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Samuels Lake intrusion: a Late Archean Cu-Ni-PGE-bearing mafic-ultramafic complex in the western Quetico Subprovince, northwestern Ontario[1]

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Abstract: The Samuels Lake intrusion, located in the central western Quetico Subprovince, is similar to an array of mafic-ultramafic intrusions along the northern boundary of the subprovince. These intrusions are referred to in the literature as the Quetico intrusions, and are accompanied by Cu-Ni-PGE mineralization and characteristically contain clinopyroxenite and minor pegmatitic phases. The Samuels Lake intrusion is elliptical in form and displays concentric zoning with a wehrlite core surrounded by a hornblendite zone and pyroxenite exterior. The PGE mineralization is associated with the occurrence of sulphides, especially chalcopyrite, in altered pyroxenite and wehrlite. High values of PGE appear related to high-temperature, late-magmatic, hydrothermal alteration.

Résumé : L’intrusion de Samuels Lake, dans le centre ouest de la Sous-province de Quetico, ressemble à un réseau d’intrusions mafiques-ultramafiques le long de la limite nord de la sous-province. Ces intrusions, désignées «intrusions de Quetico» dans la documentation scientifique, sont accompagnées de minéralisations de cuivre, de nickel et d’éléments du groupe du platine et se caractérisent par la présence de clinopyroxénite et de phases pegmatitiques mineures. L’intrusion de Samuel Lake est de forme elliptique et présente une zonation concentrique avec un coeur de wehrlite entouré d’une zone de hornblendite et d’une zone externe de pyroxénite. La minéralisation en éléments du groupe du platine est associée à la présence de sulfures, surtout la chalcopyrite, dans de la pyroxénite et de la wehrlite altérées. Les teneurs élevées en éléments du groupe du platine semblent être associées à une altération hydrothermale tardi-magmatique de haute température.

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[1] Contribution to the Western Superior NATMAP Project

INTRODUCTION

An east-trending chain of mafic-ultramafic intrusions, referred to as the Quetico intrusions (Watkinson and Irvine, 1964), occurs in the northern Quetico Subprovince adjacent to the boundary with the Wabigoon Subprovince (Fig. 1). Similar mafic-ultramafic intrusions are present in the Wabigoon Subprovince to the north, including the Lac des Iles complex, currently being mined for platinum group elements (PGEs). The Quetico intrusions may be 2688 ± 4 Ma (Davis et al., 1990), based on the age of the Blalock diorite. Quetico intrusions have been studied by Larsen (1974), Pirie (1978), MacDonald and Cherry (1988), Blackburn et al. (1989), MacTavish (1992), and Schnieders et al. (1999).

Mafic-ultramafic intrusions are not restricted to the northern margin of the Quetico belt. Several bodies occur to the southwest in the central Quetico Subprovince, at Whalen Lake, Beaverhouse Lake, Harnett Lake, Surprise Lake, and Samuels Lake (Hattori and Percival, 1999; Fig. 1). The Samuels Lake intrusion has hornblende-rich units, as well as sulphide and PGE mineralization styles (Blackburn et al., 1989), like the Quetico intrusions. However, recent U-Pb titanite ages of 2680 Ma from the Harnett Lake and Whalen Lakes bodies (Hattori and Percival, 1999) suggest a younger episode of magmatism than in the Quetico intrusions. The Samuels Lake intrusion has received little previous documentation because of poor exposures, but recent exploration has provided an opportunity to observe new exposures and drill core samples. This paper summarizes the geology of the PGE-bearing Samuels Lake intrusion observed during the 1999 field season.

SAMUELS LAKE INTRUSION

The Samuels Lake intrusion is an elliptical body approximately 600 m long by 300 m wide, surrounded by upper greenschist- to lower amphibolite-facies turbiditic wacke of the Quetico Subprovince (Fig. 2). It is readily accessible by a drilling road off the Flanders road, 14.5 km south of Highway 11. Approximately two weeks of fieldwork, consisting of detailed sampling of outcrops and drill core in conjunction with grid mapping at a scale of 1:500, was carried out during the summer of 1999. Fieldwork was focused on the Samuels Lake intrusion due to the lack of detailed previous studies, its location as one of the westernmost Quetico intrusions, its relatively undeformed nature, and recent exploration activity due to the discovery of PGE mineralization. This recent exploration activity by ProAm Exploration Corporation, which in the past year has provided core (~300 m) from several diamond-drill holes, permits detailed geological analysis of this otherwise poorly exposed intrusion.

The Samuels Lake intrusion was first sampled for PGE mineralization by M.R. Hailstone (reported in Blackburn et al., 1989). One grab sample from this expedition assayed 1550 ppb Pt, 2450 ppb Pd, 200 ppb Au, 545 ppm Ni, and 1410 ppm Cu. The property was then staked by prospectors S. Johnson and J. Bond, who obtained several assays around 3000 to 5000 ppb combined Pt, Pd, and Au, and as high as 12 327 ppb (Hood, unpub. company rept., 1998). Schnieders et al. (1999) identified the platinum-group minerals sperrylite ($PtAs_2$), froodite ($PdBi_2$), and hollingworthite ((Rh, Pt, Pd)AsS). In the fall of 1998, ProAm Exploration Corporation and Starcore Resources optioned the property in a joint

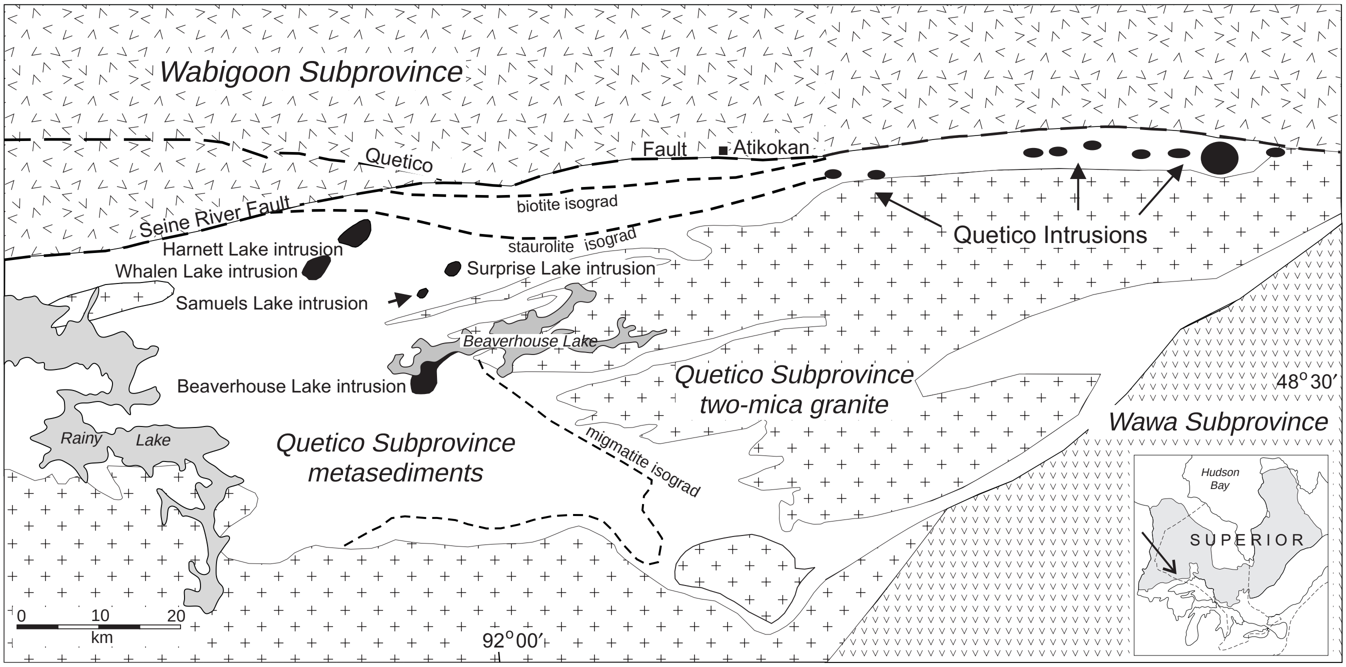

Figure 1. Geological map of the western Quetico Subprovince, northwestern Ontario. Long dashed lines represent major faults, short dashed lines represent metamorphic isograds. Rocks within the migmatite isograd contain migmatitic leucosome.

venture. During the following year they conducted soil geochemistry, magnetic geophysics, grid mapping at a scale of 1:1000, and diamond drilling on the property.

Lithology

Four distinct igneous phases are recognized in the Samuels Lake intrusion, and consist, in order of decreasing abundance, of pyroxenite, hornblendite, wehrlite, and monzodiorite/diorite. Each phase displays wide compositional variation due to different proportions of constituent minerals.

Pyroxenite

Pyroxenite is typically coarse grained (~1 cm), with mainly uralized clinopyroxene varying from 3 mm to 3 cm in grain size. It exhibits both gradational and sharp contacts with hornblendite and is interpreted to represent a cumulate. Variable quantities of magnetite locally form magmatic layering (Fig. 3). Large uralized clinopyroxene crystals commonly contain numerous pods of acicular amphibole, producing the appearance of inclusion-rich crystals in hand specimens. Accessory minerals include, in order of decreasing abundance, plagioclase, primary hornblende, biotite, magnetite, calcite, actinolite, apatite, titanite, orthoclase, pyrrhotite, chalcopyrite, pentlandite, and pyrite. Actinolite, orthoclase, and pyrite are alteration products; some biotite and magnetite may be secondary as well. Some coarse biotite is likely to be primary, based on its similarity in grain size to magmatic clinopyroxene. Sulphides, together with oxides, are sporadically distributed, occurring in disseminated and blebby forms, most commonly interstitial to silicate minerals, and they may form veinlets (Fig. 4). Pyrrhotite is by far the most abundant sulphide mineral, followed by chalcopyrite and pentlandite. Sulphide blebs and veinlets commonly contain euhedral, compositionally zoned apatite (Fig. 5). Based on assay results, the PGE mineralization appears to be

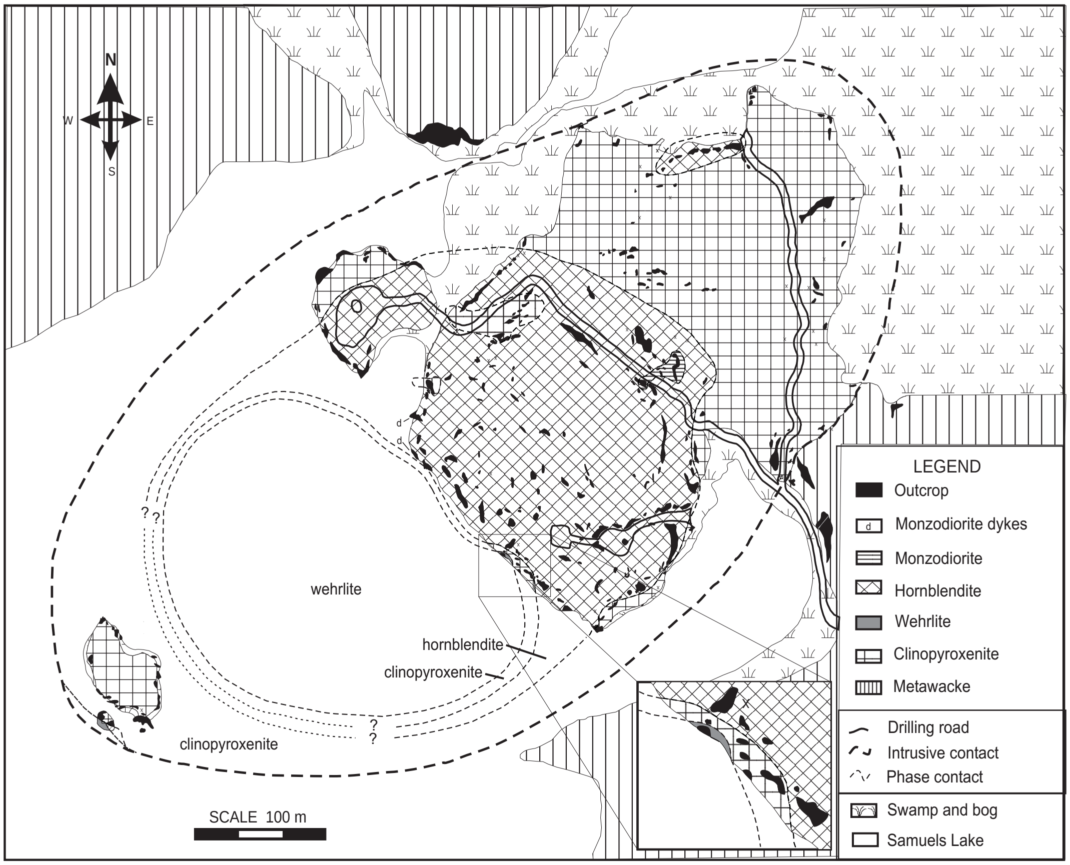

Figure 2. *Geological map of the Samuels Lake intrusion, Atikokan area, northwestern Ontario. Phase contacts were interpreted using surficial mapping and drill logs.*

generally associated with sulphide minerals. Calcite is also sporadically present, interstitial to silicate minerals of possible primary origin, and in secondary veinlets.

Pyroxenite, along with the wehrlite phase, is the main host of Cu-Ni-PGE mineralization. The mineralization occurs mostly in sulphide-rich (especially chalcopyrite), altered, uralized pyroxenite. Sulphide-rich, altered rocks have yielded assays around 3 to 5 g/t PGE (Hood, pers. comm., 1999).

Figure 3. *Layering produced by concentrations of magnetite, possible decorating an original magmatic layering.*

A pegmatitic pyroxenite phase consists of equant, green, uralized clinopyroxene in a matrix of plagioclase, with small elongate hornblende crystals. This unit also grades into pegmatitic gabbro containing plagioclase-cored euhedral hornblende crystals. The pegmatitic phase forms veins up to 20 cm wide and pods up to 1 m in size.

Hornblendite

Hornblendite occurs in the centre of the intrusion, but also forms large pods within the uralized pyroxenite. Rafted fragments of uralized pyroxenite were also noted, suggesting that the hornblendite is younger. It is typically medium to coarse grained, with preferred crystal orientation, and is distinguished from uralized pyroxenite by the elongate nature of constituent hornblende crystals. This phase contains variable amounts of brown biotite and plagioclase, and grades to hornblende gabbro. Disseminated fine-grained biotite, calcite, magnetite, and calcite-quartz-feldspar veinlets appear to have formed during alteration. Hornblendite is generally not strongly magnetic, and no interstitial calcite was observed. A plagioclase-rich pegmatitic subphase with plagioclase-cored euhedral hornblende is present locally (Fig. 6).

Hornblendite is a component of all Quetico intrusions along the northern subprovince boundary, but rarely hosts significant sulphide or PGE mineralization. This phase does not contain significant PGE or Cu-Ni mineralization in the Samuels Lake intrusion.

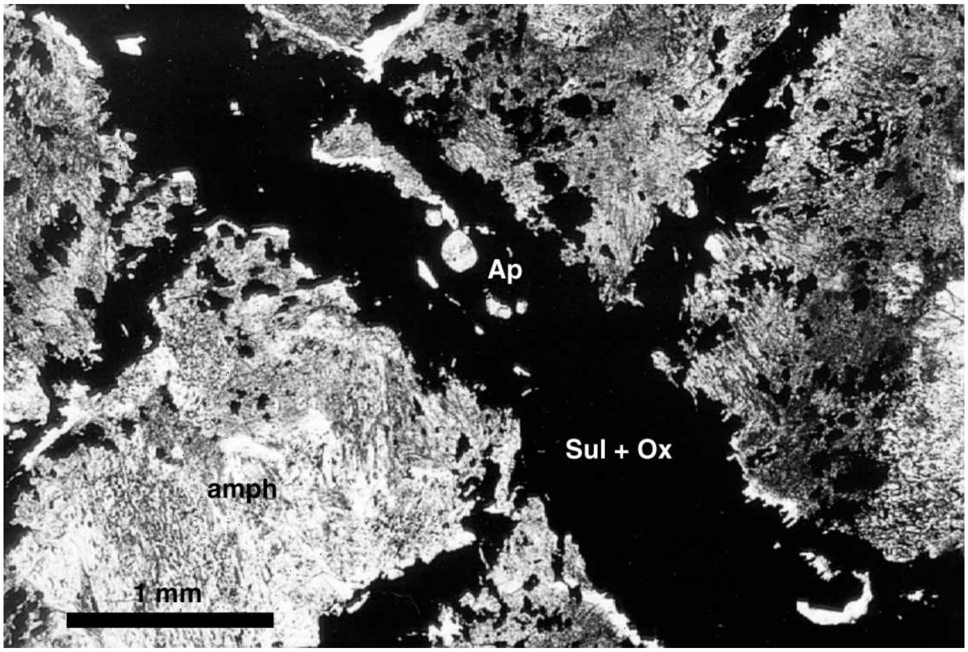

Figure 4*. Photomicrograph of sulphide-oxide veinlets in altered clinopyroxenite (sample: DDH 6, 201.55 m depth). Amph = secondary amphibole, Ap = apatite, Sul = pyrrhotite and chalcopyrite, Ox = magnetite.*

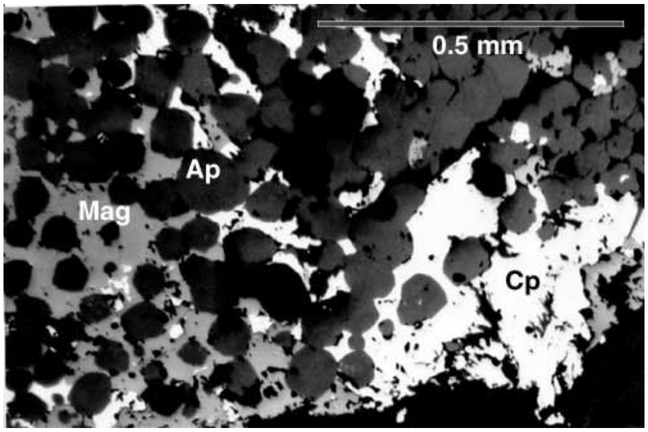

Figure 5. *Reflected-light photomicrograph of sulphide-oxide veinlet shown in Fig. 4. Note abundant euhedral apatite (Ap) grains in a mixture of chalcopyrite (Cp) and magnetite (Mag).*

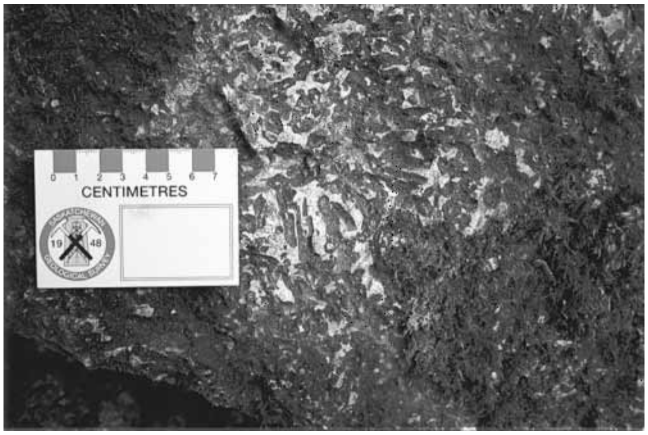

Figure 6. *Pegmatitic plagioclase with plagioclase-cored euhedral hornblende crystals at Samuels Lake.*

Wehrlite

This phase is composed primarily of clinopyroxene and serpentinized pseudomorphs of olivine. Olivine retains characteristic shape and fracture patterns, but is completely replaced by mesh-textured serpentine (Fig. 7). Clinopyroxene is commonly uralized to amphibole, with cores of relict clinopyroxene, but diopsidic clinopyroxene crystals are also found in some samples including those with high volumes of sulphide minerals (Fig. 7). Accessory minerals include coarse-grained (> 1 mm) biotite, apatite, chlorite, magnetite, pyrrhotite, chalcopyrite, and calcite. Grain size is typically coarse (0.5–1 cm; Fig. 7 and 8), with rare olivine pseudomorphs exceeding 2 cm. Sulphides may constitute up to 40 volume per cent of this phase and hence, wehrlite hosts the bulk of Cu-Ni mineralization, as well as some PGE mineralization.

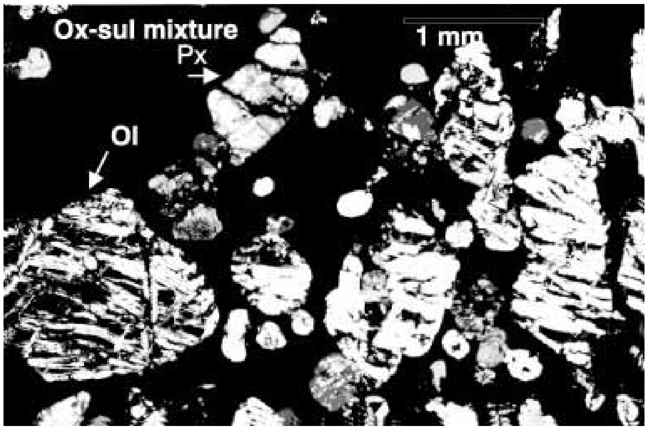

Figure 7. *Photomicrograph of interstitial sulphide in wehrlite (DDH 6, 113.5 m depth) Olivine (Ol) and clinopyroxene (Px) crystals are surrounded by a mixture of sulphide and oxide (Ox + Sul). Olivine grains are pseudomorphed by mesh-textured serpentine.*

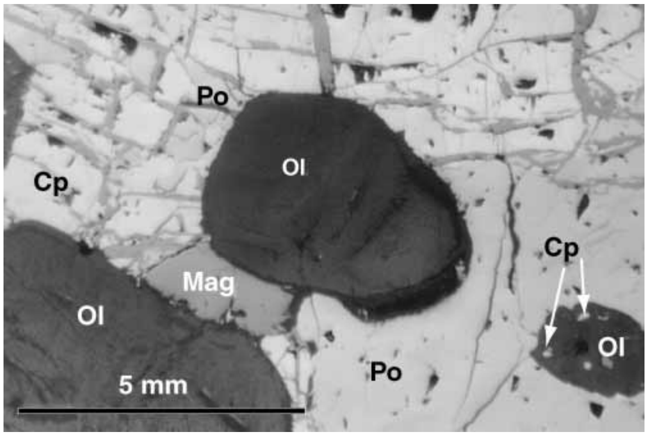

Figure 8. *Reflected-light photomicrograph of interstitial sulphide-oxide mixture in wehrlite (DDH 6, 113.5 m depth). Rounded grains of olivine (Ol) are surrounded by pyrrhotite (Po), chalcopyrite (Cp), and magnetite (Mag).*

Olivine-bearing phases are not common in Quetico intrusions, but MacTavish (1992) noted the occurrence of hornblende wehrlite in the Kawene and Chief Peter intrusions. The wehrlite and olivine-rich clinopyroxenite at Kawene Lake are discontinuously surrounded by hornblendite (MacTavish, 1992), in a similar configuration to that at Samuels Lake.

Monzodiorite/diorite

This is a relatively minor phase consisting of approximately 30 cm wide dikes and an inclusion-rich plug, both of which were observed to cut the hornblendite phase. It is therefore interpreted to be the youngest igneous phase. This phase is fine to medium grained (~1–2 mm) and is composed primarily of plagioclase with minor K-feldspar and pyrrhotite.

Interstitial calcite is present in several samples. The plug contains abundant wehrlite inclusions (Fig. 9) and a single diorite xenolith (Fig. 10), a rock type not observed elsewhere in the intrusion.

Structure

The intrusion is elliptical at surface, exhibiting rudimentary concentric zoning with an outer uralized pyroxenite phase with a core of hornblendite and wehrlite (Fig. 2). Pyroxenite forms several separate, near-vertical plugs in the core of the intrusion. It was difficult to establish the precise boundaries and relationships between different igneous units due to poor exposure. Some contacts are gradational over 1 m, whereas others are sharp. Gradational contacts, together with an interfingering relationship suggest that all mafic-ultramafic intrusive phases are contemporaneous. Interfingering of pyroxenite and hornblendite was observed in one outcrop, and drill core shows minor interfingering between wehrlite and pyroxenite, as well as between wehrlite and hornblendite. Considering the well preserved primary igneous textures of the rocks, the interfingering is unlikely due to deformation. Instead, it is interpreted to be a primary magmatic feature.

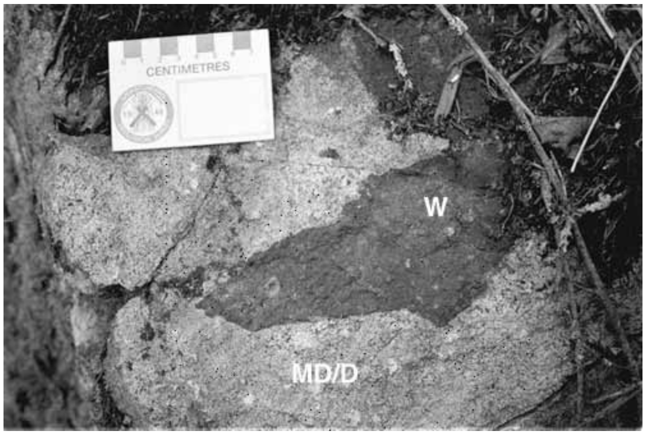

Figure 9. Wehrlite (W) inclusion hosted by monzodiorite/diorite (MD/D) plug intruding hornblendite, Samuels Lake intrusion.

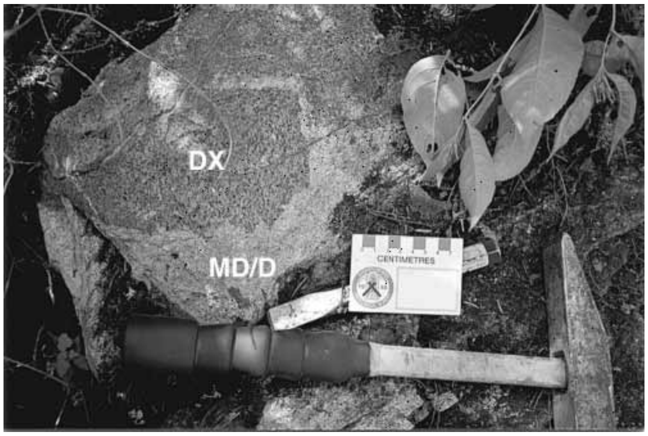

Figure 10. Exotic dioritic xenolith (DX) in monzodiorite/diorite plug (MD/D) intruding hornblendite at Samuels Lake intrusion.

Contacts between the intrusion and host metasedimentary rocks are not well exposed at surface. In drill core, contacts are also obscure due to the effects of contact metamorphism in the sedimentary rocks that resulted in increases in grain size, mainly of plagioclase, within a few centimetres of the contact. Higher proportions of biotite and pyrrhotite were also observed in the relatively narrow (1–2 m) aureole. Chill zones were not observed in outcrop or drill core, suggesting that the magmas may have intruded hot country rocks. The contact exposed at surface exhibits a slight decrease in grain size of uralized pyroxenite toward the contact. This is followed by a sharp contact with a hornblende gabbro phase exhibiting a sharp irregular contact with contact-metamorphosed sedimentary rocks (Fig. 11).

Subsurface structure is currently poorly constrained; however, drill intersections support the weak concentric zoning observed at surface. Drill core also indicates small- to moderate-scale shearing and faulting. It is currently interpreted that the intrusion represents either a plug, fed by a small feeder pipe, or a pipe which fed a much larger body that has been subsequently eroded. This general model may be supported by Pirie (1978), who noted that the large southern Elbow Lake intrusion (3 x 2 km) is much less mafic that the smaller North Elbow Lake intrusion (~1.5 km diameter) and proposed that the Southern Elbow Lake intrusion represents a shallower intrusive level in which granitoid compositions have evolved through assimilation of metasedimentary rocks.

Sulphide and PGE mineralization

Sulphide minerals occur throughout the Samuels Lake intrusion. They consist primarily of pyrrhotite, chalcopyrite, and pyrite with minor pentlandite. With the exception of pyrite,

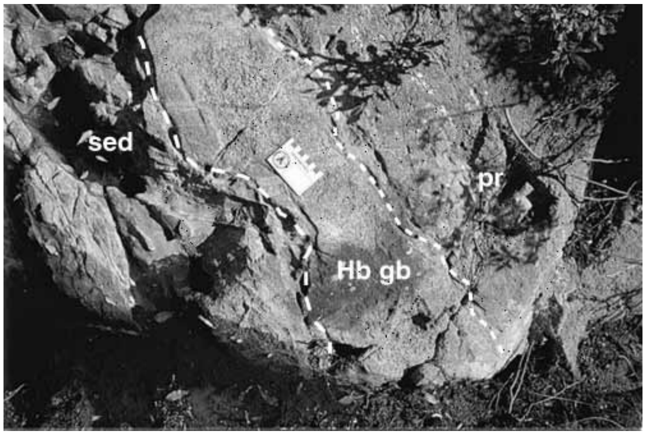

Figure 11. Sole surface exposure of the contact between the Samuels Lake intrusion and host metasedimentary rocks; pr = pyroxenite, Hb gb = hornblende gabbro, sed = metasedimentary rock.

they appear primarily in disseminated and blebby forms in hand specimen, but are interstitial to the silicate minerals in thin section. Thin-section study also reveals that sulphides almost always occur together with minor magnetite. Assemblages of sulphide, oxide, and apatite locally form veinlets cutting altered silicate assemblages (Fig. 4 and 5). Where present, coarse-grained biotite appears pristine, and low-temperature minerals, such as chlorite, are minor, suggesting that the Ni-Cu sulphide mineralization took place at moderately high temperatures. Pyrite is clearly secondary, forming quartz-feldspar-calcite veins and on joint surfaces.

Sulphide minerals are most abundant in the uralized pyroxenite and wehrlite phases of the Samuels Lake intrusion. Sulphides in the uralized pyroxenite are typically less than 15 volume per cent, and disseminated. Their abundance is closely associated with the degree of silicate alteration. The uralized pyroxenite phase hosts the bulk of PGE mineralization in the Samuels Lake intrusion. Based on assays, PGE mineralization is related both to chalcopyrite content and to the degree of alteration of silicate minerals.

The wehrlite phase hosts the bulk of the sulphide mineralization, averaging 3 to 10 volume per cent, but approaching 50 volume per cent locally. Sulphide minerals in this phase occur as an interconnected matrix. Silicate minerals in the sulphide-rich portions exhibit a variable degree of rounding, suggesting corrosion by sulphide-bearing fluids. The proportion of serpentinized olivine pseudomorphs decreases and uralized clinopyroxene becomes more rounded with increasing sulphide content. Copper-nickel mineralization is relatively uniform (0.2–1 wt % Cu, 0.15–1 wt % Ni) throughout much of the wehrlite phase (Hood, unpub. company rept., 1998). PGE mineralization, however, is more variable, but reached the 1000 ppb range in the most sulphide-rich zones (~ 40 vol %). It is important to note that although PGE mineralization is related to the occurrence of chalcopyrite, high chalcopyrite contents in the wehrlite phase do not everywhere correspond to high PGE contents. In one location, a xenolith of metasedimentary rock within this phase displays chalcopyrite veinlets and hosts PGE mineralization in the 1 ppm range (Hood, pers. comm., 1999).

DISCUSSION AND SUMMARY

Preliminary observations suggest that although the Samuels Lake intrusion is proximal to the Harnett Lake, Whalen Lake, Surprise Lake, and Beaverhouse Lake alkaline intrusions, it is significantly different. Although the alkaline bodies do contain melanocratic, hornblende-rich units, they are volumetrically minor in comparison to those at Samuels Lake. Furthermore, syenitic and carbonatitic phases, such as those observed in the Beaverhouse Lake intrusion, were not observed at Samuels Lake.

The Samuels Lake intrusion is lithologically similar to the string of Quetico intrusions located along the northern boundary of the Quetico Subprovince, and probably represents one of the westernmost examples. The Quetico intrusions range in form from metre-scale dikes to elliptical stocks approximately 3 by 2 km in size. They exhibit a characteristic range of hornblende-rich rock types similar to those observed in the Samuels Lake intrusion. The smaller intrusions are composed of diorite, hornblende leucogabbro to hornblende melagabbro, and hornblendite (MacTavish, 1992; this study). The larger intrusions, such as the North Elbow Lake stock, contain a variety of rock types, including hornblende leucogabbro through hornblendite, hornblende clinopyroxenite, and hornblende wehrlite (Lassen et al., 2000). These larger intrusions also display some rudimentary zoning, similar to that observed in the Samuels Lake intrusion, consisting of a hornblende wehrlite or hornblende clinopyroxenite core surrounded by gradational, commonly discontinuous envelopes of clinopyroxene hornblendite, hornblendite, hornblende gabbro, and rare diorite (MacTavish, 1992). All bodies contain uralized clinopyroxene and serpentinized olivine resulting from late magmatic, and/or regional metamorphic alteration. They also display a characteristic, minor, pegmatitic, plagioclase-rich unit that contains plagioclase-cored euhedral hornblende. MacTavish (1992) compared this rock type to the appinite suite of the Caledonian orogen in Ireland and Britain.

The Samuels Lake intrusion contains significant sulphide mineralization, particularly in the wehrlite unit. Possible sources for the sulphur include 1) assimilated sedimentary rocks; 2) hydrothermally transported late magmatic sulphur; and 3) immiscibly separated magmatic sulphide from the silicate melt. If sulphur was assimilated from the host rocks, it must have been from sulphide-rich units, because the low silica contents of the ultramafic intrusive rock types preclude assimilation of significant volumes of sediment.

Extensive alteration in the clinopyroxenite unit suggests hydrothermal activity, but the occurrences of veining and brittle fracture-filling textures are very limited and sulphide-rich portions do not extend beyond the walls of the intrusion. In addition, corroded, but unaltered, clinopyroxene grains in sulphide-rich wehrlite suggest the crystallization of most sulphide minerals at magmatic temperatures. We therefore suggest that most of the sulphur was a component of the intrusion's parental magmas.

PGE mineralization is not related to high concentrations of Ni-Cu-Fe sulphides at Samuels Lake, as noted previously. This style of PGE mineralization is similar to that in the Quetico intrusions, being mostly associated with small irregular zones of finely disseminated, blebby, Cu-Ni sulphides. These zones commonly contain from 1 to 30 volume per cent sulphides (average 4–5 vol%), consisting of chalcopyrite, pyrrhotite, pentlandite, magnetite, and minor pyrite. Platinum-group minerals in the Quetico intrusions commonly occur in contact with, or in close association with, chalcopyrite, pyrrhotite, or pentlandite, with lesser amounts within, or interstitial to, silicates (MacTavish, 1992). These high-PGE zones are most commonly associated with mineral alteration zones, mainly uralized clinopyroxene, and secondary actinolite, biotite, calcite, and remobilized sulphide minerals, similar to the observed relationships in the Samuels Lake intrusion. The alteration was most likely caused by late magmatic hydrothermal fluids, and may be partly controlling the PGE distribution within the sulphide-rich zones. This style of mineralization is similar to the Roby zone of the Lac des Iles mafic-ultramafic complex, in which the bulk of the PGE mineralization is hosted within a pyroxene cumulate with associated chalcopyrite, pyrrhotite, pentlandite, pyrite, and altered silicate minerals (Sutcliffe et al., 1988).

The mafic-ultramafic intrusions, including the Samuels Lake intrusion, occur within an east-northeast-trending array that is oblique to the east-trending boundary between the Quetico and Wabigoon subprovinces. Common uralized clinopyroxenite, wehrlite, and similar sulphide- and PGE-mineralization styles support the association of these intrusions. Wehrlite is a very minor component of most Quetico intrusions, but is significant volumetrically in the Lac des Iles complex (Sutcliffe et al., 1988). Assuming that these bodies are of similar age, the array of intrusions that crosses the subprovince boundary suggests that the Quetico and Wabigoon subprovinces were in their current relative positions by the time of emplacement of the intrusions (2688 ± 4 Ma).

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