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Late Archean alkaline magmatism in the western Quetico belt, Superior Province, Ontario¹

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Abstract: The Quetico alkaline province of the western Quetico metasedimentary belt comprises at least 20 small intrusions with distinct alkaline affinity that were emplaced during a short period of time in the late Archean. Bulk compositions vary from ultramafic, through mafic, intermediate and felsic rocks, which display mutual intrusive relationships. Carbonatite dykes form a minor component of the intrusions. The alkaline affinity of the magma(s) parental to the intrusive bodies is suggested by the presence of phlogopitic biotite inclusions in high Na₂O augite, together with the occurrence of secondary, blue-alkali amphibole along fractures, and evidence for early crystallization of apatite.

Résumé : La province alcaline de Quetico, dans la partie occidentale de la ceinture métasédimentaire de Quetico, contient au moins 20 petites intrusions d'affinité nettement alcaline, qui ont été mises en place en un court intervalle pendant l'Archéen tardif. Les roches se recoupent et leurs compositions générales sont ultramafiques, mafiques, intermédiaires et felsiques. Des dykes de carbonatite forment une composante mineure des intrusions. Le (les) magma(s) parentaux des corps intrusifs auraient eu une affinité alcaline, comme le suggèrent la présence d'inclusions de biotite phlogopitique dans l'augite riche en Na₂O, la présence d'amphiboles alcalines bleues secondaires le long de fractures, et des indices d'une cristallisation précoce de l'apatite.

¹ Contribution to the Western Superior NATMAP Project

INTRODUCTION

Application of current plate-tectonic models to rocks of early Precambrian age, and particularly the Archean, has become widespread. However, it is still unresolved whether Archean processes are comparable to (e.g. de Wit, 1998), or significantly different from (e.g. Hamilton, 1998) those observed today. In detail, very little is known about how plate tectonics operated in the early Earth, or its relationship to magma genesis. Additional insight into the Archean thermal and tectonic regime may be offered by studying the late Archean Quetico alkaline province, a suite of carbonate-bearing magmatic complexes associated with a recently discovered carbonatite body. Study of the Quetico intrusions may contribute important information on the nature of magmatic processes at ca. 2.7 Ga, and by inference, shed light on the tectonic regime operative late in the history of the Superior Province.

A number of intrusions from the study area have been described by MacTavish (1992). Rocks of mafic-ultramafic composition with alkaline affinities have been the target of exploration for copper, nickel, and platinum-group elements for several decades (Watkinson and Irvine, 1964; Blackburn et al., 1989; Pettigrew et al., 2000). The intrusions investigated in this project are located within a few tens of kilometres of the well studied, highly silica-undersaturated Poohbah complex (Mitchell and Platt, 1979; MacTavish, 1992), and may be petrogenetically related to this intrusion. The Poohbah complex is characterized by the presence of

melanite garnet and abundant nepheline in mafic units (malignite), but primary calcite has not been reported. This preliminary report attempts to give a broad overview of the character of several bodies examined in the Quetico alkaline province in the summer of 1999.

GENERAL GEOLOGY

The study area is located within the western Quetico metasedimentary belt (Fig. 1) and is underlain mainly by metagreywacke and derived migmatitic and granitic rocks (Percival, 1989). To the north and south, it is bounded by the Wabigoon and the Wawa greenstone belts, respectively. Small intrusions with alkaline affinity, representing about 5% of the area, were emplaced at ca. 2680 Ma, during regional deformation (Hattori and Percival, 1999a; Fig. 1). They represent the dominant intrusive type along the northern margin of the Quetico belt to the south, southeast, and southwest of Atikokan (Fig. 1). Bodies of alkaline rock are cut by dykes of peraluminous granite, dated elsewhere in the range 2.67 to 2.65 Ga (Percival and Sullivan, 1988). Some intrusions have characteristic oval shapes with the long axis parallel to the east-northeast regional trend of steeply dipping bedding and foliation, and some bodies have tectonically foliated margins. Exceptions to this pattern are the easternmost intrusions (North and South Elbow Lake intrusions), which are more equant in form.

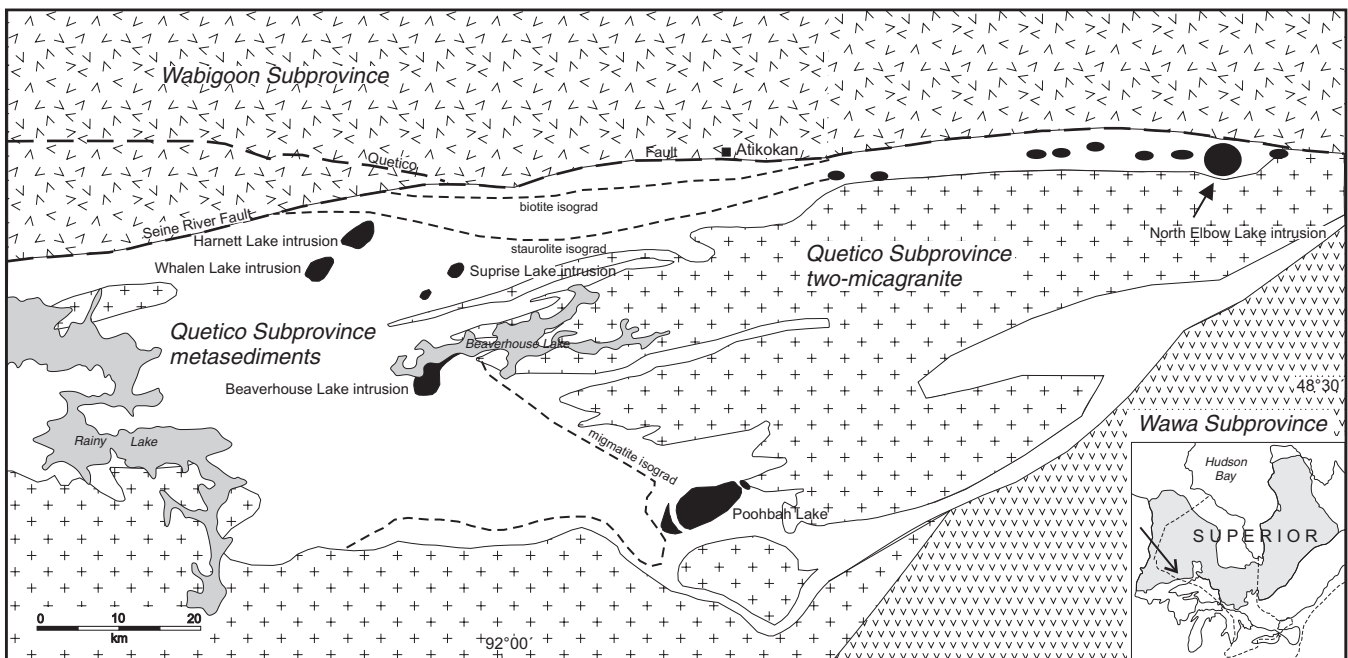


Figure 1. Location of the studied intrusions in the western Quetico Subprovince.

CHEMICAL COMPOSITIONS

The intrusions span a broad compositional spectrum from mafic and ultramafic, such as the North Elbow Lake intrusion (MacTavish, 1992), to intermediate and felsic, such as the Harnett Lake intrusion (Hattori and Percival, 1999a). In addition, carbonatite was discovered associated with the Beaverhouse intrusion during the 1999 field season. The intrusions were initially located on the basis of their strong positive aeromagnetic anomalies (Pye and Fenwick, 1984). The alkaline nature of the ultramafic and mafic compositions may be predicted from the occurrence of phlogopitic biotite as inclusions in sodium-rich (4–6 wt % Na²O) aegirine augite from the Whalen Lake and Beaverhouse Lake intrusions (Hattori and Percival, 1999a) (Fig. 2). In addition, there is petrographic evidence for early crystallization of apatite with high contents of rare-earth elements (REE) and strontium, together with the occurrence of nepheline (Fig. 3). However, the absence of associated alkaline volcanic rocks, which more closely indicate original bulk composition, together

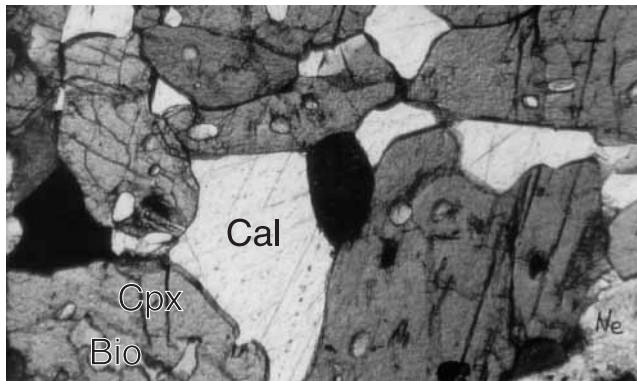


Figure 2. Photomicrograph of phlogopitic biotite (Bio) inclusion in aegirine augite (Cpx) in association with calcite (Cal), Beaverhouse Lake intrusion. Field of view is 1.7 mm.

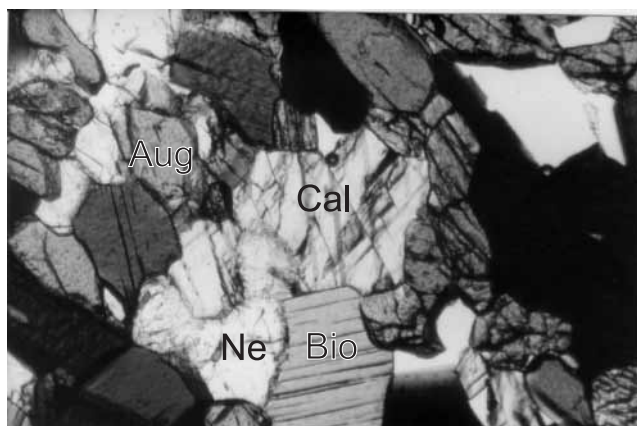


Figure 3. Photomicrograph of nepheline (Ne) in association with augite (Aug), biotite (Bio), and calcite (Cal) from the Beaverhouse Lake intrusion. Field of view is 1.7 mm.

with evidence for cumulate processes in some of the mafic complexes, call into question the assumption of an alkaline parental magma. Further work is needed to establish whether these rocks in fact are derived from alkaline magma(s), or whether they represent cumulates that originated from a hydrous tholeiitic or calc-alkaline magma that crystallized abundant hornblende.

The felsic intrusive rocks consist of varying amounts of perthite, biotite, and hornblende. Titanite is an important accessory phase, forming up to 1–3% of the rocks. Other accessory phases include calcite, epidote, magnetite, and apatite. The ultramafic to mafic intrusive complexes consist mainly of hornblende pyroxenite, hornblendite, wehrlite, diorite, gabbro, and minor pyroxenite. Some intrusions show a bimodal distribution of rock types, with both mafic- ultramafic units and felsic units dominated by hornblende and alkali feldspar, respectively. For instance, in the Whalen Lake body, mutually intrusive relationships and mingling between mafic and felsic rock types suggest that these units are contemporaneous. These relationships suggest that the mafic and felsic compositions are petrogenetically related.

FIELD CHARACTERISTICS

North Elbow Lake intrusion

The North Elbow Lake body is the most silica-undersaturated of the studied intrusions, with compositions ranging from mafic to ultramafic (Fig. 4, 5). Hornblende is the dominant mineral throughout the intrusion, and some units consist entirely of hornblende. Diorite and gabbro are abundant locally. Xenoliths of sedimentary rock in various stages of assimilation are abundant in some parts of the body, but are not common in general. A coarse zonation is apparent, from hornblende clinopyroxenite, locally with plagioclase phenocrysts, in the interior, to an outer mantle dominated by gabbro and hornblende diorite.

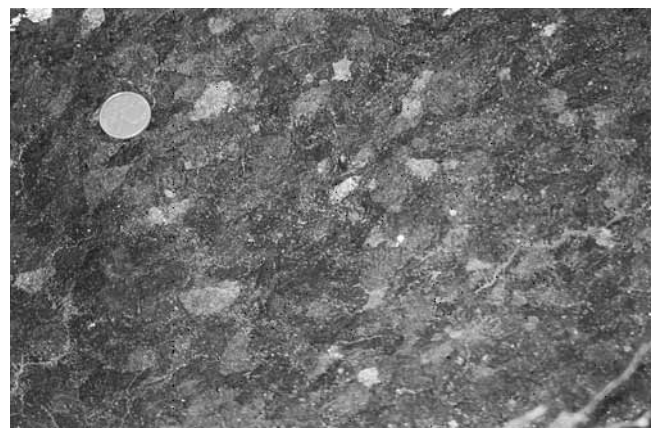


Figure 4. Ultramafic unit from the North Elbow Lake intrusion.

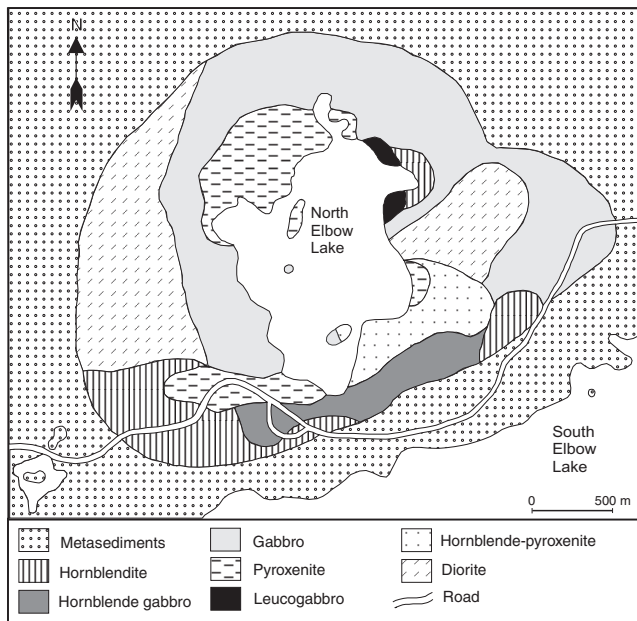


Figure 5. Sketch map of the North Elbow Lake intrusion.

Whalen Lake intrusion

Limited exposure and complex crosscutting relationships hamper lithological mapping and interpretation in the Whalen Lake intrusion. At least two lithological units are present: 1) gabbro, dominated by biotite-bearing hornblende-rich rocks; and 2) syenite, consisting mainly of alkali feldspar and lesser amounts of clinopyroxene, hornblende, calcite, titanite, and secondary epidote. In places, mutual dyking relationships between these two rock types provide evidence of magma mingling, and magmatic layering is locally recognizable. Abundant xenoliths of sedimentary rock in various stages of assimilation are characteristic of this body (Fig. 6). These show preferred orientations and commonly display convoluted contacts with the host rock, suggesting interaction between the outer parts of the xenoliths



Figure 6. Abundant sedimentary xenoliths in the Whalen Lake intrusion.

and the magma. This interpretation is supported by the observation that in rare locations, hybrid zones are developed between the xenoliths and intrusive material.

Harnett Lake intrusion

This intrusion is dominated by intermediate to felsic rock types (Fig. 7) and consists mainly of syenite composed of abundant alkali feldspar and lesser amounts of hornblende, biotite, and some clinopyroxene. Accessory phases include titanite, calcite, and epidote. Minor melasyenite consists predominantly of hornblende. Within the leucocratic units, two magmatic phases are easily distinguished: an older grey dioritic composition and a younger pink syenitic phase. Locally, the two rock types exhibit cusped-lobate mutual contacts, a feature characteristic of magma mixing between coexisting liquids.

Beaverhouse Lake intrusion

The Beaverhouse Lake body is composed dominantly of syenite made up of varying amounts of alkali feldspar, clinopyroxene, hornblende, biotite, nepheline, calcite, and apatite. It is the only strongly silica-undersaturated composition of the intrusions studied to date, with abundant nepheline and a variety of carbonatitic rock types, one of which consists chiefly of calcite. Well developed flow patterns for alkali feldspar phenocrysts suggest that the syenitic magma was emplaced as a crystal-rich mush. In places, decimetre-scale magmatic layering is evident. The syenitic body is cut by an apatite-bearing, carbonate-rich dyke. Only one contact of the greater than 4 m wide dyke is exposed. The contact between

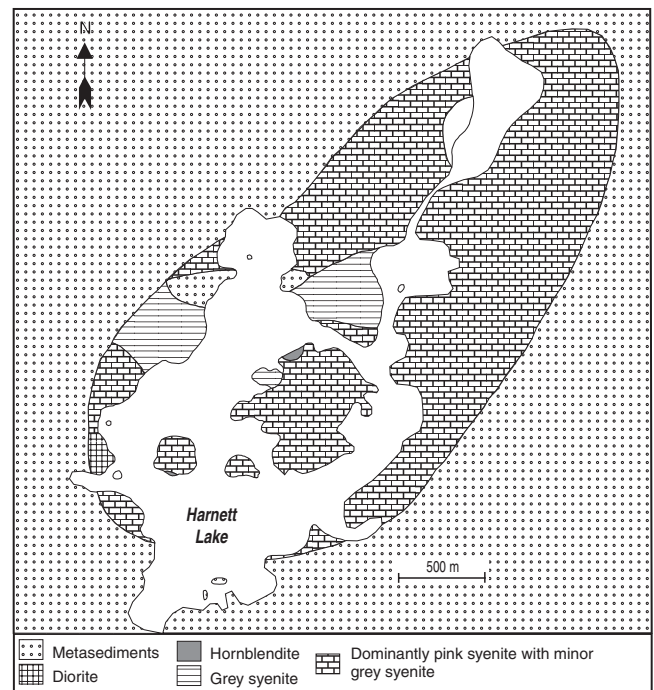


Figure 7. Sketch map of the Harnett Lake intrusion.



Figure 8. Undulating contact between syenite (Sy) and carbonatite (Cb), Beaverhouse Lake intrusion.

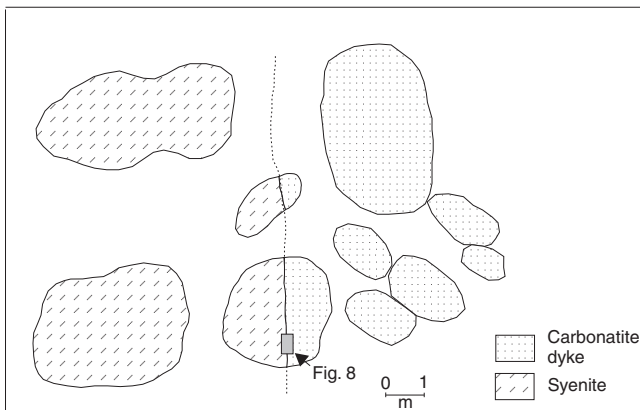


Figure 9. Sketch of carbonatite dyke locality in the Beaverhouse Lake intrusion. Box shows location of contact shown in Figure 8.

the dyke and host syenite is highly irregular and wavy on a decimetre scale (Fig. 8, 9), suggesting ductile conditions during the time of dyke emplacement. A second major carbonate-rich unit consists of approximately 50% biotite and 50% calcite. This body is at least 25 m long and 15 m wide. It is intruded by a 30 cm wide dyke of almost pure calcite, with accessory clinopyroxene.

DISCUSSION

Alkaline intrusions emplaced at ca. 2680 Ma are abundant in the Superior Province (Corfu et al., 1989; Hattori and Percival, 1999a). No alkaline rocks older than 2700 Ma have been reported on Earth, and many researchers have speculated as to whether the paucity of alkaline rocks reflects a different tectonic regime in the Archean than that of today (e.g. Fyfe, 1974; Bickle, 1978; Arndt, 1983; Sleep, 1992). In particular, higher mantle temperatures could have hampered formation of small degrees of melt in relatively large volumes of the mantle, required to produce magmas of alkaline

composition (e.g. Blichert-Toft et al., 1996). The intrusions in this study are the most silica undersaturated bodies documented to date in the Superior Province. They are likely to be close in composition to original mantle-derived melts and are good candidates for studying processes that operated in the late Archean mantle in this region.

Archean carbonatitic complexes are sparse in the geological record, with only around a dozen locations known worldwide (Woolley, 1989; Tilton and Bell 1994, Hattori and Percival, 1999a; this study). In addition, the origin of igneous carbonatite is generally not well understood, even in modern settings. Field relations and mineral assemblages demonstrate that the carbonatite units observed in the Beaverhouse Lake intrusion are of igneous origin (cf. Hattori and Percival, 1999a). The contacts are intrusive, and the high volume of carbonate, together with the presence of minerals like aegirine augite, phlogopitic biotite, and high-REE apatite from associated lithological units, indicate that they do not represent late calcite veins. Similar conclusions were reached on the basis of strontium, carbon, and oxygen isotopic compositions of calcite (Hattori and Percival, 1999b). Carbonatite intrusions are commonly emplaced during extensional periods within stable cratons. The carbonatites of the western Quetico Subprovince differ in having been emplaced in an environment of active compression and metamorphism during cratonization of the Superior Province (Hattori and Percival, 1999a). If the carbonatite at Beaverhouse Lake is coeval with the ca. 2.68 Ga alkaline suite, it is the oldest yet reported from the Superior Province. Isotopic studies (cf. Hattori and Percival, 1999a) suggest contributions by an asthenospheric component to some of the alkaline igneous rocks. Conversely, Proterozoic and Phanerozoic carbonatite intrusions in the Superior Province are considered to have originated from the subcontinental lithospheric mantle (e.g. Bell and Blenkinsop, 1987).

Further work will establish age and geochemical relationships to magma types of adjacent areas and examine from what chemical reservoirs the alkaline units originated.

SUMMARY

The Quetico alkaline province consists of a number of intrusive bodies spanning a compositional spectrum from ultramafic to syenitic, which are locally associated with carbonatite. Some intrusions show complex mutual intrusive relationships between mafic and felsic units, taken as evidence of magma mingling and possible cogenetic origin. Field relations in the Beaverhouse Lake intrusion suggest emplacement of carbonatite dykes during crystallization of the host syenite.

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