zones of strong alteration, brecciation and local ductile shearing. Where outcrops are scarce, faults are interpreted from aeromagnetic trends and topographic lineaments visible on aerial photographs. In the area between Seal Lake and Wuchusk Lake, an east- to east-northeast-trending fault has been traced for approximately 5 km. A northwest-trending fault is also present along the eastern shore of the Naskaupi River where it flows into Seal Lake, and a north-northwest-trending fault occurs along the Naskaupi River in the southeastern part of the map area.

The northeast-trending fault, between Wuchusk and Seal lakes, is marked by a *ca.* 50-m-wide zone of strongly recrystallized, altered, brecciated and, in some areas, sheared sedimentary and gabbroic rocks. Immediately west of the small lake that straddles the fault zone, strongly recrystallized and silicified, quartz-feldspar-rich sedimentary rocks contain thin, attenuated quartz lenses and stingers indicating a dextral sense of movement along discrete shear planes (Plate 10). As no other kinematic indicators were found, the overall sense of displacement is unknown. Lineations associated with this fault, however, exhibit general northerly trends and plunge gently to moderately to the north or south. A southerly plunge is more prevalent, suggesting that the fault has at least a partial north to north-northeast thrust component. At the northeast extension of this fault, fine- to very fine-grained, recrystallized and altered breccia containing gabbro and sedimentary rock pro-


**Plate 10.** *Strongly chloritized and silicified quartz-rich sediment occurring in northeast-trending fault zone, between Seal and Wuchusk lakes (Unit 2a). Note dextral offset of grey quartz–feldspar vein along later, subvertical quartz vein in the right of photo. (Station VN08-086, UTM coordinates 592126E/6025468N)*

toliths comparable to the adjacent host rocks delineates the fault zone. The extension of the fault zone to the western edge of the map area is defined by isolated exposures of similarly chloritized, epidotized and brecciated sedimentary and gabbroic rocks. Because ductile features are developed in the central part of the fault, and brittle features in its northeast and southwest extensions, may indicate that higher level deformation affected its northeast and southwest extensions.

The northwest-trending fault exposed north of Loon Lake peninsula, is marked by a 10- to 15-m-wide zone of strongly altered, folded and locally sheared, quartz-rich sedimentary rocks. Lineations show a moderate south to southwest plunge. No obvious kinematic indicators were apparent in these outcrops. In the southeast, a northwest-trending, 2- to 3-m-wide zone of fine-grained fault breccia cuts through mixed sedimentary and fine-grained gabbroic rocks along the Naskaupi River (Figure 3). This zone is not exposed inland from the shoreline and thus may be a local feature. Alternatively, it may be a southerly extension of the northwest-trending fault along the east shore of the Naskaupi River. If this explanation has any merit, then the three fault zones may be part of the same feature and outline the hinge area of the large $F_2$ fold and thus may represent an early, pre-$D_2$ feature.

All three faults, mentioned above, appear to be localized along thin sedimentary layers in contact with gabbro sills of the Wuchusk Lake Formation. Calon and Hibbs (1980) noted that within the southern Seal Lake Group, thrust and high-angle reverse faults are commonly developed parallel to the limbs of macroscopic $F_2$ folds as well as parallel to lithological contacts, where large competency contrasts exist between adjacent units. The faults observed in the 2008 survey area substantiate their conclusions. The three faults are thus interpreted to be part of a single feature that follows the contact of sedimentary rocks and gabbro along the limbs and hinge area of the eastern Seal Lake syncline. Faulting between relatively competent gabbro sills separated by thin intervals of less competent, sedimentary layers on both the limbs and in the hinge area of the regional syncline, would suggest the operation of flexural slip. In ideal flexural slip, the limbs would be relatively undeformed, and most of the strain would be concentrated in the hinge zones (Hobbs *et al.*, 1976). The generally higher degree of deformation exhibited by rocks in the core and hinge of the syncline underlying the Loon Lake peninsula compared to the relatively weak deformation evident in the limbs would suggest this type of slip mechanism. Alternatively, these faults could be earlier thrusts that were reactivated during regional $D_2$ folding.

### METAMORPHISM

Petrographic work has yet to be undertaken on samples collected during the 2008 survey. Baragar (1981) described chlorite ± epidote ± iron-oxide assemblages as having replaced olivine and, to a lesser extent, pyroxene in the basalts and gabbros to the south of Seal Lake. He noted that plagioclase is typically altered to saussurite and mica, and clay mineral assemblages. North of Seal Lake, Baragar (1981) described tremolite ± pumpellyite in olivine pseudomorphs in the gabbroic rocks. The general distribution of low-grade metamorphism resulting in tremolite-bearing assemblages to the north of Seal Lake, and the slightly higher intensity, chlorite-dominated alteration assemblages to south of Seal Lake, was noted during the 2008 survey. This is particularly the case in coarse-grained gabbroic rocks and, to a lesser extent, in the basalts.

Metamorphism attained a maximum of greenschist facies in the south and evidence of only pumpellyite facies being reached in the north. The higher metamorphic grade in the southern Seal Lake Group is possibly the result of Grenvillian folding and thrusting of the lower stratigraphic formations.

### CORRELATION OF GEOLOGY WITH REGIONAL AEROMAGNETIC DATA

To support the placement of some geological contacts and faults in the map area, they have been superimposed on the 1:250 000-scale aeromagnetic map of Kilfoil (2008; Figure 4).

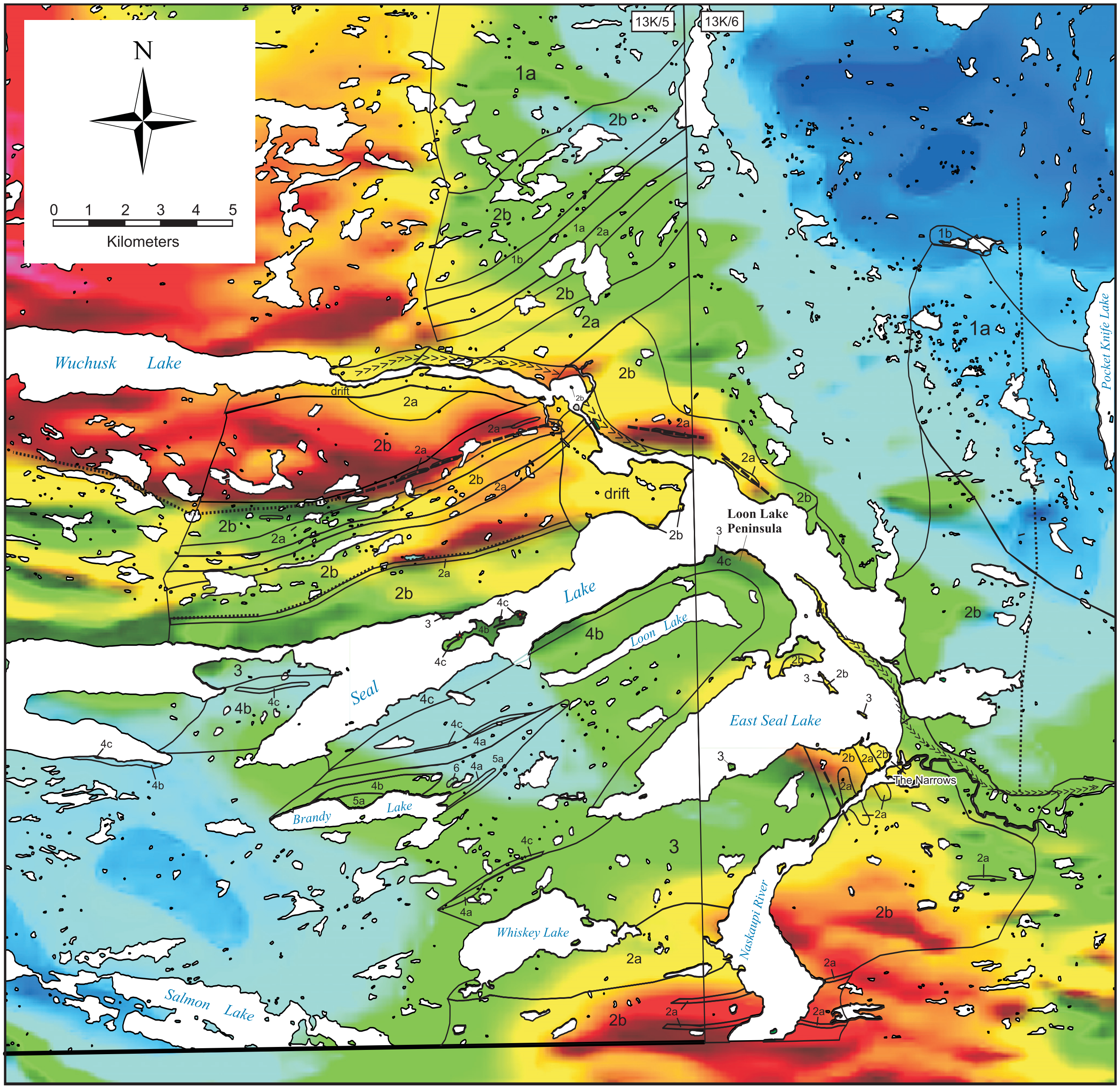
Generally, areas of high aeromagnetic signature correlate with gabbro sills of the Wuchusk Lake Formation. Moderate aeromagnetic signatures reflect the underlying volcanic and argillaceous sedimentary rocks of the Salmon Lake Formation and the dominantly arenaceous rocks of the Whiskey Lake Formation. The low aeromagnetic signature, located to the west of Brandy Lake, correlates with the core of the main Seal Lake syncline of Brummer and Mann (1961) which, in this area, is dominated by arenaceous rocks of the Upper Red Quartzite Formation and flanked by Adeline Island sedimentary rocks and minor basalt. The pronounced low aeromagnetic signature in the northeast corresponds with the extensive basaltic flows and minor sedimentary rocks of the Majoqua Lake Formation.

Of particular interest, are the relatively narrow, west- to southwest-trending aeromagnetic highs located between Wuchusk and Seal lakes and on the east side of the Naskaupi River where it flows into Seal Lake. The southern edges of these narrow magnetic highs appear to correlate with delineated faults. The relatively large undulating aeromagnetic high between Wuchusk and Seal lakes is underlain predominantly by gabbroic rocks and the southern edge of this signature delineates the northeast- to west-trending fault. The trend of the southern edge of this aeromagnetic high suggests that the fault may swing northwesterly toward the west end of Wuchusk Lake. A similar correlation is observed on the east side of the Naskaupi River where the northwest- to west-trending fault is associated with a small, west-northwest-trending, elliptical aeromagnetic high. A west-southwest-trending fault is interpreted, on the basis of an airphoto lineament and the aeromagnetic signature, to occur along the contact of a gabbro sill and a thin zone of sedimentary rocks exposed approximately 2 km north of Seal Lake. This fault may connect with similar trending faults mapped by Fahrig (1959) to the west of the present map area.

## MINERAL OCCURRENCES

The Seal Lake region is historically well known for its numerous native copper and copper-sulphide mineral occurrences, with over 250 individual indications, showings and prospects being recorded (Brummer and Mann, 1961). Most of these are associated with the upper volcanic flows and gabbro sills of the Salmon Lake Formation and the overlying clastic sediments of the Adeline Island Formation. Minor uranium occurrences are known from the basal unconformity and in conglomerates near the base of the group (Baragar, 1969; Marten and Smyth, 1975).

During the 2008 survey, two prospects and several indications and showings were investigated in the eastern Seal Lake area. Some of these were sampled for geochemical




## LEGEND

Seal Lake Group

*Upper Red Quartzite Formation*

| 6 | Mature, red-weathering quartzite |
|---|---|

*Adeline Island Formation*

| | |
|---|---|
| 5a | Interbedded quartzite, sillstone, minor slate and mafic volcanic flows |
| 5b | Mafic volcanic flows |

*Salmon Lake Formation*

| | |
|---|---|
| 4c | Argillaceous sedimentary rocks. Predominantly red slates, shales and siltstones containing thin arenaceous interbeds and rare limestone and stromatolites |
| 4b | Weakly to strongly foliated mafic volcanic flows and sills with minor intercalated sedimentary rocks |
| 4a | Fine-to coarse-grained, ophilic-textured gabbro sills |

*Whiskey Lake Formation*

| 3 | Interbedded sillstones and sandstones, containing minor slate and mafic volcanics, and rare chert |
|---|---|

*Wuchusk Lake Formation*

| | |
|---|---|
| 2b | Fine-to coarse-grained, ophitic- to intergranular-textured gabbro. Occurs as sills of variable thickness |
| 2a | Arenaceous sedimentary rocks. Predominantly quartz-rich sandstones and siltstones with subordinate argillaceous and calcareous sediments |

*Majoqua Lake Formation*

| | |
|---|---|
| 1b | Pink-to red-weathering sandstone |
| 1a | Amygdaloidal to porphyritic-textured massive basalt flows |

## SYMBOLS

*Geological contact (approximate)* ........................

*Fault (approximate, assumed)* ..............................

**Figure 4.** *Compilation of regional aeromagnetic data, geological contacts and faults in the map area.*

analyses and assays, and results are pending. Since these occurrences have been extensively studied by various mining and exploration companies in the past, they are only briefly discussed here. The UTM coordinates (NAD27, Zone 20) of the occurrences were determined by Global Positioning System (GPS).

### EAST SEAL LAKE SHOWING No. 68 (MODS FILE NUMBER 013K/05/Cu020; UTM COORDINATES 595389E/6017017N)

The East Seal Lake showing No. 68 is located on the southwestern end of East Seal Lake, ca. 150 m south of the southern shoreline (Figure 3) and lies within the Salmon Lake Formation. The prospect has been partially exposed by surface trenching and consists of several, disrupted native copper-bearing quartz + calcite veins hosted by fine-grained basalt near its contact with fine-grained maroon slate.

The mineralized veins are 5 to 50 cm wide and contain cores of native copper forming irregular seams and nuggets (up to 30 cm long and 8 cm wide) and associated with abundant malachite and locally azurite (Plate 11). In some of the thinner veins, the alteration minerals and native copper are evenly distributed throughout. The host basalts are extensively silicified, chloritized and quartz veined along the mineralized vein contacts. Quartz + calcite veining and alteration are also extensive near the contact of the basalts and slates and are found to both crosscut and parallel the foliation. The basalt host to this mineralization is homogenous, light green, massive to moderately foliated, and fine grained. The well-cleaved slate is fine grained, red- to maroon-weathering and occurs as metres to tens-of-metres thick intercalated layers and, as a more extensive zone to the west of the occurrence underlying the mafic volcanics.

**Plate 11.** *Tarnished and ‘exposed’ native copper nugget with malachite staining hosted in sheared quartz +/- carbonate vein, within chlorite-rich mafic volcanics. Mineralized veins are usually concordant to the fabric in host mafic volcanic. Individual nuggets have been measured up to 30 cm long and 10 cm wide at this locality. Pencil is 14 cm long (East Seal Lake showing No. 68, MODS number 13K/5/Cu020, UTM Coordinates 595389E/6017017N)*

The copper mineralization is scattered over a ca. 10 $m^2$ area, and cursory prospecting did not reveal any further indications. No copper mineralization was observed to occur within the slate, with the exception of minor malachite staining of thin, intercalated slate layers at the immediate contact with the mineralized basalts. In comparison to other native copper occurrences in the Seal Lake Group, very little detailed work has been carried out at showing No. 68 and, despite obvious trenching efforts, there appears to have been only limited sampling.

### EAST SEAL LAKE SHOWING No. 206 (MODS FILE NUMBER 013K/05/Cu 097; UTM COORDINATES 595294E/6017109N)

The East Seal Lake showing No. 206 is located 135 m northwest of showing No. 68 and consists of strongly altered, chlorite schist having thin intercalated layers of maroon slate. Mineralization consists of abundant malachite and minor azurite staining associated with chalcocite and is hosted within sheared and altered zones within the basalts. Native copper was not observed at this locality. Veining is less extensive at this occurrence as compared to the extensive quartz + calcite veins at showing No.68 to the southeast. Moreover, the mineralization here appears limited to fracture and foliation surfaces. The occurrence has been exposed in a 2- to 3-m-long trenched area, but it appears that very little if any detailed work has been carried out.

### WHISKEY LAKE NORTH PROSPECT (MODS FILE NUMBER 013K/05/Cu 003; UTM COORDINATES 592098E/6015436N)

The Whiskey Lake North prospect is located approximately 1.5 km north of the west end of Whiskey Lake and consists of a series of trenches that expose the contacts between gabbro sills and grey slates and pink sandstones (Gandhi and Brown, 1975; Wilton, 1996). Although assessment reports indicate 11 trenches exist, only one of these was located.

Examination of the trench and several previously sampled zones of this prospect, indicates copper sulphide and copper carbonate mineralization occurs in quartz + carbonate veins and as disseminated sulphides in a gabbro sill. The trenched area (denoted by bo, ma, cpy on Figure 3) is approximately 10 m long by 3 m wide and exposes a fine- to medium-grained gabbro sill overlying grey slate and minor intercalated, fine-grained sandstone layers. Sulphide mineralization was observed only within the fine-grained marginal phase of the gabbro and exhibited three modes of occurrence: 1) 1- to 10-cm-wide, irregular quartz + calcite veins and lenses within the gabbro containing variable amounts of chalcopyrite, pyrite, malachite, azurite and fine-grained bornite (Plate 12); 2) 1 to 3 percent disseminated chalcopyrite and pyrite within some zones of the gabbro margin, and 3) abundant malachite and azurite 'coatings' and aggregates on fracture surfaces within the gabbro. Gandhi and Brown (1975) suggested that the grey slate unit in contact with the gabbro sill is part of the Adeline Island Formation. Robinson (1956) recorded this occurrence as Whiskey Lake No.1 and reported average assays across the trenches of 0.08 percent Cu over 9 m and 1.6 percent Cu over 18 m.


**Plate 12.** *Chalcopyrite, minor bornite and malachite hosted in quartz + carbonate vein in a fine-grained diabase sill. Note zonation 'from coarse quartz' + minor carbonate crystals in core to fine-grained, predominantly carbonate + minor quartz at vein margins. North Whiskey Lake prospect, MODS number 13k/5/Cu003, (UTM coordinates 592098E/6015436N)*

Approximately 400 m north of this trench (denoted as bo, ma on Figure 3), fine-grained bornite and malachite alteration are sporadically hosted within thin (2- to 5-cm wide) quartz + carbonate veins that cut fine-grained basalt. Gabbro is absent within the immediate area of this occurrence, in contrast with the southern showing. However, thin zones of maroon slate are intercalated with basalts in this area and, despite the absence of native copper, may be more related to the type of occurrence observed 3.5 km to the northeast at East Seal Lake showings No. 68 and No. 206.

### BRANDY LAKE PROSPECT (MODS FILE NUMBER 013K/05/Cu 031; UTM COORDINATES 591171E/6017958N)

The Brandy Lake prospect is located approximately 300 m north of the northeastern shore of Brandy Lake (Figure 3) and has been described in detail by Murthy and Gandhi (1972), Gandhi and Brown (1975), Wilton and Brace (1988) and Wilton (1996). The Brandy Lake prospect area is underlain by mafic volcanic flows, green, grey and red slate, red sandstone and gabbro that are exposed in a series of small trenches within an approximate area of 500 m by 1000 m; these rocks are part of the Adeline Island Formation. Murthy and Gandhi (1972) reported chalcocite mineralization in a 60-cm-wide and 1.5-m-long zone of grey slate in contact with diabase and basalt in one of the trenches; grab samples returned assays of 7.5 and 10 percent Cu and 0.17 and 0.26 ounces per ton Ag. At the Brandy Lake Main showing, chalcocite and bornite mineralization are hosted by sheared and locally hematized sandstone (Wilton, 1996).

Only one of the western trenches was examined during the 2008 survey. The trench is located about 100 m north of the Brandy Lake shoreline and consists of a 6-m-long by 2-m-wide trench containing amygdaloidal to vesicular basalt, and grey slate layers. Mineralization comprises aggregates of malachite + fine-grained chalcocite + minor bornite in small veins and fractures at the contact of altered vesicular basalt and grey slate. Most of the mineralization occurs within the mafic volcanic rocks, but is also present, to a lesser extent, in the adjacent slate.

### SEAL LAKE SHOWING No. 126 (MODS FILE NUMBER 013K/05/Cu 053; UTM COORDINATES 593475E/6021815N)

The Seal Lake showing No. 126 is located on the eastern end of Cross island (Figure 3). The mineralization consists of a 0.5- to 2-cm-wide by 20-cm-long native copper seam with associated malachite staining and fine-grained chalcocite hosted within quartz + pink calcite veins in fine-grained basalt. The exposure is approximately 5 m in length and the mineralization was observed over a *ca.* 75-cm-long section.

### SEAL LAKE SHOWING No. 125 (MODS FILE NUMBER 013K/05/Cu 052; UTM COORDINATES 591980E/6021341N)

The Seal Lake showing No. 125 is located on the western end of Cross island (Figure 3). The occurrence consists of minor bornite mineralization hosted by basalt near the contact with fine-grained, maroon slates. Minor malachite staining is also present along fracture surfaces within the mafic volcanic unit at the bornite locality and approximately 20 m to the west.

## NEW OCCURRENCES

Two previously unreported native copper occurrences and two ilmenite occurrences were found within the map area.

### VN08-021 (UTM COORDINATES 594044E/6019803N)

The occurrence is located 800 m south of the western end of Loon Lake (Figure 3). Mineralization consists of a single fleck of native copper and minor malachite staining hosted by quartz + calcite veins in basalts of the Salmon Lake Formation (Unit 4b).

### VN08-140 (UTM COORDINATES 592278E/6020468N)

The occurrence is located 1.7 km west of the west end of Loon Lake (Figure 3). At this locality, a 4-m-high vertical cliff face exposes intercalated maroon to grey slate and fine-grained sandstone containing numerous thin, concordant quartz + carbonate veins. The veins that range from 0.5 to 2 cm in width host trace native copper flecks and minor malachite staining.

## ILMENITE OCCURRENCES

At two gabbro localities, ilmenite occurs in sufficient quantities to warrant discussion. On a small island in the Naskaupi River between Wuchusk Lake and Seal Lake (Figure 3), an isolated outcrop of medium-grained, equigranular, massive gabbro contains ilmenite + minor magnetite aggregates comprising up to 75 percent of the rock. However, this covered an area of only *ca.* 3 m by 2 m. A second noteworthy locality is located on a small island in East Seal Lake where similar ilmenite concentrations are noted within a medium- to coarse-grained, massive gabbro to leucogabbro. The ilmenite-rich phase in both occurrences appears be a much localized feature of the gabbro. Wilton (1996) noted that in some outcrops, primary ilmenite in the gabbro and diabase sills in the Seal Lake area is of sufficient grade and grain size to constitute a potential Ti resource.

### A NOTE ON MINERALIZATION

Wilton (1996) commented on the origin of copper mineralization in rocks of the Seal Lake Group. He concluded that the mineralization appears to be syn- to posttectonic, with respect to $D_1$ folding and shearing, and is a product of a single mineralizing event. He also noted that the mineralization is epigenetic with respect to the host rocks. Cursory examination of some of the occurrences in the eastern Seal Lake area did not find any evidence to contradict the conclusions of Wilton (1996).

### SCINTILLOMETER READINGS

Scintillometer readings were recorded at most outcrops (about 250 readings) using a handheld Radiation Solutions RS-120 Super-Scintillometer. Gabbroic rocks recorded the lowest readings of 30 to 60 counts per second (cps). Mafic volcanic rocks yielded readings ranging from 50 to 70 cps, for relatively unaltered basalts in the north of the map area, to 70 to 90 cps for altered basalts south of Seal Lake. Sedimentary rocks yielded readings in the range 100 to 250 cps and the fine-grained sedimentary rocks (siltstones and slates) typically gave the higher readings. A single exposure of black-weathering, fine-grained shale, located at the western edge of the map area, approximately 2 km south of the shoreline of Wuchusk Lake (Figure 3, U occurrence), yielded a maximum reading of 600 cps. The rock is distinctive and is one of three outcrops of black schistose shale observed north of Seal Lake within the Wuchusk Lake Formation (*see* description of Unit 2a).

## SUMMARY

The 1:50 000-scale mapping carried out during 2008 corroborates the subdivision of the rocks of the eastern Seal Lake area into six previously defined stratigraphic formations, with slight modifications. The overall structure conforms to the eastern hinge and parts of the northern and southern limbs of an east-northeast-trending, southwest-plunging syncline centred in the map area. An early deformation resulted in development of the main penetrative east-northeast $S_1$ fabric. Faults were likely active during the latter stages of this early deformation. A second phase of deformation produced local $F_2$ folds and open warping of the stratigraphy. Faults developed parallel to the limbs of the syncline, along contacts between units with large competency differences. Preliminary analysis suggests that these faults possess a thrust component as well as probable dextral slip movement. Rocks exposed in these faults exhibit features of both high-strain ductile as well brittle deformations. The presence of faults along zones of weakness in the limbs and hinge of the syncline suggests folding occurred *via* flexural slip. A slight increase from lower greenschist facies in the south to pumpellyite facies in the north, attests to the progressive decrease in metamorphic grade away from the Grenvillian-related thrusting that is recognized in the southern parts of the Seal Lake Group. Mineral occurrences are hosted predominantly in sheared and altered quartz-carbonate veins that are associated with the contacts of many of the constituent volcanic, sedimentary and gabbroic rocks. Mineralization comprises native copper, chalcocite, bornite, malachite, azurite and chalcopyrite, and ilmenite is locally concentrated in the coarse-grained gabbros. All mineralization, with the exception of the ilmenite occurrences, and disseminated pyrite in gabbros and sedimentary rocks, is considered to be epigenetic in origin in keeping with the conclusions of recent comprehensive studies of the major mineral occurrences.

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