ENRICHED MANTLE COMPONENT(S) IN PROTEROZOIC CONTINENTAL FLOOD BASALTS OF THE CAPE SMITH FOLDBELT, NORTHERN QUÉBEC

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ABSTRACT

The Cape Smith foldbelt is one of Earth's best exposed Proterozoic mobile belts and provides a natural laboratory for the study of Proterozoic mafic magmatism. Magmatism associated with circa 2.04 Ga rifting of the Superior Province resulted in the formation of tholeiitic and alkaline basalts as well as minor rhyolites, collectively known as the Povungnituk Group. Despite their continental setting, the tholeiites are not typical continental-flood basalts in that they lack significant negative Nb and Ta anomalies relative to light rare earth elements and primitive mantle, thus indicating that crustal contamination did not play a major role in their evolution. Although crystal fractionation along a gabbroic cotectic can account for much of the variation in trace-element concentrations, this process cannot explain the wide range of observed incompatible trace-element ratios within the Povungnituk Group. Variations of La/Sm and Nb/Zr reveal the presence of a highly enriched component in many of the lavas and that mixing between this enriched component and a relatively depleted end member can account for the range of trace element ratios observed in the Povungnituk Group, and may also be responsible for enriched tholeiites found in other parts of the eastern Trans-Hudson orogen, such as the Flaherty Formation of the Belcher Islands. The most enriched tholeiites are spatially associated with an alkaline suite, but moderately enriched tholeiites are widespread in the Povungnituk Group. It appears that the Paleoproterozoic mantle source for the Povungnituk Group lavas contained a dispersed enriched component that was responsible for the generation of tholeiitic basalts enriched in incompatible trace-elements. Despite their continental setting, the Povungnituk Group lavas exhibit a range of incompatible trace-element contents similar to that from tholeiitic

to highly alkaline lavas in modern ocean-island-basalt suites, such as Hawaii, the dominant relatively depleted lavas of the Povungnituk Group are most similar to the basalts of oceanic-plateau suites, and the upper lava flows of some continental flood-basalt suites.

SOMMAIRE

La ceinture plissée de Cape Smith est l'une des ceintures mobiles d'âge Protérozoïque les mieux exposées sur Terre, et elle constitue un laboratoire naturel pour l'étude du magmatisme mafique Protérozoïque. Des basaltes tholéiitiques et alcalins, ainsi que des volumes mineurs de rhyolites composant le Goupe de Povungnituk, se sont formés lors d'une période de magmatisme associée à une phase de rifting de la Province du Supérieur datée autour de 2.04 Ga. Malgré leur positionnement sur un socle continental, les tholéiites ne représentent pas des basaltes de plateaux typiques en ce qu'ils ne montrent pas d'anomalies négatives significatives en Nb et Ta relativement aux terres rares légères et à la composition du manteau primitif. Ceci indique qu'une contamination par la croûte continentale n'a pas joué un rôle majeur durant leur évolution. Bien que le fractionnement de cristaux suive une ligne cotectique gabbroique pouvant rendre compte d'une grande partie de la variation des concentrations en éléments en traces, ce processus ne peut pas expliquer les écarts dans les rapports entre les éléments en traces incompatibles observés dans le Groupe de Povungnituk. Les variations des rapports La/Sm et Nb/Zr révèlent la présence d'une composante fortement enrichie dans plusieurs des laves, et indiquent qu'un mélange entre cette composante enrichie et une composante relativement appauvrie pourrait expliquer les variations de ces rapports dans le Groupe de Povungnituk. Ce mélange pourrait aussi être responsable de l'enrichissement des tholéiites présentes dans d'autres secteurs de la partie Est de l'orogène Trans-Hudsonienne, tel que dans la Formation de Flaherty sur les Îles Belcher. Les tholéiites les plus enrichies sont associées spacialement à une suite alcaline, alors que d'autres modérément enrichies sont répandues dans le Groupe de Povungnituk. Il semble

que la source mantélique Paléoprotérozoïque des laves du Groupe de Povungnituk contenait une composante enrichie dispersée, responsable de la génération des basaltes tholéiitiques enrichis en éléments en traces incompatibles. Bien qu'elles se présentent sur un socle continental, les laves du Groupe de Povungnituk montrent des concentrations en éléments en traces incompatibles similaires à celles des laves tholéiitiques à fortement alcalines des suites basaltiques des îles océaniques modernes, telles qu'à Hawaii. Les laves du Groupe de Povungnituk sont représentées principalement par des laves relativement appauvries qui s'apparentent aux basaltes de plateaux océaniques et aux laves de la partie supérieure de certaines suites de basaltes de plateaux sur les continents.

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PREFACE

This thesis consists of a study of the extrusive igneous rocks exposed within the Povungnituk Group of the Cape Smith foldbelt in northern Quebec. The author's observations and findings are reported in a manuscript entitled " Enriched mantle component(s) in Proterozoic continental flood basalts of the Cape Smith foldbelt, northern Quebec", that will be submitted to the ***Journal of Petrology***. The regional scope of this study provides strict constraints of the magmatic processes that have played a role in the petrogenesis of a Proterozoic flood-basalt province. In addition to the manuscript, this dissertation contains an expanded introduction and appendices containing a complete data set. The results and conclusions of this study are based on 225 samples, half of the samples were collected by Don Francis and Andrew Hynes during previous studies and from the summer field season of 1998. The other half of the samples were obtained from the Ministere de l'Energie et des Resources du Quebec (MERQ, collected from 1983-1988 field seasons). All of the samples were analyzed for major and trace element chemistry by T. Ahemdali at McGill University using XRF. Of these, 31 samples were analyzed for rare earth elements (REE) using an inductive coupled mass spectrometer at Actllabs in Ancaster, Ontario. The author is responsible for the numerical modelling calculations and the interpretation of the geochemical data.

INTRODUCTION

Although basalt is one of the most common rock types, found in all tectonic environments on Earth, the origin and evolution of large basaltic suites remains a controversial issue. Large volumes of magma are generally associated with hot spot traces, which suggest the presence of a mantle plume. Ascending plumes are thought to originate from the core-mantle boundary or from the 670 km seismic discontinuity (boundary between the upper and lower mantle) and spread laterally upon impingement on the lithosphere-asthenosphere and/or the crust-mantle boundaries. These ascending plumes may are thought to generate enormous pools of magma and are assumed to be the source for large igneous provinces (LIP), such as continental flood-basalts, accumulations of basalt at rifted continental margins and oceanic plateaus. Significant controversy remains, however, regarding the nature of the parental magmas and the contribution of the lithospheric mantle to the magmatism associated with LIP. Some petrologists argue that mantle plumes are not necessary for LIP; instead the melting of wet lithospheric mantle during lithospheric rifting has been proposed (e.g., Anderson, 1994). The large degrees of partial melting required for basaltic provinces are thought to be facilitated by high concentrations of volatiles in the shallow mantle, which reduce the temperature of the solidus of the upwelling mantle (Sheth, 1999). If mantle plumes are ultimately the source for ocean-island basalts (OIB) and continental flood-basalts (CFB), then the primary basalts from these settings should have similar geochemical characteristics. Many CFB provinces, however, have major, trace element and radiogenic isotope concentrations that differ from those of OIB. Arndt et al. (1992) have attributed some of these geochemical differences to the effects of crustal contamination, while others have argued that CFB acquire their geochemical signature from metasomatized lithospheric mantle (Gallagher and Hawkesworth, 1992). Recent melting experiments suggest that tholeiitic basalts from OIB and CFB as well as alkaline basalts can be produced by melting of heterogeneous plumes with a basaltic component (Kogiso et al., 1998). The controversy illustrates the state of understanding about the source regions of CFB and other large igneous provinces.

CFB are dominated by relatively evolved tholeiitic basalts to andesites (<9 wt% MgO), but commonly also contain lesser volumes of picritic basalts (>12 wt% MgO), alkaline basalts, and rhyolites (Cox, 1980). The ubiquitous tholeiitic basalts commonly display relatively restricted major-element compositions constrained by the gabbroic cotectic, but have variably enriched incompatible trace-elements (Cox, 1983). Continental flood-basalts usually have fractionated rare-earth-element (REE) profiles and anomalously low Nb concentrations relative to large ion lithophile elements (LILE) and light REE when normalized to primitive mantle compositions (e.g., Cox and Hawkesworth, 1985). Several hypotheses have been proposed to account for this distinctive geochemical signature, including mixing between depleted and enriched mantle sources (Campbell and Griffiths, 1990), crustal contamination (Ellam and Cox, 1989), and combinations of enriched mantle components and crustal contamination (Arndt and Christensen, 1992).

The generally low magnesium number (MgO/(MgO + FeO)) and low Ni and Cr concentrations of CFB compared with compositions of mantle peridotites and picritic lavas indicate that the ubiquitous tholeiitic basalts of CFB cannot be in equilibrium with assumed mantle source compositions (Fo_{90}-Fo_{92}). Thus most continental tholeiites appear to represent differentiated melts of more primitive parental magmas. Some petrologists, however, have proposed that the tholeiitic lavas of CFB could represent primary melts derived by partial melting of iron-rich mantle sources (Wilkinson and Binns, 1977). Recent experiments have suggested that CFB are direct melts of recycled oceanic crust impregnating mantle-source regions (Takahashi et al., 1998), which eliminates the need for cumulates and picritic parental magmas.

PROBLEM ADDRESSED

Detailed stratigraphic studies of CFB provinces have revealed intriguing geochemical patterns. The lower sequence of the Siberian Traps, for example, comprises basalts, picrites and alkali volcanics with high concentrations of Ti, whereas the upper sequence consists of low to intermediate-Ti basalts (Lightfoot et al., 1990). Similarly, the basal Coppermine River basalts display strong trace-element enrichment relative to the upper flows (Griselin et al., 1997). These studies suggest that there is commonly a decrease in trace-element enrichment with stratigraphic height. The trace element signatures observed in the lower lavas of CFB are often attributed to crustal contamination of mantle-derived liquids undergoing low-pressure crystal fractionation in the crust (e.g., Fram and Lesher, 1996). This process has been modeled successfully to explain the enrichment of LREE, negative Nb anomaly, low ε_{Nd}, and high ε_{Sr} of the Columbia River Basalts (Carlson, 1984) and the Coppermine River basalts (Griselin et al., 1997). When crustal contamination is absent the concentrations and relative abundances of trace elements in magmas reflect the compositions of the mantle source region and the conditions under which melting occur (Pearce and Norry, 1979). At high pressures melts are highly magnesian, but the degree of partial melting is low and thus the concentrations of incompatible trace-elements are high (Cox, 1980). As the pressure decreases, the degree of partial melting increases and the concentrations of highly to moderately incompatible trace-elements decrease (Cox, 1980). Thus, the variable incompatible-trace-element concentrations found in many CFB may be due in part to the mixing of melts produced under different physical conditions and/or derived from distinct mantle-source regions.

In this study, the implications of stratigraphic and regional variations in major and trace elements of Proterozoic continental basalts (Povungnituk Group) exposed within the Cape Smith foldbelt of northern Québec are investigated in order to constrain the magmatic process(es?) that have played a role in their petrogenesis. In addition, a previous study (Legault, 1994) has suggested that there is a petrogenetic link between continental flood-basalts exposed on the Belcher Islands (eastern Trans-Hudson orogen) and the continental flood-basalts of the Povungnituk Group. This study will help determine the nature of the petrogenetic link between the Belcher Islands and the Povungnituk Group by employing a regional lithochemical-sampling program to map the distribution of trace elements across the entire Povungnituk Group and by comparing our results with those obtained from the Belcher Islands (Legault, 1992). Thus the results from this study will not only provide constraints on the magmatic processes responsible for the origin and evolution of the mafic volcanics of the Paleoproterozoic Povungnituk Group, but will also provide a basis for reassessing the correlations with other parts of the Trans-Hudson Orogen.

GEOLOGICAL SETTING AND PREVIOUS WORK

The Cape Smith foldbelt is a fold and thrust belt located on the Ungava Peninsula of northern Québec. It is comprised of rocks formed during Paleoproterozoic continental rifting of the Superior Province and represents an allochthonous segment of the Trans-Hudson Orogen (St-Onge et al., 1992). The orogen is interpreted as an arc-continent collisional belt that comprises autochthonous, parautochthonous, and allochthonous tectonostratigraphic units structurally overlying the Superior and Churchill Provinces (Lucas et al., 1992; St-Onge and Lucas, 1993). This south-verging thrust belt contains tectonostratigraphic assemblages that record more than 200 m.y. of plate divergence and convergence (St-Onge and Lucas, 1993). Rifting of the 2.7-2.9 Ga Superior Province basement at ~2.04 Ga (Machado et al., 1991) resulted in the development of a volcanic rifted margin (Povungnituk Group) and a subsequent oceanic basin (Chukotat Group). Taken together, the Povungnituk and the Chukotat Groups comprise a voluminous pile of clastic sediments and mafic volcanics that record the progressive evolution of magmas during a Proterozoic rifting event (Francis et al., 1983).

The first work in the Cape Smith foldbelt was done by the Québec Department of Natural Resources (Bergeron, 1957b; Bergeron, 1959; DeMontigny, 1959; Beall, 1959; Beall, 1960; Gelinas, 1962, and Schimann, 1978a) and supplemented by reconnaissance mapping by the Geological Survey of Canada (Taylor, 1974). More recently there have been detailed studies of the regional volcanic chemistry and structure of the Cape Smith foldbelt (Baragar, 1974; Miller, 1977; Schwarz and Fujiwara, 1977; Hynes and Francis, 1982; Francis et al., 1983, and Picard et al., 1990) and the entire foldbelt has been mapped at a scale of 1:50 000 by the Geological Survey of Canada (St-Onge et al., 1993) and by the Ministère de l'Énergie et des Réssources du Québec (MERQ) (Lamothe, 1986).

The geochemical data for the mafic volcanics of the Povungnituk Group prior to this study indicated that they were relatively evolved (MgO <9 wt%) tholeiitic basalts with high Fe, Ti and LREE contents (Francis et al., 1983; Picard et al., 1990). In addition to the tholeiites, highly alkaline lavas including basanite and nephelinites have also been documented in the Povungnituk Group (Picard et al., 1990). These alkaline lavas have highly enriched trace-element contents and isotopic values, which suggest an enriched mantle source region (Gaonac'h, 1992). Isotopic values for a small number of tholeiitic basalts of the Povungnituk Group (ε_{Nd} values from +2 to +3) are similar to those of the alkaline lavas, leading some authors to suggest a similar mantle source region for these two lava types (Hegner and Bevier, 1991). The results of this study, however, indicate that the trace-element characteristics of the Povungnituk Group basalts reflect mixing between two distinct sources, one relatively trace-element depleted end member and a relatively trace-element enriched end member.

Enriched mantle component(s) in Proterozoic continental flood-basalts of the Cape Smith foldbelt, northern Québec

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ABSTRACT

The Cape Smith foldbelt is one of Earth's best exposed Proterozoic mobile belts and provides a natural laboratory for the study of Proterozoic mafic magmatism. Magmatism associated with circa 2.04 Ga rifting of the Superior Province resulted in the formation of tholeiitic and alkaline basalts as well as minor rhyolites, collectively known as the Povungnituk Group. Despite their continental setting, the tholeiites are not typical continental-flood basalts in that they lack significant negative Nb and Ta anomalies relative to light rare earth elements and primitive mantle, thus indicating that crustal contamination did not play a major role in their evolution. Although crystal fractionation along a gabbroic cotectic can account for much of the variation in trace-element concentrations, this process cannot explain the wide range of observed incompatible trace-element ratios within the Povungnituk Group. Variations of La/Sm and Nb/Zr reveal the presence of a highly enriched component in many of the lavas and that mixing between this enriched component and a relatively depleted end member can account for the range of trace element ratios observed in the Povungnituk Group, and may also be responsible for enriched tholeiites found in other parts of the eastern Trans-Hudson orogen, such as the Flaherty Formation of the Belcher Islands. The most enriched tholeiites are spatially associated with an alkaline suite, but moderately enriched tholeiites are widespread in the Povungnituk Group. It appears that the Paleoproterozoic mantle source for the Povungnituk Group lavas contained a dispersed enriched component that was responsible for the generation of tholeiitic basalts enriched in incompatible trace-elements. Despite their continental setting, the Povungnituk Group lavas exhibit a range of incompatible trace-element contents similar to that from tholeiitic

to highly alkaline lavas in modern ocean-island-basalt suites, such as Hawaii, the dominant relatively depleted lavas of the Povungnituk Group are most similar to the basalts of oceanic-plateau suites, and the upper lava flows of some continental flood-basalt suites.

INTRODUCTION

Continental flood-basalt provinces (CFB) comprise vast thicknesses of laterally extensive basaltic lavas that cover large continental areas within a relatively short time period. Despite their volumetric significance, however, the nature of the source regions and the processes that form these basalts are not well understood. CFB are dominated by relatively evolved tholeiitic basalts and andesites (<9 wt% MgO), but they may also contain minor volumes of rhyolites, alkaline basalts, and high-Mg basalts (i.e., picrites, >12 wt% MgO). Although the ubiquitous tholeiitic basalts of CFB display a relatively restricted major element composition and mineralogy, similar to that of evolved mid-ocean-ridge basalts (MORB), their trace element characteristics are quite variable and are typically distinct from those of MORB. Detailed chemical studies of CFB (e.g., Cox and Hawkesworth, 1985) have shown that their lavas are typically enriched in light rare earth elements (LREE, e.g., La, Ce), large ion lithophile elements (LILE, e.g., Rb, K), and radiogenic isotopes (e.g., ^{87}Sr, ^{143}Nd), but have relatively low concentrations of high field strength elements (HFSE, e.g., Nb, Zr) with respect to LILE and LREE when normalized to primitive mantle compositions. These geochemical characteristics have been attributed to a variety of petrogenetic processes including: (a) crustal contamination

(Ellam and Cox, 1989), (b) melting of enriched subcontinental mantle (Ellam and Cox, 1991), (c) mixing between depleted and enriched mantle sources (Campbell and Griffiths, 1990), (d) combinations of melting of enriched mantle and crustal contamination (Arndt and Christenensen, 1992). The number of proposed hypotheses illustrates the considerable debate regarding the origin and evolution of CFB.

The parental magmas of CFB are believed to pool at the crust mantle boundary (Cox, 1980) and then filter through the continental crust, during which low-pressure crystal fractionation and crustal contamination may play an important role in their petrogenesis. The generally low magnesium number (MgO/(MgO+FeO)) and low Ni and Cr concentrations of CFB compared with peridotite nodules and picritic lavas indicate that CFB cannot be in equilibrium with typically assumed mantle source compositions (Fo_{90}-Fo_{92}), and therefore do not represent primary (undifferentiated) mantle melts. On the other hand, Wilkinson and Binns (1977) proposed that the tholeiitic lavas of CFB represent primary melts derived by partial melting of iron-rich mantle sources, while other melting models suggest that CFB are direct melts of a basaltic component impregnating mantle-source regions (Takahashi et al., 1998). These models do not, however, account for the picritic magmas that have been documented in many CFB provinces, where they frequently occur at or near the bases of the lava piles (e.g., Deccan, Krishnamurthy, 1977; Karoo, Bristow, 1984).

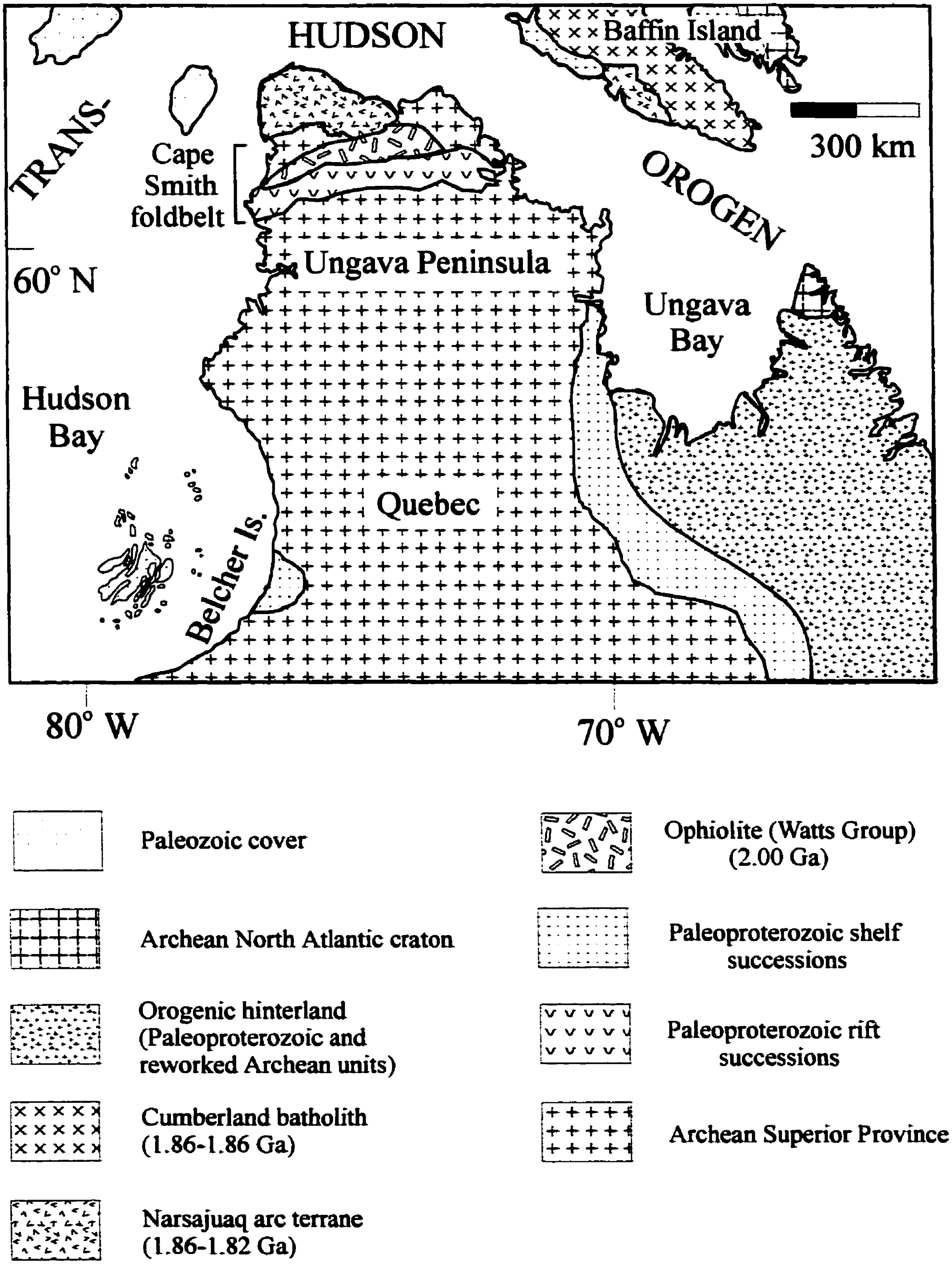
Studies of CFB have revealed intriguing geochemical patterns within their volcanic stratigraphy. The lower sequence of the Siberian Traps, for example, comprises basalts, picrites, and alkali volcanics with high concentrations of Ti, whereas the upper sequence consists of low to intermediate-Ti basalts (Lightfoot et al., 1990b). Similarly, in the northern Paraná CFB, high-Ti basalts underlie basalts with intermediate Ti contents (Mantovani et al., 1985). These studies suggest that there may be a tendency for decreasing trace-element enrichment with increasing stratigraphic height, tending toward oceanic-plateau trace-element profiles. Many CFB also display a distinct provinciality based on the trace-element concentrations. The Paraná CFB exhibits two geochemically distinct basalt types: a low TiO_2 and P_2O_5 basalt dominant in the southern portion of the province, and a high to moderate TiO_2 and P_2O_5 basalt dominant in the north (Mantovani et al., 1985). Mantovani et al. (1985) have attributed the different basalt compositions to distinct mantle-source regions. A similar provinciality has been observed in the Karoo CFB in South Africa, with basalts in the northern area being enriched in trace elements relative to those in the south (Cox et al., 1967). In general, CFB exhibit variable trace-element characteristics, particularly in terms of TiO_2 contents, which has commonly been attributed to different mantle-source compositions (e.g., Cox, 1983; Bellieni et al., 1984; Mantovani et al., 1985). On the other hand, most continental tholeiites lie on the gabbroic cotectic (olivine + clinopyroxene + plagioclase liquidus assemblage) along which major elements such as Si change relatively little during large degrees of crystallization because of the similarity of the magma and the gabbroic cumulate compositions, fractional crystallization could explain much of the wide range in TiO_2 found in many CFB. Many of the geochemical characteristics of CFB may reflect crystal fractionation and crustal contamination rather than different mantle-source regions. The concentrations of TiO_2 range from <1 wt% to >3 wt% in some provinces, which would require extensive crystallization (~75%, assuming Ti is a perfectly incompatible element) along the gabbroic cotectic.

This paper examines the implications of stratigraphic and regional variations in major and trace elements in the basalts of the Povungnituk Group, a Proterozoic flood-basalt province located in the Cape Smith foldbelt of northern Québec. Our new results indicate that, despite the continental setting of the PG basalts, they are not typical of contaminated continental flood-basalts as previously claimed (Francis et al., 1983; Picard et al., 1990). The absence of significant negative Nb and Ta anomalies relative to light rare earth elements, and carbonaceous chondrite compositions, as well as the presence of unfractionated trace-element profiles, suggest that crustal contamination has not played a major role in the evolution of these tholeiitic basalts. Neither closed-system, nor open-system crystal fractionation models can reproduce the range of trace element concentrations observed within the PG. Regional variations in incompatible trace-element ratios reveal the existence of two mantle components. These new results show that there may be two distinct mantle sources in the PG lavas, and that the trace-element-enriched lavas reflect a dispersed enriched mantle component rather than crustal contamination. The dispersed nature of the enriched component suggests that mixing of mantle-derived melts (and possibly sub-continental lithospheric-derived melts) may be responsible for the variation of incompatible-trace element concentrations found in the PG lavas. In this paper, we argue that a heterogeneous plume-type source or significant melt contribution from the lithospheric mantle could be responsible for the trace-element systematics of the Paleoproterozoic PG lavas.

GEOLOGICAL SETTING AND PREVIOUS WORK

The Cape Smith foldbelt is located near the tip of the Ungava Peninsula in northern Québec (Fig. 1) and has been interpreted to be the foreland thrust belt of the Paleoproterozoic Ungava orogen (St-Onge et al., 1992). This foldbelt is exposed from the eastern shores of Hudson Bay to the western shoreline of Ungava Bay, and separates the Archean gneisses of the Superior Province in the south from the gneisses of the Churchill Province to the north. The first published observations on the metamorphosed and imbricated supracrustal rocks of the Cape Smith foldbelt were given by Low (1899). Low (1902) also first described the pillow-basalt flows and documented their mineralogical and textural transition from low-grade basalts to amphibolite-facies metabasites. The geology of the Cape Smith foldbelt is largely attributable to the work of the Quebec Department of Natural Resources (DeMontigny, 1959; Bergeron, 1957b; Bergeron, 1959; Beall, 1959; Beall, 1960; Gold, 1962; Gelinas, 1962; and Schimann, 1978a), supplemented in later years by reconnaissance mapping by the Geological Survey of Canada (Taylor, 1974) and by more detailed studies of regional volcanic chemistry and structure (Baragar, 1974; Schwarz and Fujiwara, 1977; Miller, 1977; Hynes and Francis, 1982; Francis et al., 1983). Since these publications, the entire foldbelt has been mapped at a scale of 1:50, 000 by the Geological Survey of Canada (St-Onge and Lucas, 1993) and the Ministère de l'Énergie et des Réssources du Québec (MERQ) (Lamothe, 1986).

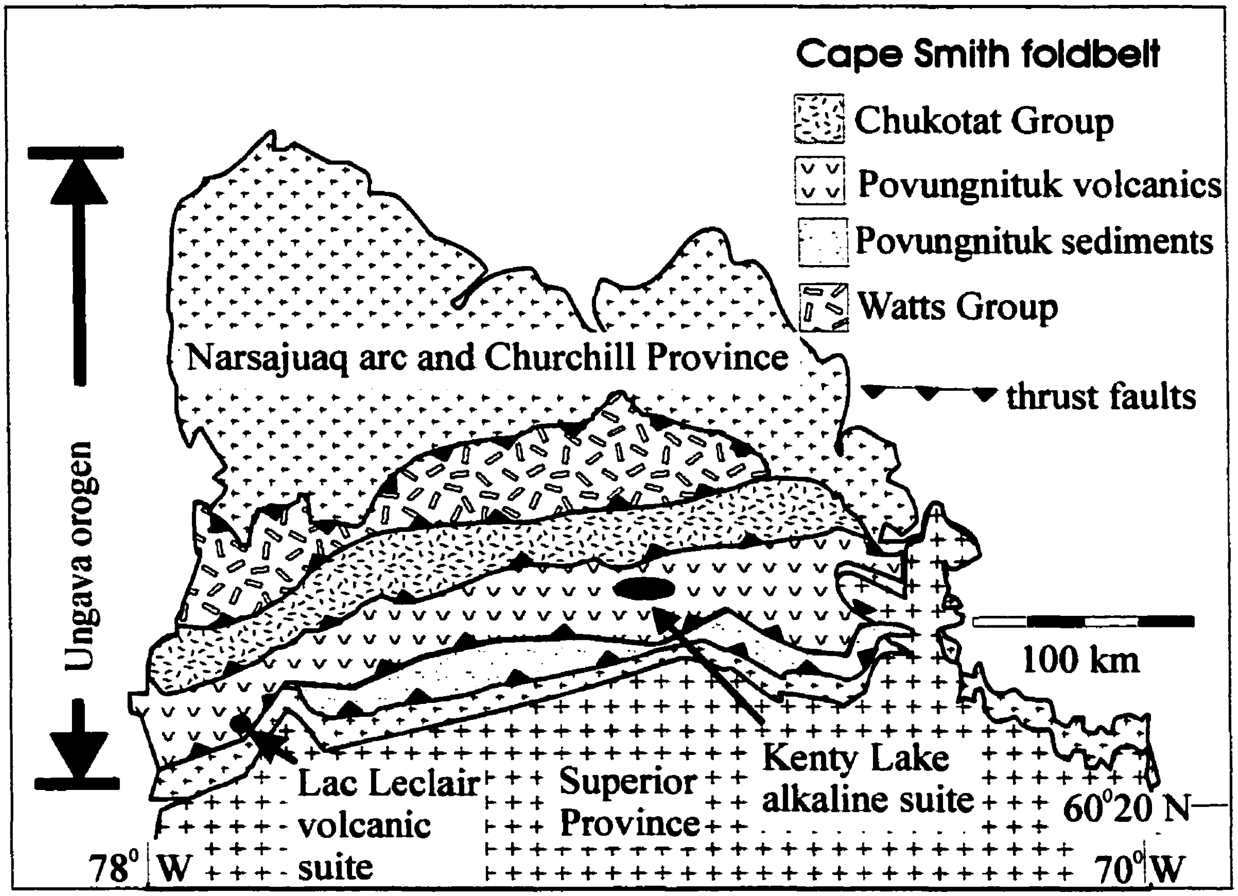
Fig. 1. Geologic map of northeastern Archean Superior craton and the eastern Trans-Hudson Orogen (after St-Onge et al., 2000).


HUDSON
TRANS-
OROGEN
Baffin Island
300 km
Cape Smith foldbelt
60° N
Ungava Peninsula
Ungava Bay
Hudson Bay
Quebec
Belcher Is.
80° W
70° W
Paleozoic cover
Archean North Atlantic craton
Orogenic hinterland (Paleoproterozoic and reworked Archean units)
Cumberland batholith (1.86-1.86 Ga)
Narsajuaq arc terrane (1.86-1.82 Ga)
Ophiolite (Watts Group) (2.00 Ga)
Paleoproterozoic shelf successions
Paleoproterozoic rift successions
Archean Superior Province

The southern portion of the Cape Smith foldbelt is characterized by a Paleoproterozic tectonostratigraphic assemblage of parautochthonous and allochthonous sedimentary and volcanic sequences (Povungnituk and Chukotat Groups) associated with rifting of the Superior craton (Hynes and Francis, 1982; Francis et al., 1983; Picard et al., 1990; St-Onge and Lucas, 1990a). Stratigraphic and field relationships suggest the Povungnituk and Chukotat Groups were accumulated on or adjacent to the rifted Superior Province craton during the Paleoproterozoic (Hynes and Francis, 1982; Francis et al., 1983; Hegner and Bevier, 1991; Picard et al., 1990; St-Onge and Lucas, 1990l). The older PG consists of a lower succession of autochthonous and parautochthonous clastic sediments (conglomerate, quartzite, ironstone, semipelite and pelite) that are overlain by parautochthonous, predominantly volcanic, sequences of basalt (both pillowed and tabular flows) of the upper Povungnituk Group with minor alkaline and rhyolitic lavas (St-Onge and Lucas, 1993; Goanac'h, 1992). Francis et al. (1983) and St-Onge and Lucas (1993) have interpreted the PG as being comprised of continent-derived sediments and continental flood-basalts that accumulated in a tectonically active rift basin. The proportion of clastic sediments decreases from the southern margin towards the centre of the basin and the sediments were likely derived from erosion of the Superior craton to the south (Hynes and Francis, 1982). Sedimentary features suggest deposition in fluviatile and shallow marine environments on stable and rifted continental crust of a north-facing continental margin (St-Onge and Lucas, 1993). Thin laterally discontinuous lenses of rhyolite occur intercalated with basanites, nephelinites, and related phonolitic volcanics near the top of the PG in the center of the foldbelt (Gaonac'h, 1992). In addition, carbonate-rich alkaline lavas have been documented near the base of the PG (Lac LeClair volcanic suite, Baragar et al., 1994; Fig. 2). Other than the minor rhyolite and alkaline volcanics, the lavas of the upper PG are dominated by LREE enriched tholeiitic basalts, basaltic andesites and syn-volcanic sills for a total volcanic accumulation of up to 6.7 km (St-Onge and Lucas, 1990a). The volcanic and sedimentary rocks of the Povungnituk Group are intruded by massive gabbroic sills, which are interpreted as the feeder system for the basalts of the PG (St-Onge and Lucas, 1993), but there are also layered gabbro-peridotite sills that may be related to the younger Chukotat Group volcanics.

The Chukotat Group consists of allochthonous sequences of picritic to tholeiitic basalts with associated layered sills that are in fault contact with the structurally lower PG. Three lavas types have been distinguished by Francis et al. (1983): 1) olivine-phyric basalt, 2) pyroxene-phyric basalt and, 3) plagioclase-phyric basalt. The olivine-phyric basalts of the Chukotat Group are Mg-rich (18 wt% MgO) and could represent liquids in equilibrium with Earth's upper mantle, while the plagioclase and pyroxene-phyric lavas appear to represent differentiated magmas that have suffered significant crystal fractionation since segregating from the upper mantle (Francis et al., 1983). The trace element geochemistry of the Chukotat magmas is similar to that of oceanic basalts (MORB), whereas the Povungnituk Group basalts are characterized by Fe, Ti and LREE-enriched tholeiites (Francis et al., 1983), and thus have geochemical signatures more similar to continental flood-basalts. The succession from the PG to the Chukotat Group

Fig. 2. General geology of the Cape Smith foldbelt (after St-Onge et al., 1993)


Cape Smith foldbelt
Chukotat Group
Povungnituk volcanics
Povungnituk sediments
Watts Group
thrust faults
Narsajuaq arc and Churchill Province
Ungava orogen
100 km
Lac Leclair volcanic suite
Superior Province
Kenty Lake alkaline suite
60°20 N
78° W
70° W

was thought to represent the transition from continental flood-basalts to oceanic magmatism during rifting of the Superior Province (Francis et al., 1983).

Both the Povungnituk and Chukotat Groups are disposed in a series of laterally equivalent, north-dipping blocks, separated by high angle, south-verging reverse faults (Hynes and Francis, 1982). The presence of coarse-grained, continent-derived sediments and tholeiitic magmas with continental affinities in southernmost thrust blocks of the PG suggests that the succession was deposited near or overlying continental crust. Conversely, the absence of continentally-derived sediments within the Chukotat Group and the trace element similarities with MORB suggest that this succession formed far from the continental margin. Based on these observations the volcanism of the PG is interpreted as associated with Proterozoic-continental rifting (Hynes and Francis, 1982).

The northern portion of the Cape Smith Belt is characterized by another tectonostratigraphic assemblage consisting of the Watts Group, a sequence of layered ultramafic and mafic rocks, massive and pillowed basalt flows, mafic sills and sheeted dykes (Scott et al., 1989; Scott et al., 1991); the Spartan Group, a clastic sedimentary sequence of laminated pelites and semipelites (St-Onge and Lucas, 1993); and the Parent Group, a magmatic arc system dominated by calc-alkaline volcanics (St-Onge and Lucas, 1993). These volcano-sedimentary and plutonic suites rest structurally on Archean migmatitic tonalites and gneisses.

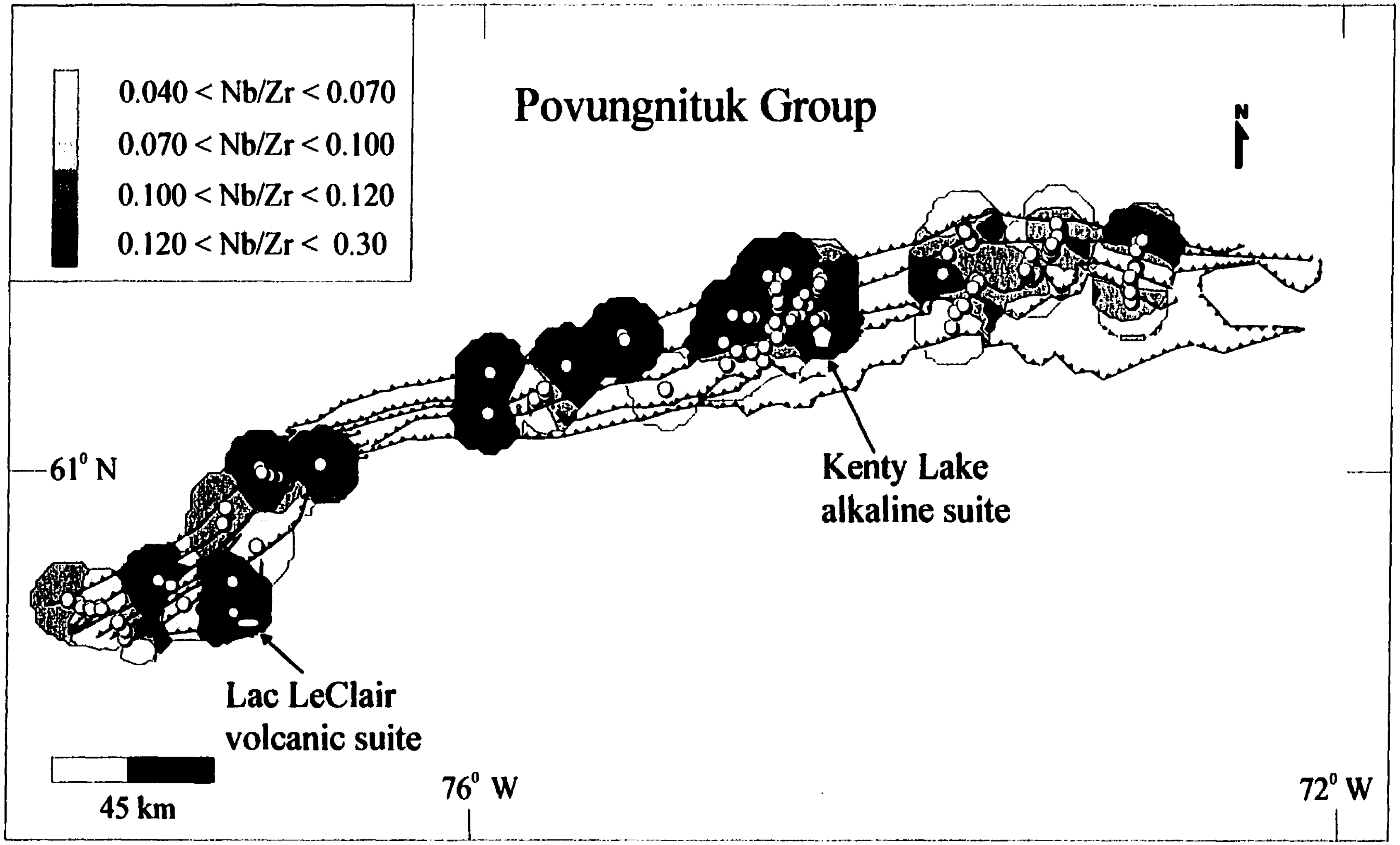
The Cape Smith foldbelt is essentially a synclinorium with the north-dipping limb differentially thickened due to south vergent thrusting (St-Onge and Lucas, 1993). Three phases of deformation (D_1-D_3) are recognized within the foldbelt (Hynes and Francis, 1982; Hoffman, 1985; St-Onge and Lucas, 1993). The earliest deformation (D_1) produced a bedding-parallel cleavage, north-south extension lineations, and recumbent isoclinal folds of bedding in semi-pelite. The second phase of deformation (D_2) produced east-trending (parallel to trend of the belt), variably plunging folds of bedding and D_1 cleavage. Later D_3 deformation produced northwest trending cross folds responsible for the variable plunges of D_1 and D_2 folds. Several geotectonic models have been proposed for the formation of the Cape Smith foldbelt (Dimroth et al., 1970; Gibb and Walcott, 1971; Dewey and Burke, 1973; Thomas and Gibb, 1977; Baragar and Scoates, 1981; Hoffman, 1985). Much of the debate centers on whether the foldbelt itself marks the site of a major collisional suture. Early models proposed that the Cape Smith foldbelt represented a major suture resulting from the collision of two continents (Gibb and Walcott, 1971). Others interpreted the foldbelt as an in-situ rifted segment of the Circum-Superior foldbelt (Baragar and Scoates, 1981). Likewise, Francis et al. (1983), Hynes and Francis (1982) and Picard et al. (1990) proposed that the Povungnituk and the Chukotat Groups were the result of progressive opening of an oceanic rift. Hynes and Francis (1982) argued that because the primary sedimentary facies are similar on either margin of the foldbelt that only a small, narrow seaway separated them. Hoffman (1985) proposed a new tectonic model in which the foldbelt represents an allochthonous outlier, or klippe, isolated from its root zone by a post-thrusting basement antiform cored by Archean rocks. According to this model, the suture would be located 50 to 100 km north of the belt, where a major discontinuity is evident in the gravity and magnetic fields (Thomas and Gibb, 1977; Canada, 1983). The main evidence for the klippe model is the lack of any major thrust faults penetrating the basement around the eastern extremity of the Cape Smith foldbelt, and contrasting regional trends in the aeromagnetic data (Hoffman, 1985). St-Onge and Lucas (1993) elaborated on the klippe model and proposed that the Ungava orogen contains evidence for the development of a wide ocean that was subsequently destroyed during plate convergence leading to arc-continent collision. Recently several authors have suggested that the emplacement of layered ultramafic sills, accumulation of komatiitic and alkaline basalts during rifting of the northeast Superior craton are consistent with the impingement of a mantle plume (St-Onge et al., 2000).

Legault et al. (1994) proposed that the geochemical data of Picard (1990) suggested that flows in the eastern part of the PG were enriched in incompatible trace-elements compared with those in the west, a difference they likened to differences in the basalts of the Eskimo and Flaherty Formations in the Belcher Islands (Fig. 1). Legault (1994) attributed the trace-element-enriched nature of the Eskimo Formation to crustal contamination, and the results of their study prompted a return to the PG, involving the systematic sampling of three new sections as well as the reanalysis of samples previously collected during a regional mapping project conducted by the Ministère de l'Énergie et des Réssources du Québec (MERQ).

SAMPLES AND ANALYTICAL METHODS

In comparison with the limited coverage of previous geochemical studies of the PG, this study is based on a regional sampling program covering the entire PG (Fig. 3). Three new sample transects were conducted in the eastern portion of the PG and samples from the central and western portions were obtained from previous regional mapping projects (MERQ samples collected in 1983-1988 field seasons) and from previous detailed studies (Hynes and Francis, 1982; Francis et al., 1983; Gaonac'h et al., 1992). Two hundred and twenty-five powdered samples were analyzed for major and trace elements by X-Ray fluorescence (XRF) using a Philips PW2400 3kw automated XRF spectrometer system (McGill University geochemical laboratories). Major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P) and trace elements (Ba, Cr, Cu, Ni, V, and Zn) were analyzed using 32mm diameter fused beads prepared from a 1:5 sample:Lithium Tetraborate mixture. Other trace elements (Ga, Nb, Rb, Sr, Th, U, Y, and Zr) were determined by analyzing 40mm diameter pressed pellets prepared at a pressure of 20 tons from a mixture of sample powder with 20% (by weight) Hoechst Wax C Micropowder. Calibration lines were prepared using Certified International Reference Materials. The accuracy for the major elements is within 1% (0.5% for Si). For trace elements the accuracy is within 5%. The instrument precision is within 0.6% relative, when the same disc is analyzed repeatedly for the same element. A subset of 31 samples, chosen to cover the range of trace-element concentrations (Zr) observed in the Povungnituk Group samples, were analyzed for trace elements (including REE) using inductively-coupled plasma mass spectrometry (ICP-MS, PE Elan 6100, Actlabs geochemical laboratories).

Fig. 3. Sample locations within the Povungnituk Group superimposed on a Nb/Zr contour map, in which contours are based on an inverse distance weighing technique calculated with Vertical Mapper software, which uses an algorithm employing a moving average interpolator of nearby data points.


0.040 < Nb/Zr < 0.070
0.070 < Nb/Zr < 0.100
0.100 < Nb/Zr < 0.120
0.120 < Nb/Zr < 0.30
Povungnituk Group
N
61° N
Kenty Lake
alkaline suite
Lac LeClair
volcanic suite
45 km
76° W
72° W

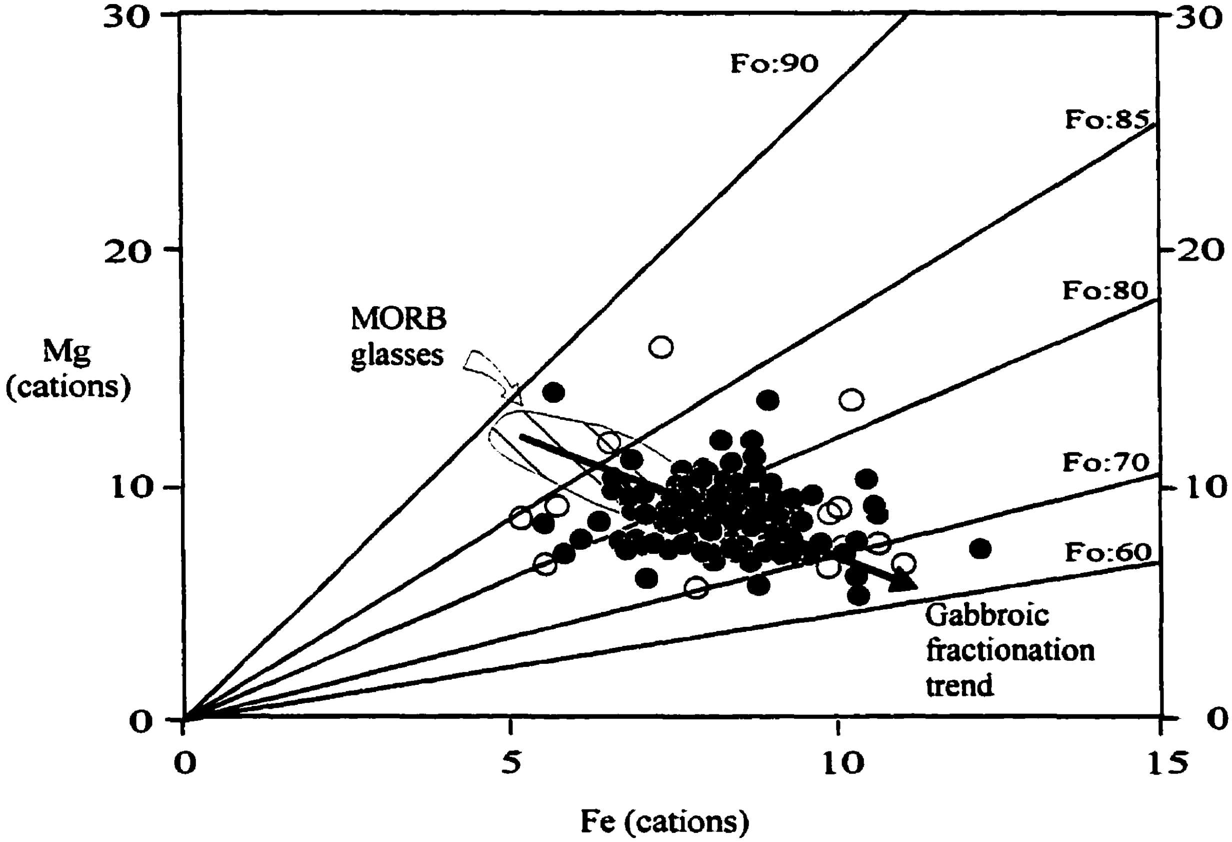
Samples were fused with lithium metaborate and calibrated with Certified International Reference Materials. Precision limits for all trace elements including REE determined by ICP-MS are calculated to be less than 5%.

POVUNGNITUK THOLEIITE SUITE

The lavas of the PG are predominantly green aphyric basalts that outcrop as smooth-topped massive flows and pillowed lavas. Vesiculated flow tops are easily recognized in the field and are generally north facing. The PG lavas are altered to mineral assemblages of sub-greenschist to greenschist facies and are dominated by sericitized plagioclase and chloritized pyroxene. In the eastern extremity of the belt, however, metamorphism can reach amphibolite grade. Extensive calcite and epidote veining provides evidence for the mobility of Ca and the alkali elements, which is likely in part responsible for the scatter of these elements in the bulk-rock analyses. In order to minimize uncertainty in element mobility care was taken in the field to avoid veined materials, and only fine-grained, homogenous samples were analyzed for major and trace element compositions.

The chemical compositions of the PG lavas indicate that they are predominantly hypersthene and quartz normative, Fe and Ti-rich basalts. Their relatively evolved nature is indicated by their low MgO contents (<10 wt%) and elevated FeO contents (up to 15 wt%). The most primitive (highest MgO) lavas, however, could have coexisted with an olivine composition of Fo_{89} (Fig. 4). The PG lavas are more Fe-rich than MORB glasses,

Fig. 4. Mg versus Fe in cation units for the Povungnituk Group tholeiitic basalts. (Filled circles are the low-Zr lavas and unfilled circles are the high-Zr lavas, as shown in figure 6).The lines radiating from the origin represent the loci of liquid compositions which would coexist in equilibrium with the indicated olivine composition, based on Roeder and Emslie (1970), where Fe/Mg $K_D = 0.3$, and assuming 10% of the total Fe is Fe^{3+}. The shaded region represents the field for Famous Glasses (data from Bryan, 1979). The solid line represents ~65% closed-system crystal fractionation along the gabbroic cotectic (20% Ol, 30% Cpx, 50% Plag).

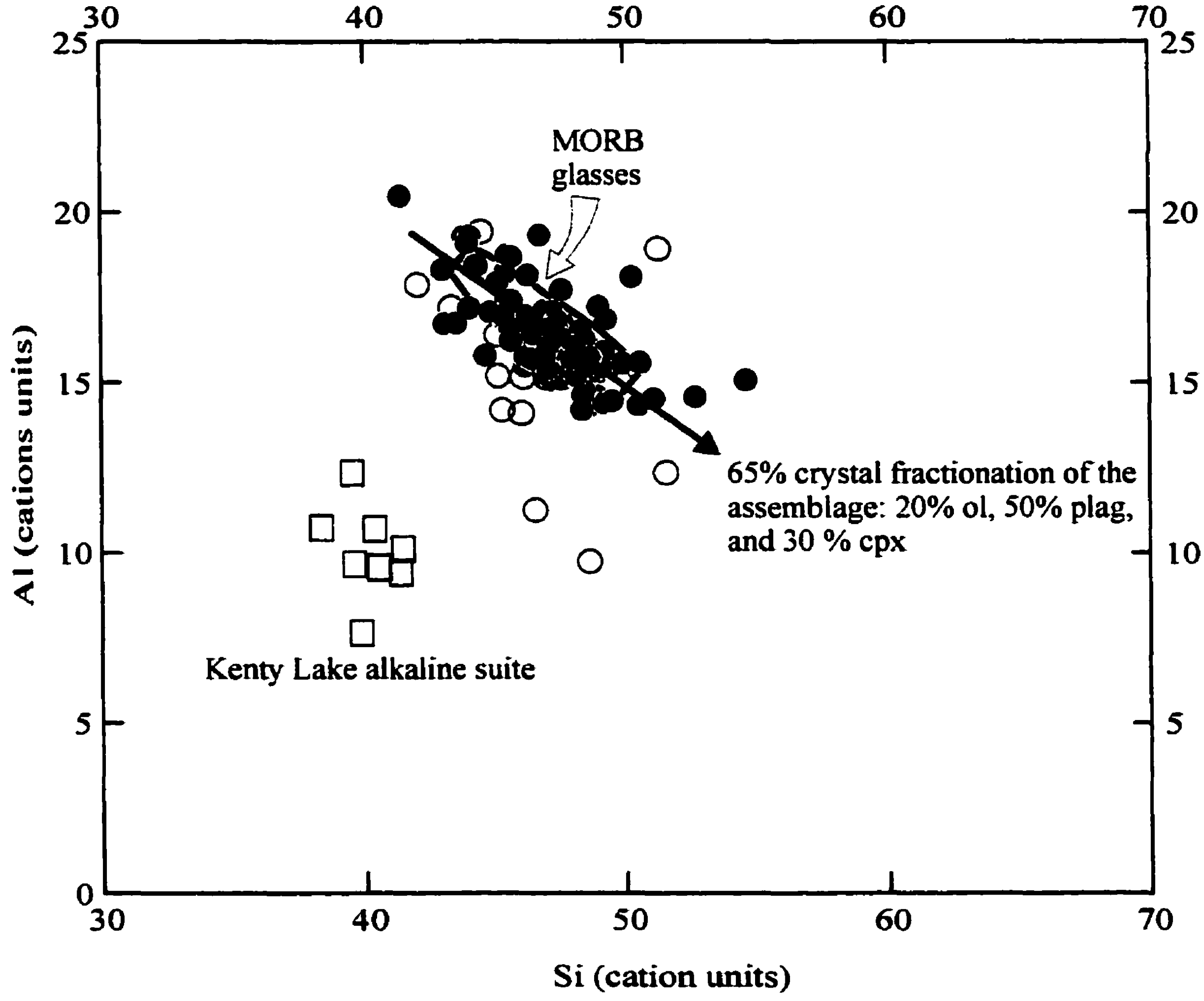


30
20
10
0
30
20
10
0
Fo:90
Fo:85
Fo:80
Fo:70
Fo:60
MORB glasses
Mg (cations)
Gabbroic fractionation trend
0
5
10
15
Fe (cations)

but generally follow a similar decreasing MgO and increasing FeO trend (Fig. 4). Based on this fractionation trend, and their normative mineralogy, the PG lavas are predominantly tholeiitic basalts. The few PG lavas that have higher MgO contents (10-12 wt%) may represent magmas fractionating only olivine and clinopyroxene having not reached the plagioclase saturation, the MgO content of the lavas that have reached plagioclase saturation is approximately 7-8 wt%.

The majority of the PG lavas exhibit a dispersed trend of increasing Si with decreasing Al that is indicative of plagioclase fractionation along the gabbroic cotectic (Fig. 5). The range in Si is consistent with approximately 65% crystal fractionation of the assemblage: 20% olivine + 30% clinopyroxene + 50% plagioclase. The scatter observed for the PG tholeiites in Al and Si space could be the result of major element mobility during metamorphic alteration. Unlike elements such as Ca and the alkalis Al, however, is generally considered to be relatively immobile. Furthermore, there is no evidence that the outliers are more altered than other samples as their loss on ignition (LOI) values are <5%, which is similar to values for the samples that lie along the gabbroic fractionation trend. Thus the scatter in Al and Si space may conceivably reflect a range of parental magmas experiencing different melting conditions, source composition and/or contaminated by continental crust. Other relatively immobile elements such as the high field strength elements (eg., Nb, Zr) and REE (eg., La, Sm) are well correlated in chemical variation diagrams (Cann, 1970) and are believed to reflect magmatic processes.

Fig. 5. Al versus Si in cation units for the Povungnituk Group tholeiitic basalts. The solid line represents the gabbroic fractionating assemblage of 20% olivine + 30% clinopyroxene + 50% plagioclase using K_D values after Hart and Dunn (1993). Shaded region represents the field of Famous MORB glasses (data from Byran, 1979), (symbols same as Fig. 4).



MORB glasses
65% crystal fractionation of the assemblage: 20% ol, 50% plag, and 30 % cpx
Kenty Lake alkaline suite
Al (cations units)
Si (cation units)
30
40
50
60
70
0
5
10
15
20
25

Most of the PG tholeiites exhibit uniformly low concentrations of compatible trace-elements, such as Ni and Cr, and moderately incompatible trace-elements like Zr. There are, however, some lavas that are relatively enriched in incompatible trace-elements (Fig. 6a, 6b), and there appears to be two different magmatic series within the PG, one with low Zr and the other with high-Zr compositions (Fig. 6a, 6b). High degrees of fractional crystallization (65%) are required to account for the range of trace element contents observed in both the high and low-Zr magmatic series (Fig. 7). The high-Zr lavas of the PG appear to be spatially associated with an alkaline volcanic suite, except for one sample all of the high-Zr series lavas lie within a 80 km radius from the Kenty Lake alkaline suite, the lone exception is located near the Lac LeClair volcanic suite. Lavas of the more dominant low-Zr series occur throughout the PG and are intercalated with the lavas of the high-Zr series. Most of the PG tholeiitic lavas with enriched trace-element profiles correspond to the high Zr-series there are, however, minor enriched tholeiitic basalts of the low-Zr series (Fig. 7) and are widely distributed within the PG. The tholeiitic lavas of the PG also exhibit significant variations of incompatible-trace element ratios such as La/Sm (Fig. 8) and Nb/Zr (Figs. 3 and 9), which correlate positively to the degree of relative trace-element enrichment and the absolute concentration levels of incompatible elements (Figs. 8 and 9). The trace-element profiles for the PG tholeiitic lavas range from unfractionated to relatively enriched patterns, with respect to carbonaceous chondrites (Fig. 10). Most of the lavas of the low-Zr series have relatively flat unfractionated trace-element patterns with slightly positive Nb anomalies with respect to LREE and carbonaceous chondrites (Fig. 10). The low-Zr series also

Fig. 6. a) Ni versus Zr, b) Cr versus Ni in ppm for the Povungnituk tholeiitic basalts. The arrows represent approximately 65% closed-system fractionation along the gabbroic assemblage (Ol/Px/Pl, 20/30/50) for two distinct end-members and define two magmatic series. The filled circles represent the low Zr series and the open circles represent the high Zr series.

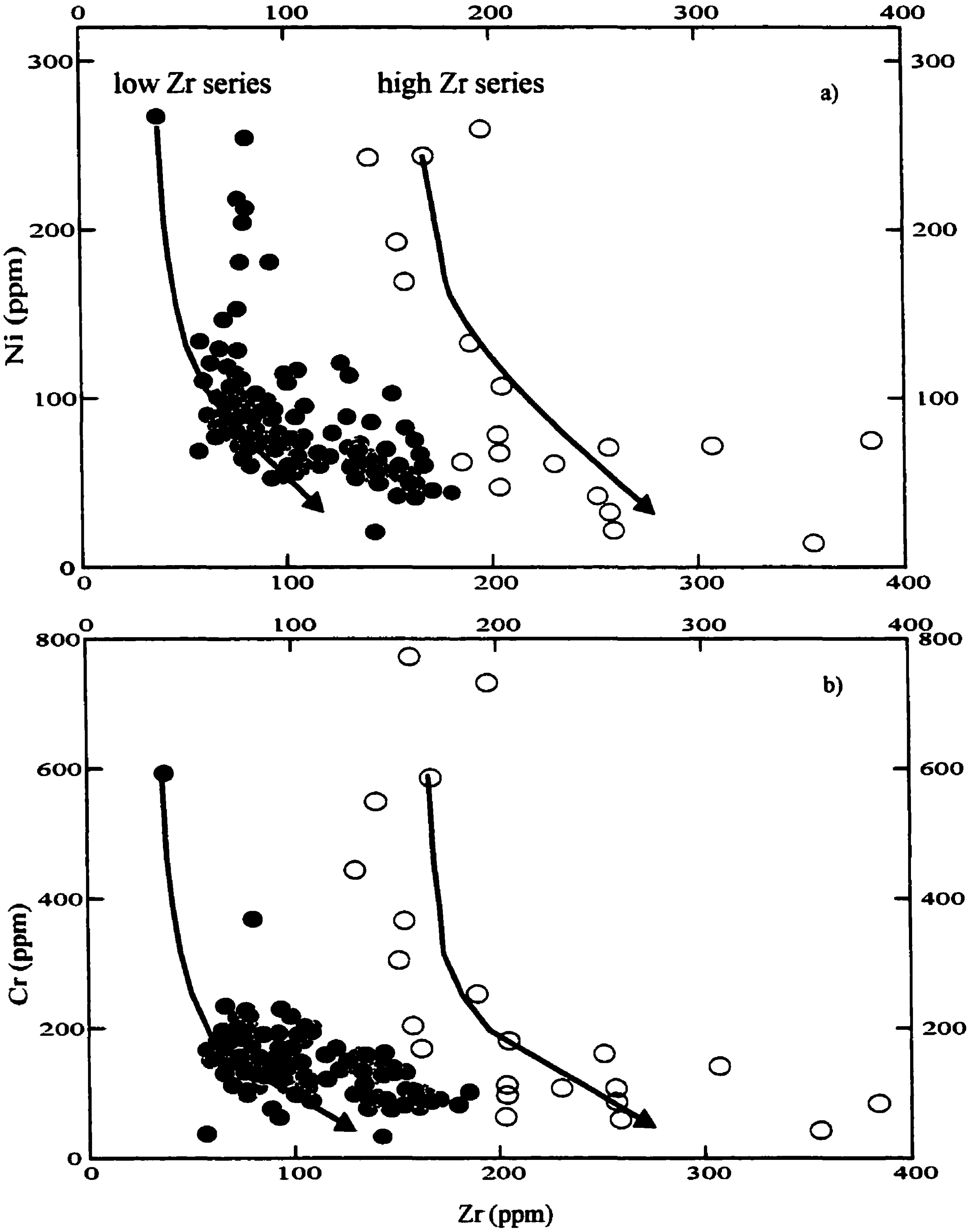
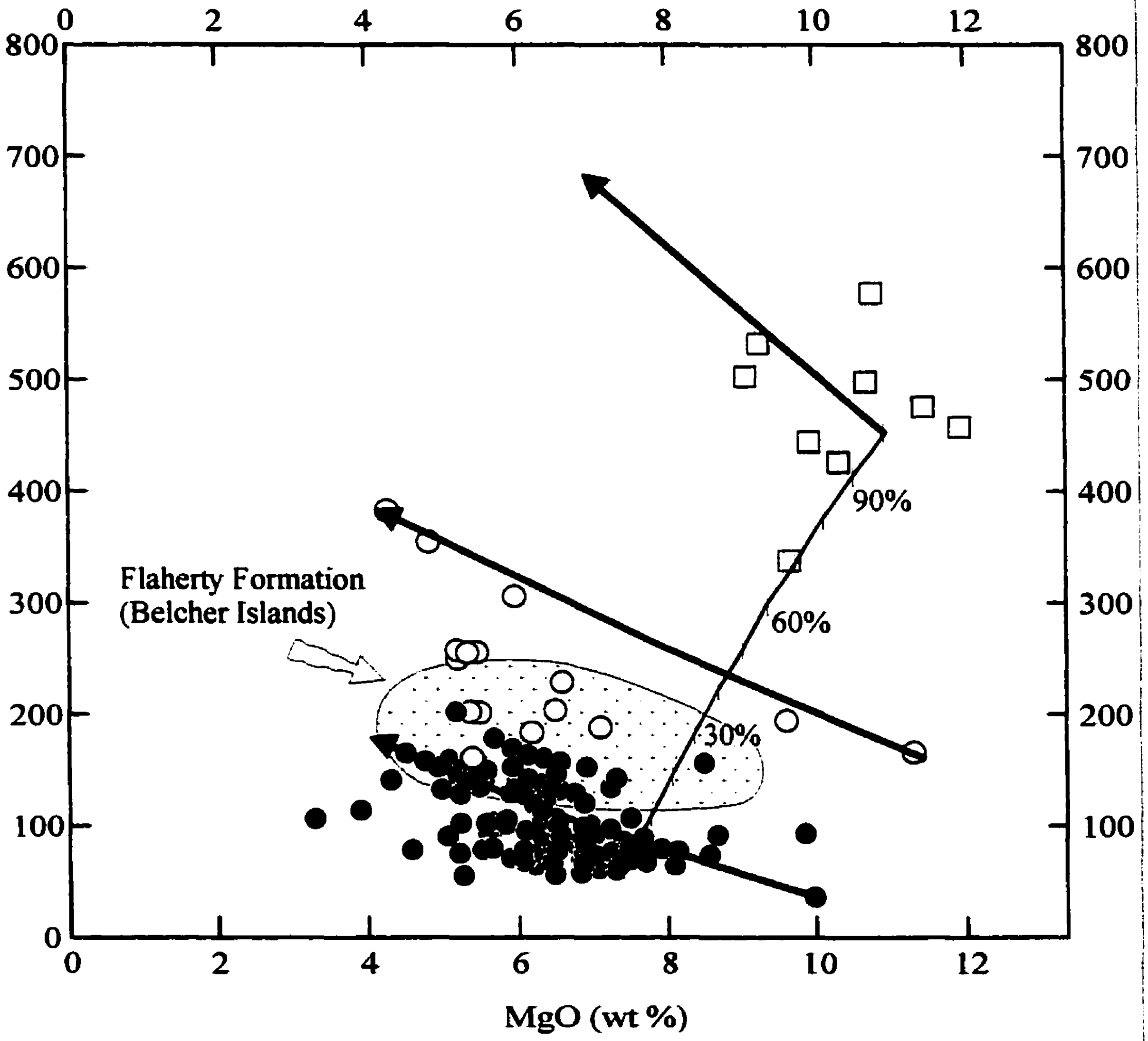
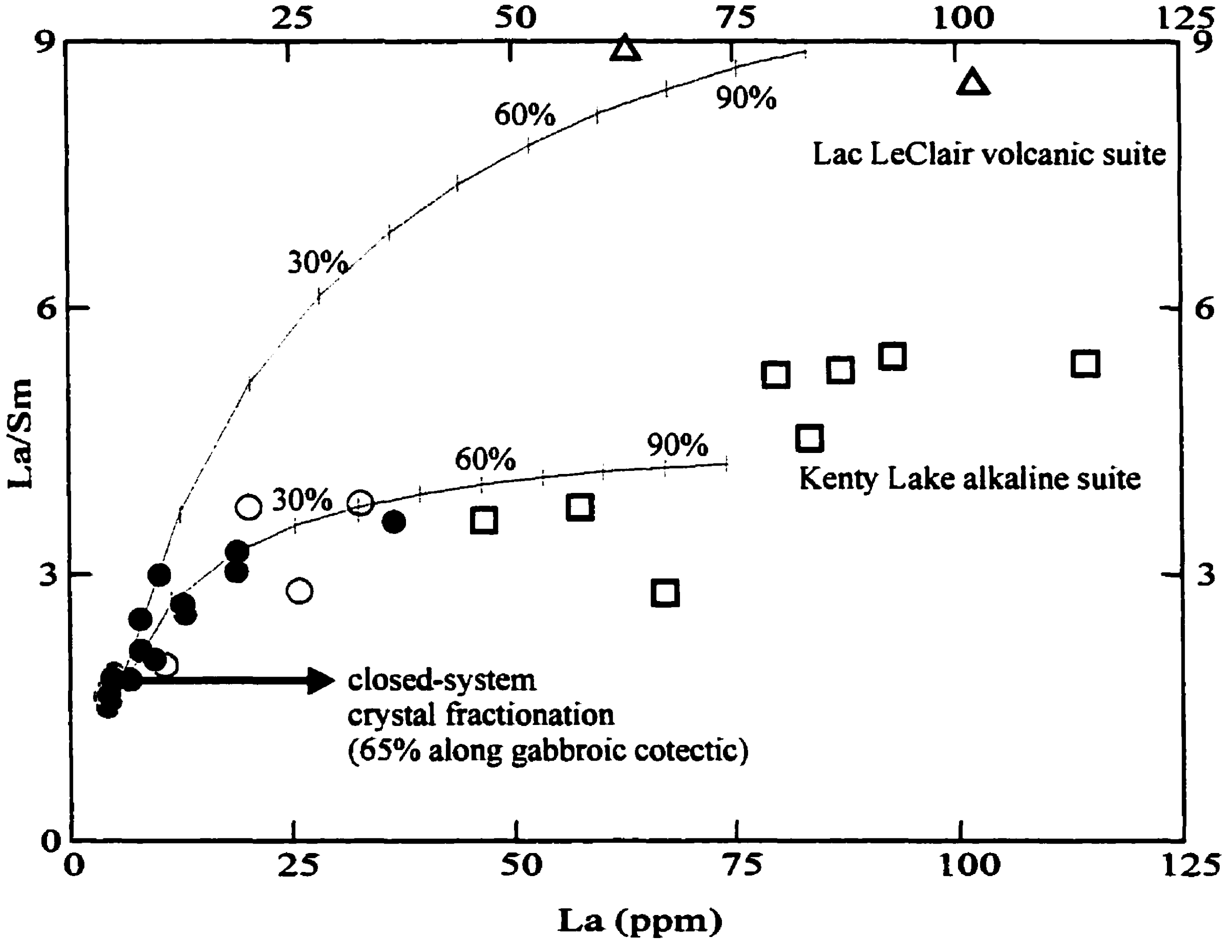

low Zr series
high Zr series
a)
b)
Ni (ppm)
Cr (ppm)
Zr (ppm)
0
100
200
300
400
800
600

Fig. 7. Zr versus MgO wt% plot for the Povungnituk Group tholeiites (circles) and the Kenty Lake alkaline suite (squares). Arrows represent ~65% closed-system crystallization with the gabbroic assemblage (same as Fig. 6). Parental magmas are taken as the most MgO-rich basalts for the Povungnituk Group and an average value of all samples from the Kenty Lake alkaline suite.



0
2
4
6
8
10
12
800
700
600
500
400
300
200
100
0
Zr (ppm)
MgO (wt %)
Flaherty Formation
(Belcher Islands)
90%
60%
30%

Fig. 8. La/Sm versus La plot for the Povungnituk Group. La/Sm ranges from <2 to >3. Small arrow represents ~65% closed-system crystal-fractionation along the same gabbroic cotectic as in Fig. 6. The solid lines represent binary mixing (see magma mixing section in text) curves between a low-La end-member and the average composition for the Kenty Lake alkaline suite and the Lac LeClair volcanic suite (triangles). Each hash mark on the mixing line represents 10% of the enriched end-member.



25
50
75
100
125
9
9
60%
90%
Lac LeClair volcanic suite
30%
6
6
La/Sm
60%
90%
30%
Kenty Lake alkaline suite
3
3
closed-system
crystal fractionation
(65% along gabbroic cotectic)
0
0
25
50
75
100
125
La (ppm)

Fig. 9. Nb/Zr versus Nb for the Povunituk Group, Kenty Lake alkaline suite and the Lac LeClair volcanic suite. The solid lines represent binary mixing curves between a low-Nb end-member and the average composition for the Kenty Lake alkaline suite and the Lac LeClair volcanic suite. Each hash mark on the mixing line represents 10% of the enriched end-member.

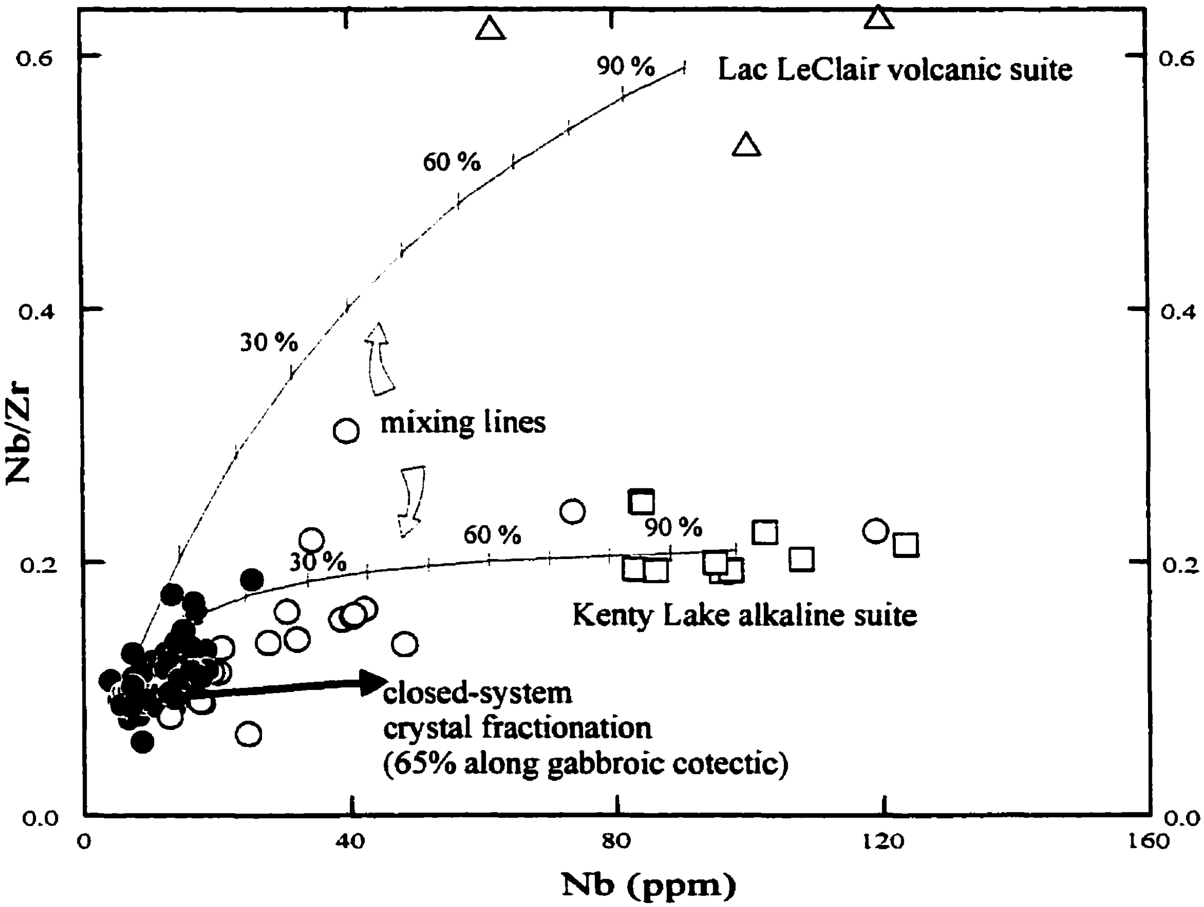

Nb/Zr
Nb (ppm)
0.0
0.2
0.4
0.6
0
40
80
120
160
Lac LeClair volcanic suite
Kenty Lake alkaline suite
mixing lines
30 %
60 %
90 %
30 %
60 %
90 %
closed-system
crystal fractionation
(65% along gabbroic cotectic)

Fig. 10. Chondrite normalized trace element patterns for the Povungnituk Group tholeiitic basalts. Normalizing values from McDonough and Frey (1990).

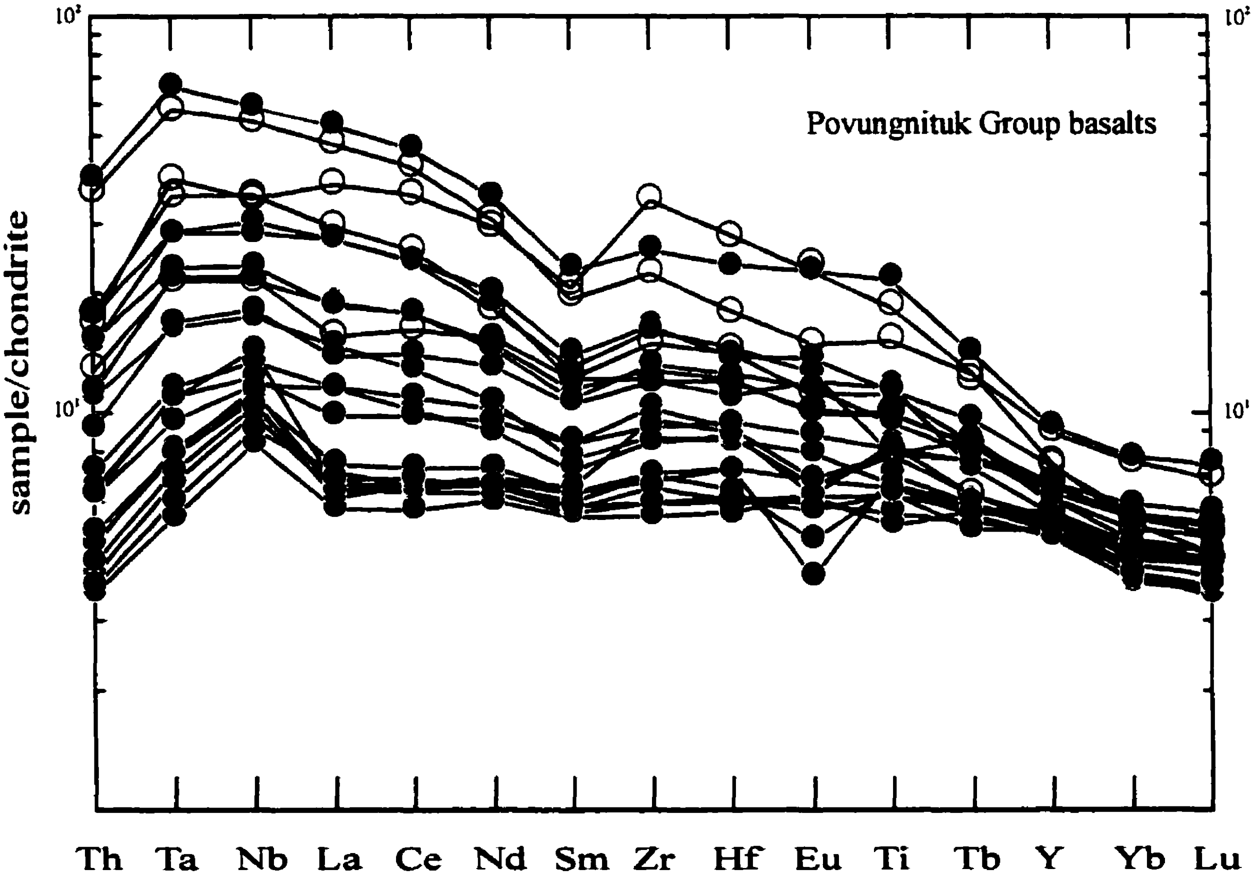

10²
10²
10¹
10¹
sample/chondrite
Povungnituk Group basalts
Th
Ta
Nb
La
Ce
Nd
Sm
Zr
Hf
Eu
Ti
Tb
Y
Yb
Lu

exhibit relatively enriched trace-element patterns similar to that of the high-Zr series (Fig. 10).

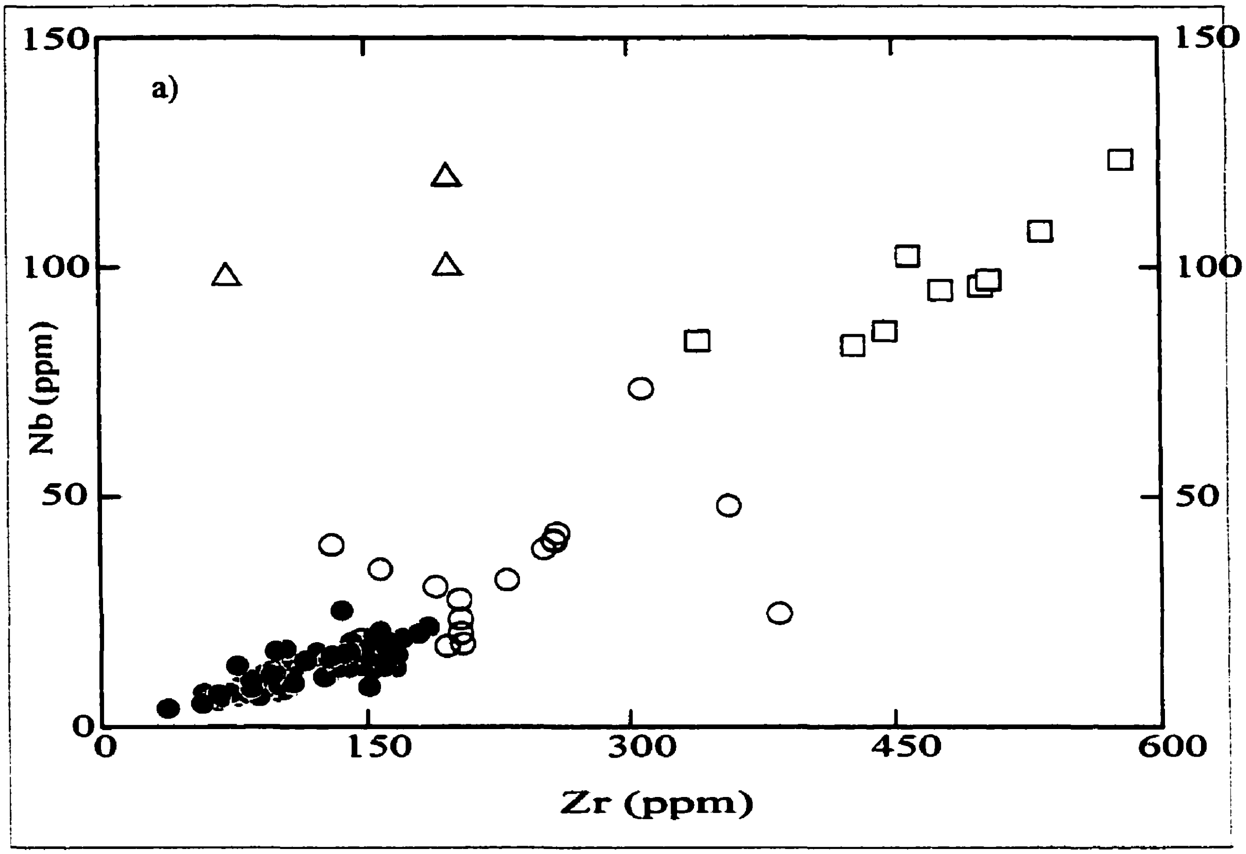
KENTY LAKE ALKALINE SUITE

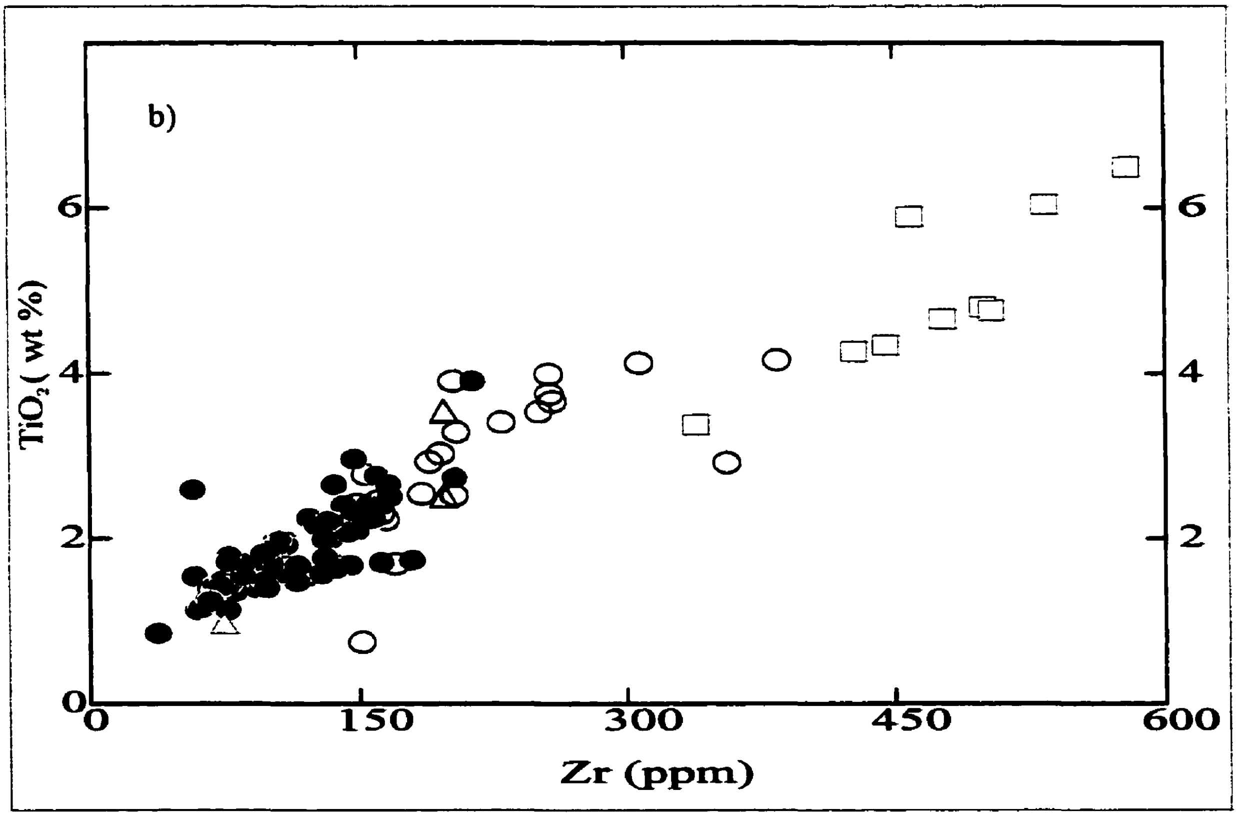
The Kenty alkaline suite comprises a lower sequence of mafic lavas intercalated with pyroclastic deposits and an upper sequence of trachytic lavas with rare alkali-feldspar phenocrysts (Gaonac'h et al., 1992). The entire suite is only several hundred meters in thickness and is restricted to one locality near the top of the PG at Kenty Lake (Gaonac'h et al., 1992), where the lavas are exposed in two adjacent thrust blocks. The mafic lavas in this suite consist of basanites and nephelinites that are strongly enriched in Ti, Nb, and Zr relative to the PG tholeiitic basalts (Fig. 11), but similar to modern alkaline equivalents (Gaonac'h et al., 1992).

LAC LECLAIR VOLCANIC SUITE

Unusually carbonate-rich alkaline lavas have been described by Baragar et al. (1992) in the western portion of the Cape Smith foldbelt (Fig. 3). The Lac LeClair volcanic suite comprises a 500 m thick sequence of carbonatitic, ultramafic lapilli tuffs and lavas (Baragar et al., unpublished) that outcrops in the southern extremity of the belt, near the unconformity with the Superior craton. The presence of the Lac LeClair volcanic suite among the platformal sequence sediments of the lowermost PG indicates

Fig. 11. a) Nb versus Zr and b) TiO_2 versus Zr for the Povungnituk Group tholeiitic basalts (circles), the Lac LeClair volcanic suite (triangles) and the Kenty Lake alkaline suite (squares).


a)
150
100
50
0
Nb (ppm)
0
150
300
450
600
Zr (ppm)


b)
6
4
2
0
TiO2 (wt %)
0
150
300
450
600
Zr (ppm)

that it may be one of the first volcanic manifestations of rifting and subsidence during the development of the Cape Smith Foldbelt (Baragar et al., 1992). According to the IUGS classification system, the ultramafic lavas would be described as meimechites because of high MgO, but low K and P contents. Meimechites from the type locality at Meimecha-Kotuj, Siberia, however, have significantly higher SiO_2, and lack the carbonate-rich compositions that characterize the Lac LeClair volcanics. On the other hand, the Lac LeClair volcanic lavas are more Mg-rich and have lower Al concentrations than typical ultramafic lamprophryes, but have insufficient carbonate (CO_2 <20%) to be classified as carbonatites.

DISCUSSION

The Povungnituk Group basalts represent relatively evolved mafic magmas with Mg # and contents of compatible trace elements such as Ni and Cr that are too low to have coexisted in equilibrium with accepted upper mantle compositions. These evolved mafic lavas must, therefore, represent magmas that have chemically fractionated since segregating from their mantle source-region. Although there are a few samples with sufficiently high Mg contents that they could have coexisted with upper mantle peridotite (Fig. 4), the low concentrations of Ni and Cr (<250 ppm and <750 ppm, respectively, Fig. 6) and high SiO_2 contents (~50 wt %) of these relatively magnesium rich lavas indicate that they too are unlikely to be primary melts of a peridotite mantle source.

There is a wide range in the degree of trace-element enrichment in the PG basalts (Fig. 10). The majority of lavas are low in incompatible trace-elements and exhibit relatively flat unfractionated patterns. There are, however, numerous samples with variable degrees of trace-element enrichment, which approach those of the alkaline lavas (Figs. 8 and 9). The ability of fractional crystallization to reproduce the trace-element variations within the PG was modelled using a finite difference algorithm with partition coefficients from Hart and Dunn (1993). Although approximately 65% closed-system crystal fractionation of a gabbroic assemblage can explain much of the observed range, it cannot account for the entire variation in trace elements within the PG basalts (Fig. 7). Furthermore, gabbroic fractionation cannot significantly fractionate highly incompatible elements such as Nb and Zr (Pearce and Norry, 1979), therefore liquids evolving under closed-system crystal fractionation are characterized by relatively constant Nb/Zr (Fig. 9). Similarly, gabbroic fractionation is ineffective in fractionating La and Sm, and evolving liquids have relatively constant La/Sm (Fig. 8). The Nb/Zr and La/Sm are positively correlated with the absolute concentrations of Nb and La in the PG (Figs. 8 and 9), indicating that closed-system crystal-fractionation cannot explain the spectrum of observed trace element concentrations in the tholeiite basalts.

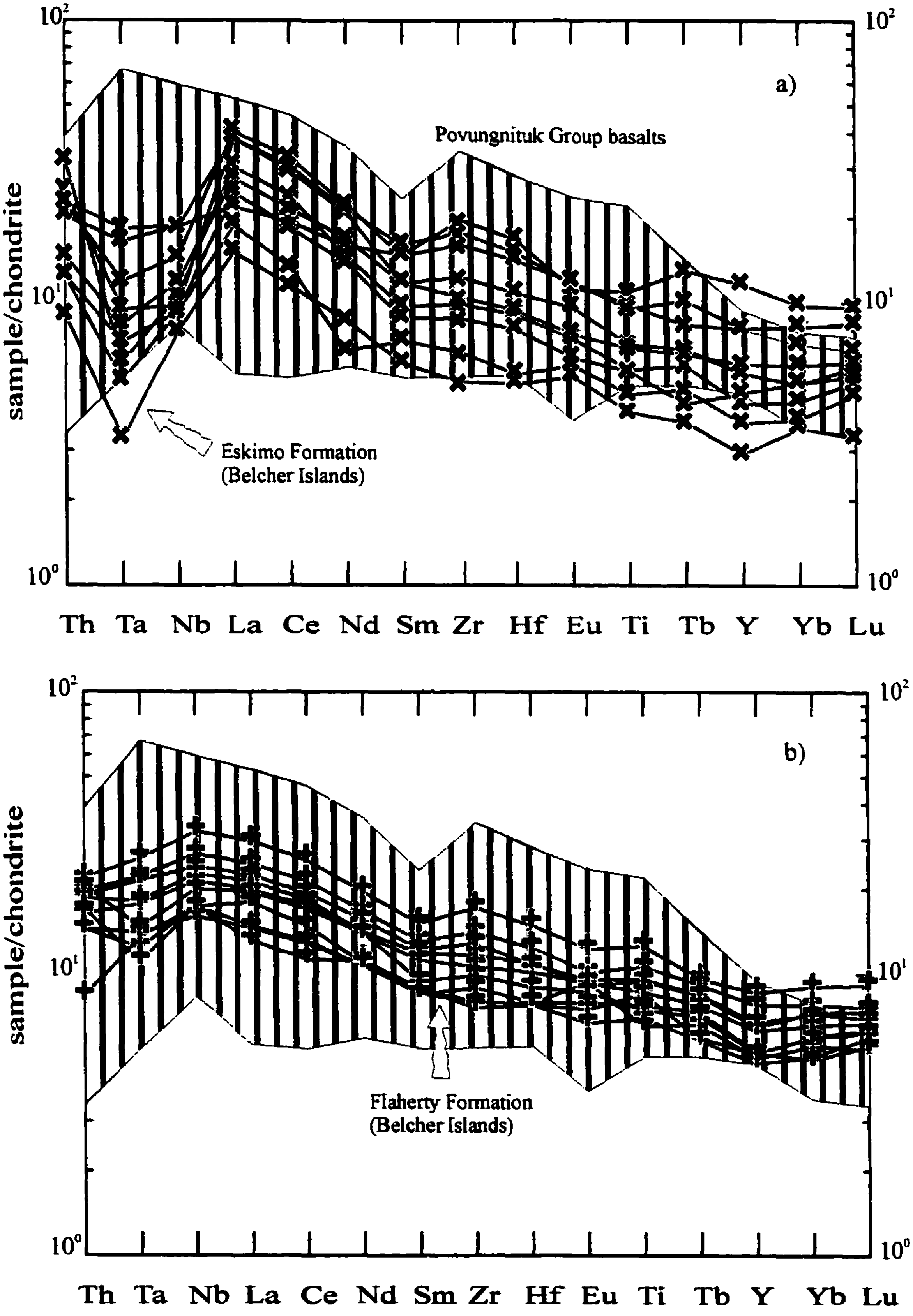
CRUSTAL CONTAMINATION

As the Povungnituk Group basalts are interpreted to have erupted through continental crust (Hynes and Francis, 1982), magmatic differentiation involving crustal contamination is a possibility. In general, continental tholeiites have distinctive trace element profiles characterized by strong negative Nb and Ta anomalies (with respect to chondrite-normalized LILE and LREE) as a consequence of crustal contamination (Cox and Hawkesworth, 1985). The PG tholeiitic basalts, however, lack significant Nb and Ta anomalies (Fig. 12a). The effect of crustal contamination on Nb and Ta abundances can be readily seen elsewhere in the eastern Trans-Hudson orogen as in the Eskimo Formation basalts of the Belcher Islands (Fig 12a). Positive $\varepsilon_{Nd(1.96Ga)}$ values for the PG lavas also indicate that assimilation of crustal material was insignificant, unlike in the Eskimo Formation, where negative $\varepsilon_{Nd(1.96)}$ values indicate significant contamination by Archean continental crust (Hegner and Bevier, 1991). Thus in contradiction to the proposal of a previous study, (Legault et al., 1994), our results indicate that crustal contamination has not played a significant role in the evolution of any of the PG lavas, and thus there is no geochemical equivalent of the Eskimo Formation within the PG.

MELT SOURCE REGIONS

Although similar $\varepsilon_{Nd(1.96\ Ga)}$ values (+2 to +3) of the PG tholeiites (Hegner and Bevier, 1991) and the Kenty Lake alkaline suite (Gaonac'h et al., 1992) have been used to suggest that they could have been derived from the same source (Hegner and Bevier, 1991), such an explanation cannot account for the differences in trace-element concentrations of these two magma types. This conclusion, however, is based on only a few samples (3 for the PG tholeiites, Hegner and Bevier, 1991), and no mechanism for generating both highly alkaline and tholeiitic lavas from a similar source is given.

Fig. 12. Chondrite normalized trace element patterns for a) the Povungnituk Group basalts (striped regin) and for the Eskimo Formation (Belcher Islands) and b) the Flaherty Formation. Normalizing factors from McDonough and Frey (1990).


10²
10¹
10⁰
sample/chondrite
a)
Povungnituk Group basalts
Eskimo Formation
(Belcher Islands)
Th Ta Nb La Ce Nd Sm Zr Hf Eu Ti Tb Y Yb Lu
b)
Flaherty Formation
(Belcher Islands)

Furthermore, the three PG samples analyzed by Hegner and Bevier (1991) have relatively restricted Nd and Sm concentrations (17.29-18.33ppm and 4.36-4.70ppm, repsectively) whereas, results from this study reveal that there is significant variation in Nd and Sm contents throughout the PG tholeiites (8.13-47.71ppm and 2.42-10.12ppm, respectively). The Nd and Sm concentrations reported by Hegner and Bevier (1991) are similar to the moderately trace-element enriched lavas from this study.

The compositions of mantle-derived melts are controlled by the compositions of the source rocks and the conditions under which partial melting occurs (pressure, temperature, and volatile content). A number of recent geochemical studies have suggested the existence of multiple source regions in the mantle in order to account for the variation in trace-element concentrations in large igneous provinces (Fitton, 1998; Takahahshi, 1998). The highly variable concentrations of incompatible trace-elements observed within the PG suggest the possibility of the involvement of several mantle sources or source compositions. Basalts produced by melting of asthenospheric mantle (e.g., MORB) are generally depleted in the highly incompatible elements relative to primitive mantle, whereas enrichment in these elements is commonly attributed to melting of enriched OIB-type mantle (i.e., deep seated plume source or enriched lithospheric mantle). Continental flood-basalts may be derived in part from the melting of the subcontinental lithosphereic mantle or may have been contaminated by melts derived from this source (e.g., Ellam and Cox, 1991). Reactions between asthenospheric-derived magmas and lithospheric mantle have been proposed to account for the geochemical characteristics observed in a number of continental flood-basalts (Ellam and Cox, 1991). Thermomechanical models (Arndt and Christenensen, 1992) suggest, however, that dry melting of cold lithospheric mantle probably contributes little to primitive continental magmas. Melting of hydrous lithosphere will, however, occur at several hundred degrees lower temperature and thus under wet conditions the lithospheric mantle may make an important contribution to the composition of continental flood-basalts (Gallagher and Hawkesworth, 1992). The enriched sub-continental lithospheric-mantle may have been the source for the Kenty Lake alkaline and Lac LeClair volcanic suites, but it is unlikely that this is also the source for the majority of the PG tholeiites since these lavas have unfractionated REE and low trace-element concentrations. Distinct provincialities in terms of trace-element enrichedment in other CFB provinces (e.g., Karoo, Ellam and Cox, 1991), have been interpreted to represent different mantle source-regions. In the Cape Smith foldbelt, although the most trace-element enriched PG tholeiites are spatially associated with the Kenty Lake alkaline centre, enriched basalts are widely distributed in the PG, intercalated with basalts having very low concentrations of trace elements (Fig. 3). This suggests that the enriched component in the PG was dispersed on a fine scale in the mantle source.

MAGMA MIXING

The presence of a highly trace-element enriched suite near the base of the Povungnituk Group (Lac LeClair volcanic suite) and another near the top of the sequence (Kenty Lake alkaline suite) clearly indicate the presence of centres of distinct types of trace-element enrichment. The question is whether mixing between trace-element enriched melts of the Lac LeClair and/or Kenty Lake suites and the more voluminous low Zr tholeiites can explain the spectrum of trace-element enrichment in the PG tholeiitic basalts.

The possibility that the spectrum of PG basalts represents mixing between a depleted and enriched component was tested by calculating mixing curves between the relatively trace-element depleted PG basalts and the mafic lavas of the two alkaline suites. The average composition of the relatively depleted PG basalts was mixed with the average compositions of primitive alkaline lavas of both the Lac LeClair volcanic suite and the Kenty Lake alkaline suite as possible enriched components (Figs. 8 and 9). Most of the trace-element enriched PG lavas fall along the mixing curve with the Kenty Lake alkaline suite, suggesting that the Kenty Lake alkaline magmas could represent the enriched component seen in the PG tholeiites. This interpretation is supported by the close spatial relationship between the majority of the trace element enriched PG tholeiites and the Kenty Lake alkaline suite (Fig. 3). Mixing calculations provide little support for the involvement of magmas like those of the Lac LeClair volcanic suite in production of the geochemical spectrum of the PG basalts (Figs. 8 and 9).

The trace-element signatures of the Flaherty Formation basalts of the Belcher Islands are similar to those of the PG tholeiites (Fig. 12b). Although the Flaherty basalts have higher incompatible trace-element concentrations than the majority of the PG lavas, they are not as enriched as the enriched PG tholeiites, and are chemically indistinguishable from the mildly enriched PG lavas. Consequently, the enriched component observed in the PG lavas may be present in the Flaherty Formation basalts.

In general, the PG lavas exhibit a spectrum of La/Sm and Nb/Zr similar to that observed for Hawaiian lavas, ranging from tholeiites to basanites and nephelinites (Fig. 13). The dominant PG tholeiites are depleted relative to Hawaiian tholeiites, however, and are more similar to the basalts of ocean plateaus. There is also a similarity of trace-element patterns between the relatively depleted PG tholeiites and the upper flows of the Coppermine River basalts, which are interpreted as having undergone minimal crustal contamination (Fig. 14, Griselin et al., 1997). The relatively depleted nature of the dominant PG tholeiites and the lack of negative high field strength element anomalies in the enriched PG tholeiites emphasize the fact that the PG volcanics are not typical continental flood-basalts. The relatively trace-element depleted contents of most of the PG tholeiites are more typical of basalts of oceanic plateaus and the upper flows of some CFB which have not been significantly contaminated with continental crust.

The geochemistry of the PG lavas can be explained in terms of the mixing of two distinct mantle components. A relatively depleted end member, which dominates the magma supply, and an enriched component. There are several possibilities for the origin of the two end-members. The enriched component may reside in a metasomatized lithospheric mantle, which melted in response to the ponding of the depleted magma from below. Alternatively, the enriched component may represent enriched mantle domains embedded in a more depleted mantle matrix, as proposed for the plum-pudding model for

Fig. 13. Nb/Zr versus La/Sm showing the range of values for the Povungnituk Group, Lac LeClair volcanic suite, Kenty Lake alkaline suite, Eskimo and Flaherty Formation, Husky Formation (Coppermine River basalts, data from Griselin et al, 1997), Caribbean Plateau (data from Kerr, 1996) and Hawaiian basalts ranging from tholeiites to highly alkaline types (data from Garcia et al., 1994).

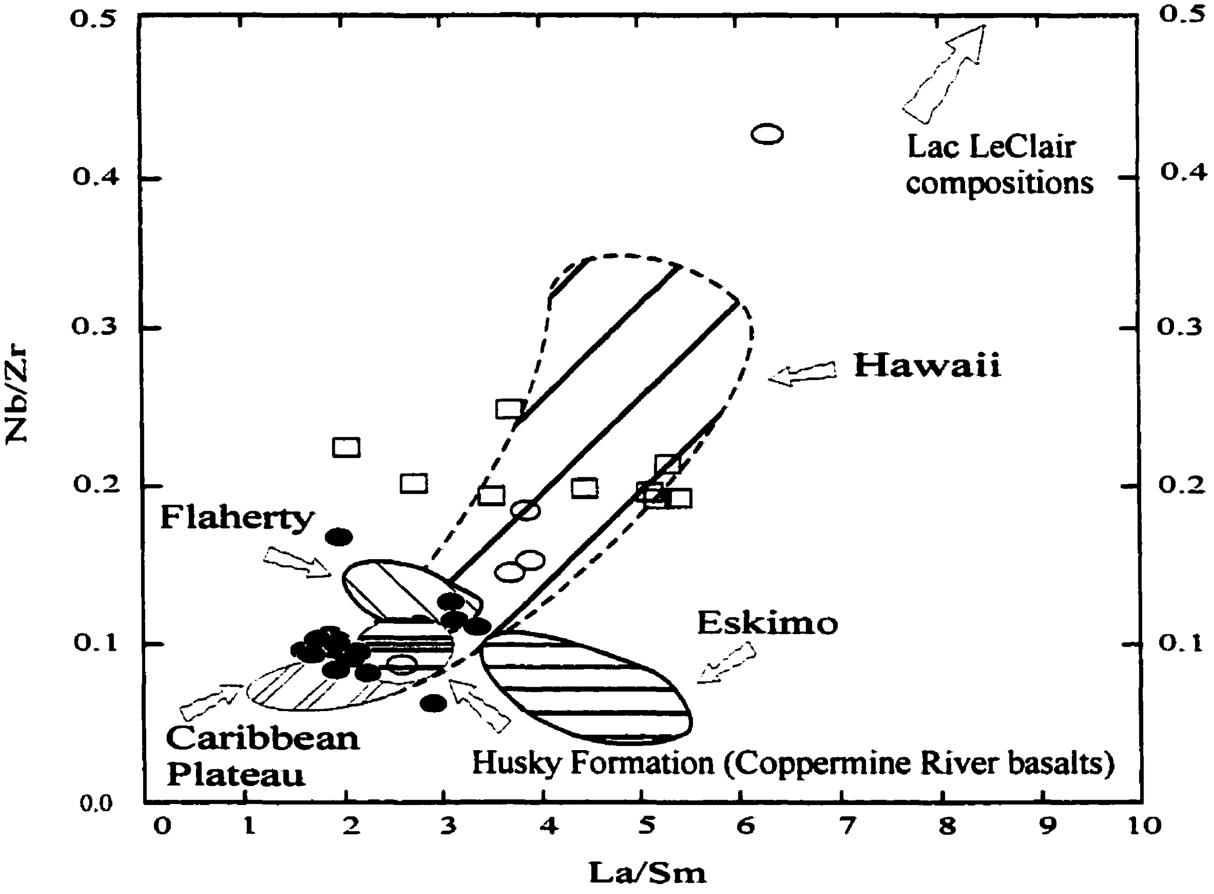
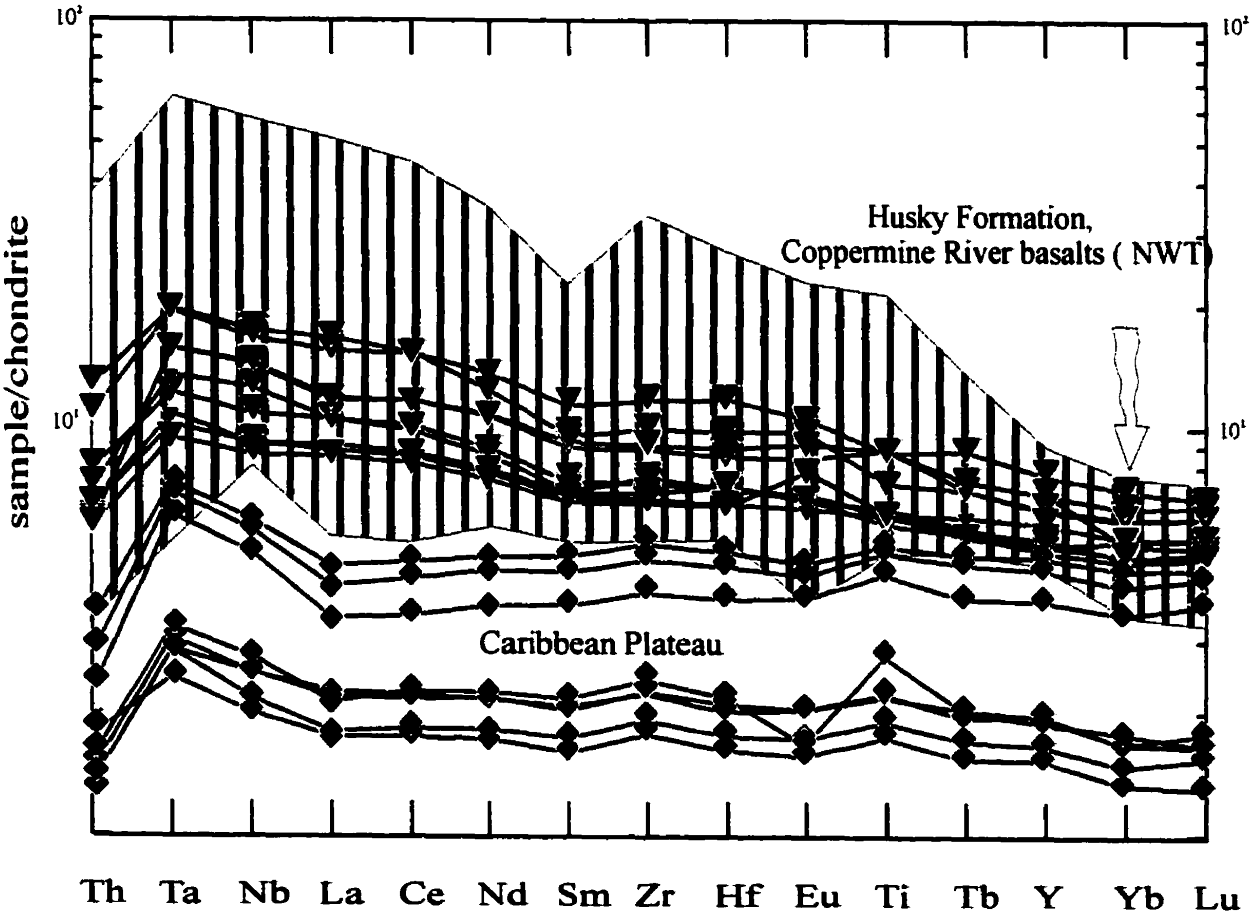

0.5
0.4
0.3
0.2
0.1
0.0
Nb/Zr
0
1
2
3
4
5
6
7
8
9
10
La/Sm
Lac LeClair
compositions
Hawaii
Flaherty
Eskimo
Caribbean
Plateau
Husky Formation (Coppermine River basalts)

Fig. 14. Chondrite normalized trace element patterns for the Povungnituk Group basalts (striped regin), the Husky Formation (triangles; data from Griselin et al, 1997), and for the Caribbean Plateau (diamonds; data from Kerr, 1996).


10²
10²
10¹
10¹
sample/chondrite
Husky Formation,
Coppermine River basalts (NWT)
Caribbean Plateau
Th
Ta
Nb
La
Ce
Nd
Sm
Zr
Hf
Eu
Ti
Tb
Y
Yb
Lu

the mantle (Davies, 1981). In this scenario, the PG lavas would reflect mixing of magmas from enriched domains with those from their more depleted matrix, either in the asthenosphere or in a more deep-seated mantle plume. The trace element evidence alone will not resolve this question. In either case, however, it is likely that the relatively depleted tholeiitic basalts which dominate the PG is deep-seated, based on the volume criteria alone. Furthermore, the existence of two Zr-fractionation trends in the PG tholeiites suggests that there may be two distinct mantle-sources, the low-Zr lavas may represent the differentiated magmas derived from a deep-seated plume whereas the high-Zr lavas may have been derived from the partial melting of lithospheric mantle.

CONCLUSIONS

The Povungnituk Group lavas are dominated by relatively evolved tholeiitic basalts, lying along the gabbroic cotectic. Even the most primitive lavas are unlikely to represent primary mantle-derived melts, but rather residual liquids that have fractionated from a more magnesium-rich parental magma. Although these basalts have relatively monotonous major element compositions, the variations in trace element abundances indicate the variable presence of an enriched-mantle-source component. Despite their continental setting, the Povungnituk Group basalts lack negative Nb and Ta anomalies relative to light rare earth elements and carbonaceous chondrites, indicating that crustal contamination did not play a significant role in their evolution. While crystal fractionation accounts for much of the variation in incompatible-trace-element concentrations, this process cannot account for the range of incompatible-element ratios observed in the Povungnituk Group. The ratios of high-field-strength elements (e.g., Nb, Zr) and rare-earth elements (e.g., La, Sm) suggest mixing between a dominate relatively depleted component and a highly enriched one represented by the Kenty Lake alkaline suite can explain the range of incompatible trace-element contents in the Povungnituk Group tholeiitic basalts. The enriched component occurs as localized centres, but also appears to be widely distributed either in the lithosphere or as enriched domains in the mantle source of relatively depleted tholeiites. The relatively depleted tholeiitic basalts that dominate the PG suite are most similar to ocean Phanerozoic plateaus or relatively depleted basalts, which appear towards the top of many CFB provinces. The trace-element characteristics of the PG basalts suggest that plume and lithosphere interaction may have play an important role in the evolution of these Paleoproterozoic continental flood basalts.

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GENERAL SUMMARY AND CONCLUSIONS

The Povungnituk Group of the Cape Smith foldbelt in northern Québec comprises sequences of clastic sediments, tholeiitic basalts, highly alkaline lavas as well as minor rhyolites. Relatively evolved tholeiitic basalts, whose major element compositions are generally consistent with the processes of gabbroic crystal fractionation, dominate the Povungnituk Group lavas. These lavas, however, reveal significant variations in trace-element concentrations, particularity LREE and HFSE. The absence of strong negative Nb and Ta anomalies relative to LREE and carbonaceous chondrites suggests that crustal contamination did not play a major role in the evolution of the Povungnituk tholeiitic basalts, despite their continental setting. Although much of the trace-element variation can be accounted for by approximately 65% crystal fraction along the gabbroic cotectic, this process cannot explain the wide range of observed incompatible trace-element ratios within the Povungnituk Group. Magma mixing between two distinct sources, a highly trace-element enriched component and a relatively depleted end member can account for much of the variation in incompatible trace-element ratios, particularity La/Sm and Nb/Zr. The dominant relatively depleted end member occurs throughout the Povungnituk Group, while the enriched end member appears to be spatially associated with a highly alkaline suite located in the centre of the Povungnituk Group, near the top of the sequence (Kenty Lake alkaline suite). Two magmatic series can be identified based on trace-element contents, a low-Zr series and a high-Zr series. The high-Zr series generally correlates with the most incompatible trace-element enriched lavas, which occur near the Kenty Lake alkaline suite, whereas the low-Zr series corresponds to the relatively depleted end member located throughout the Povungnituk Group. Within the low-Zr series, however, moderately enriched lavas are observed and can be explained by mixing between the two end members.

There are several possibilities for the origin of the two end members, however, due to the volume criteria (>6 km volcanic accumulation within the Povungnituk Group) and the geochemical similarities with oceanic plateaus (Caribbean Plateau) and the upper lavas of some continental flood-basalt provinces (Husky Formation of the Coppermine River basalts) it is likely that the dominate relatively depleted end member is a deep-seated mantle plume which may have interacted with trace-element enriched lithospheric mantle to produce the trace-element enriched tholeiitic basalts.

This study has shown that there are two chemically distinct lavas within the Povungnituk Group. A previous study has suggested that there is a petrogenetic link between the Paleoproterozoic basalts exposed on the Belcher Islands and the Paleoproterozoic basalts of the Povungnituk Group (Legault, 1994). The results from this study, however, indicate that there is no geochemical equivalent of the crustal contaminated Eskimo Formation (Belcher Islands) observed in the Povungnituk Group. Although, the trace-element enriched component observed in the Povungnituk Group does also appear to be present in the Flaherty Formation (Belcher Islands). Thus, the chemical stratigraphy established in the Povungnituk Group may be used to correlate other parts of the Trans-Hudson orogen. In order to further evaluate the proposed chemical correlations between the Povungnituk Group and other parts of the Trans-

Hudson orogen, the author suggests that detailed trace-element and isotopic studies of continental flood-basalts be conducted within the orogenic belt. In particular, a detailed study of the geochemistry of the basalts of the Labrador Trough in comparison with that established in the Povungnituk could settle an outstanding controversial issue regarding their petrogenetic relationship.

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APPENDICES

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	HI-81	HI-82	HI-84	HI-86	HI-87	HI-89	HI-91
Rock :	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	49.74	53.61	50.72	48.69	48.58	48.20	51.37
TiO_2	2.54	1.80	1.37	1.83	1.34	1.64	1.79
Al_2O_3	11.70	12.57	13.28	13.44	14.10	14.59	15.35
Fe_2O_3	16.28	7.21	13.28	15.58	12.02	14.21	12.20
MnO	0.20	0.12	0.19	0.22	0.18	0.22	0.18
MgO	5.22	3.17	6.22	6.43	8.16	7.54	5.78
CaO	5.49	8.68	12.21	9.46	8.47	7.68	6.27
Na_2O	1.85	4.50	0.54	2.30	3.50	2.77	5.02
K_2O	0.15	0.25	0.04	0.19	0.42	1.21	0.26
P_2O_5	0.22	0.19	0.11	0.15	0.10	0.13	0.15
LOI	7.44	7.65	2.78	2.41	3.49	2.67	2.33
Total	100.84	99.76	100.74	100.71	100.36	100.85	100.69

Trace Elements in ppm

Rb	3.7	3.2	2.3	4.5	9.3	35.7	6.2
Sr	88.5	75.2	309.7	324.0	92.0	94.3	145.0
V	432.0	243.0	299.0	375.0	312.0	349.0	368.0
Cr	79.4	86.2	182.0	107.4	128.6	134.1	123.8
Ni	39.0	56.0	84.0	54.0	78.0	86.0	61.0
Y	34.8	24.6	23.4	30.5	25.6	25.0	24.1
Zr	153.5	108.1	71.5	106.4	66.2	87.4	105.3
Nb	12.6	10.3	6.6	8.5	6.5	7.9	12.7
Hf	-	2.8	-	-	1.9	-	-
Ta	-	0.5	-	-	0.3	-	-

Rare Earth Elements in ppm

La	-	4.55	-	-	4.89	-	-
Nd	-	9.30	-	-	8.93	-	-
Sm	-	2.87	-	-	2.59	-	-
Eu	-	1.04	-	-	1.03	-	-
Gd	-	3.47	-	-	3.44	-	-
Tb	-	0.67	-	-	0.62	-	-
Tm	-	0.36	-	-	0.36	-	-
Yb	-	2.22	-	-	2.31	-	-
Lu	-	0.32	-	-	0.33	-	-
Th	-	0.55	-	-	0.31	-	-
U	-	0.32	-	-	0.10	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	HI-93	HI-98	HI-103	HI-63	HI-64	HI-76	HI-49
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	46.72	47.64	48.03	47.84	45.93	47.73	50.02
TiO_2	2.25	2.12	1.53	1.36	1.31	2.17	1.63
Al_2O_3	12.70	12.85	14.04	13.79	14.85	13.09	13.47
Fe_2O_3	15.87	16.17	12.02	14.05	13.62	14.97	14.88
MnO	0.24	0.24	0.20	0.20	0.22	0.21	0.22
MgO	5.26	6.40	6.64	7.65	7.87	6.67	6.64
CaO	11.44	10.66	13.33	10.74	11.89	9.95	8.48
Na_2O	0.77	1.62	2.23	2.63	1.92	2.64	2.82
K_2O	0.10	0.13	0.17	0.21	0.18	0.43	0.14
P_2O_5	0.23	0.22	0.15	0.10	0.10	0.22	0.14
LOI	4.27	2.27	2.09	2.12	2.49	1.94	2.27
Total	99.85	100.32	100.43	100.69	100.37	100.01	100.72

Trace Elements in ppm

Rb	4.0	3.3	4.2	4.3	4.8	9.5	4.1
Sr	225.0	277.6	294.4	44.4	136.1	177.4	149.0
V	443.0	377.0	286.0	293.0	303.0	361.0	342.0
Cr	150.5	547.4	192.9	184.0	184.0	101.9	136.8
Ni	80.0	227.0	72.0	99.0	111.0	48.0	68.0
Y	30.6	34.6	25.4	24.0	24.7	29.5	28.0
Zr	141.3	140.9	108.2	74.9	71.4	158.5	96.4
Nb	18.4	12.8	12.5	7.3	7.2	18.4	8.8
Hf	-	-	-	-	-	-	-
Ta	-	-	-	-	-	-	-

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	HI-51	HI-52	HI-37	HI-38	HI-1	HI-10
Rock:	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	49.08	47.47	48.80	48.67	54.92	48.82
TiO_2	1.30	1.37	1.69	1.64	0.72	1.10
Al_2O_3	13.72	14.17	13.98	13.90	17.21	17.16
Fe_2O_3	13.32	13.50	14.27	13.92	6.89	10.05
MnO	0.19	0.21	0.22	0.24	0.07	0.14
MgO	7.93	7.24	5.86	6.08	5.75	6.34
CaO	10.52	11.92	11.40	11.39	8.45	11.86
Na_2O	2.73	2.03	2.55	2.47	4.46	2.61
K_2O	0.12	0.08	0.37	0.35	0.10	0.19
P_2O_5	0.10	0.11	0.21	0.20	0.06	0.12
LOI	2.04	1.99	1.51	1.58	2.00	2.20
Total	101.04	100.09	100.86	100.44	100.63	100.59

Trace Elements in ppm

Rb	3.7	3.2	9.2	8.3	3.0	4.4
Sr	131.1	167.2	322.6	364.1	165.4	635.6
V	296.0	317.0	301.0	293.0	149.0	219.0
Cr	185.4	183.4	80.0	88.3	303.1	130.7
Ni	93.0	85.0	41.0	42.0	96.0	143.0
Y	23.4	23.4	28.7	28.2	20.3	19.6
Zr	69.0	71.4	180.2	170.7	151.3	76.4
Nb	7.5	6.6	20.3	19.3	8.8	6.5
Hf	-	-	4.5	-	-	-
Ta	-	-	1.2	-	-	-

Rare Earth Elements in ppm

La	-	-	18.80	-	-	-
Nd	-	-	24.70	-	-	-
Sm	-	-	5.78	-	-	-
Eu	-	-	2.12	-	-	-
Gd	-	-	5.94	-	-	-
Tb	-	-	0.93	-	-	-
Tm	-	-	0.42	-	-	-
Yb	-	-	2.69	-	-	-
Lu	-	-	0.36	-	-	-
Th	-	-	1.26	-	-	-
U	-	-	0.30	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	EK-23	EK-22	EK-20	EK-1	EK-2	EK-4	EK-5
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	44.73	45.29	49.48	49.61	46.66	48.33	48.24
TiO_2	1.29	1.50	1.76	1.45	2.03	1.40	2.18
Al_2O_3	3.86	15.30	13.41	13.45	13.61	14.05	13.81
Fe_2O_3	3.43	11.42	15.47	14.53	17.33	13.78	14.37
MnO	0.21	0.17	0.23	0.17	0.18	0.20	0.20
MgO	6.40	5.61	5.96	7.40	6.41	7.04	7.03
CaO	15.01	12.85	9.49	8.91	8.97	10.98	8.91
Na_2O	0.48	2.66	2.54	3.39	2.30	2.88	2.93
K_2O	0.03	0.43	0.10	0.07	0.39	0.37	0.65
P_2O_5	0.10	0.12	0.15	0.12	0.18	0.10	0.19
LOI	4.55	5.37	2.08	2.13	2.43	2.09	2.17
Total	100.10	100.73	100.67	101.23	100.50	101.23	100.68

Trace Elements in ppm

Rb	2.6	9.8	2.9	2.2	12.0	13.0	17.1
Sr	230.1	138.7	181.4	67.5	182.6	194.5	123.8
V	318.0	330.0	351.0	308.0	388.0	307.0	370.0
Cr	167.6	127.9	103.3	225.8	123.8	110.2	134.1
Ni	78.0	66.0	56.0	204.0	59.0	74.0	74.0
Y	22.8	24.3	30.2	25.1	37.9	22.5	29.1
Zr	68.7	81.7	103.2	76.8	139.4	70.1	122.1
Nb	6.1	8.1	8.8	8.3	12.8	6.5	16.2
Hf	-	-	2.9	-	-	-	-
Ta	-	-	0.5	-	-	-	-

Rare Earth Elements in ppm

La	-	-	5.10	-	-	-	-
Nd	-	-	9.86	-	-	-	-
Sm	-	-	2.79	-	-	-	-
Eu	-	-	1.14	-	-	-	-
Gd	-	-	3.45	-	-	-	-
Tb	-	-	0.62	-	-	-	-
Tm	-	-	0.33	-	-	-	-
Yb	-	-	2.16	-	-	-	-
Lu	-	-	0.31	-	-	-	-
Th	-	-	0.39	-	-	-	-
U	-	-	0.12	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample: Rock:	EK-6 Blst	EK-17 Blst	EK-16 Blst	EK-14 Blst	EK-11 Blst	EK-9 Blst	EK-8 Blst
SiO_2	47.28	48.41	46.53	48.86	51.64	49.40	48.03
TiO_2	1.78	1.42	1.40	1.31	1.41	1.37	1.77
Al_2O_3	13.51	14.55	14.79	14.05	13.81	13.56	13.37
Fe_2O3	16.03	14.35	14.77	13.89	11.95	12.56	15.33
MnO	0.22	0.17	0.19	0.18	0.16	0.19	0.22
MgO	7.04	7.51	8.70	7.87	7.52	6.18	5.67
CaO	8.40	7.85	8.07	8.93	7.31	12.84	11.87
Na_2O	3.22	3.54	2.25	3.26	4.46	1.58	1.61
K_2O	0.10	0.08	0.98	0.06	0.08	0.10	0.07
P_2O_5	0.17	0.10	0.11	0.12	0.13	0.11	0.16
LOI	2.83	2.45	3.00	2.26	2.06	2.41	2.25
Total	100.58	100.44	100.79	100.79	100.53	100.29	100.34

Trace Elements in ppm

Rb	2.6	2.3	18.7	2.2	2.5	3.2	2.9
Sr	225.1	82.9	87.5	80.2	41.5	333.7	331.5
V	344.0	310.0	324.0	297.0	284.0	292.0	360.0
Cr	188.8	205.9	182.7	366.7	217.6	179.3	104.0
Ni	71.0	169.0	107.0	199.0	104.0	137.0	52.0
Y	23.7	26.1	23.6	22.9	22.1	22.4	30.2
Zr	102.3	77.9	75.5	80.7	78.2	69.7	103.8
Nb	14.0	7.3	7.9	8.5	8.2	6.8	8.2
Hf	-	-	2.2	-	2.0	-	-
Ta	-	-	0.4	-	0.3	-	-

Rare Earth Elements in ppm

La	-	-	5.10	-	4.3	-	-
Nd	-	-	9.86	-	8.92	-	-
Sm	-	-	2.79	-	2.65	-	-
Eu	-	-	1.14	-	0.80	-	-
Gd	-	-	3.45	-	3.26	-	-
Tb	-	-	0.62	-	0.60	-	-
Tm	-	-	0.33	-	0.29	-	-
Yb	-	-	2.16	-	1.88	-	-
Lu	-	-	0.31	-	0.27	-	-
Th	-	-	3.39	-	0.42	-	-
U	-	-	0.12	-	0.21	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample: Rock:	BO-22 Blst	BO-2 Blst	BO-18 Blst	BO-17 Blst	BO-13 Blst	BO-12 Blst	BO-15 Blst
SiO_2	45.08	50.42	51.84	48.35	49.38	49.10	49.42
TiO_2	1.50	1.39	1.40	1.46	1.90	1.96	1.38
Al_2O_3	13.21	13.64	12.89	14.52	13.60	14.28	14.02
Fe_2O_3	14.21	12.14	11.79	14.28	13.15	13.35	13.59
MnO	0.21	0.21	0.19	0.23	0.20	0.18	0.20
MgO	5.97	7.16	7.42	6.25	6.02	6.13	7.05
CaO	12.90	10.57	8.04	11.46	11.80	10.77	10.58
Na_2O	1.47	3.19	4.70	2.87	1.69	2.70	2.21
K_2O	0.16	0.13	0.10	0.19	0.39	0.34	0.10
P_2O_5	0.12	0.12	0.13	0.11	0.19	0.20	0.12
LOI	5.54	1.60	2.34	1.42	1.99	1.99	2.22
Total	100.37	100.58	100.83	101.14	100.30	100.99	100.89

Trace Elements in ppm

Rb	4.4	2.2	2.8	4.4	10.5	9.0	3.5
Sr	211.2	72.5	32.6	107.6	505.9	365.8	223.4
V	341.0	310.0	265.0	323.0	309.0	313.0	310.0
Cr	170.4	201.2	194.3	153.9	136.8	150.5	182.0
Ni	191.0	120.0	83.0	91.0	55.0	66.0	75.0
Y	24.8	23.4	22.1	24.4	24.4	25.4	23.6
Zr	79.4	76.4	77.6	73.8	131.1	134.9	75.7
Nb	7.4	7.6	8.7	7.6	13.0	13.6	7.4
Hf	-	-	-	-	3.5	-	-
Ta	-	-	-	-	0.8	-	-

Rare Earth Elements in ppm

La	-	-	-	-	11.4	-	-
Nd	-	-	-	-	18.3	-	-
Sm	-	-	-	-	4.48	-	-
Eu	-	-	-	-	1.74	-	-
Gd	-	-	-	-	4.96	-	-
Tb	-	-	-	-	0.81	-	-
Tm	-	-	-	-	0.35	-	-
Yb	-	-	-	-	2.19	-	-
Lu	-	-	-	-	0.29	-	-
Th	-	-	-	-	1.12	-	-
U	-	-	-	-	0.27	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	EL-18	EL-17	EL-4	EL-3	EL-5	RC-15	RC-16
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	49.63	49.72	50.19	49.76	46.96	49.27	48.63
TiO_2	1.24	2.36	1.92	1.94	2.10	1.59	1.63
Al_2O_3	13.91	12.85	12.90	13.60	13.61	15.60	14.54
Fe_2O_3	13.35	15.20	13.90	12.92	15.38	13.99	15.13
MnO	0.19	0.22	0.20	0.20	0.24	0.22	0.20
MgO	7.57	5.55	6.66	6.74	6.51	5.19	7.14
CaO	10.29	10.89	9.36	10.50	11.64	8.79	6.78
Na_2O	2.97	2.51	3.57	3.12	2.01	3.90	3.76
K_2O	0.09	0.27	0.17	0.17	0.11	0.10	0.17
P_2O_5	0.09	0.26	0.19	0.19	0.19	0.14	0.14
LOI	1.80	0.88	2.21	1.69	1.85	1.89	2.51
Total	101.14	100.71	101.26	100.83	100.59	100.68	100.62

Trace Elements in ppm

Rb	2.6	3.6	3.8	4.1	3.0	1.9	4.1
Sr	250.0	300.7	161.6	195.9	345.8	52.5	49.3
V	302.0	390.0	335.0	318.0	366.0	351.0	333.0
Cr	194.3	85.5	145.7	131.4	147.1	190.9	227.8
Ni	72.0	38.0	57.0	49.0	113.0	169.0	87.0
Y	24.5	31.3	26.3	26.3	27.8	32.5	29.0
Zr	65.4	162.3	103.4	133.5	126.3	92.5	93.8
Nb	5.7	18.6	15.1	14.5	10.9	8.1	8.6

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	RC-17	RC-18	RC-8	RC-7	RC-2	FO-1	FO-5
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	48.46	49.95	50.02	47.56	48.76	48.11	47.58
TiO_2	1.56	1.64	2.60	2.51	1.36	2.02	2.04
Al_2O_3	13.49	13.42	12.08	11.87	13.54	13.93	13.68
Fe_2O_3	14.03	14.34	15.76	16.46	14.01	13.91	14.77
MnO	0.20	0.25	0.20	0.22	0.18	0.19	0.23
MgO	7.08	6.67	4.74	4.50	7.46	6.57	6.68
CaO	11.36	7.69	7.82	9.77	9.26	10.25	11.35
Na_2O	2.45	4.25	2.52	2.85	2.54	2.74	2.33
K_2O	0.08	0.22	0.11	0.46	0.06	0.22	0.11
P_2O_5	0.12	0.14	0.22	0.26	0.11	0.21	0.22
LOI	1.78	1.93	4.14	3.47	2.64	1.92	1.93
Total	100.61	100.49	100.21	99.92	99.91	100.07	100.92

Trace Elements in ppm

Rb	2.5	6.1	3.7	12.1	2.3	5.3	3.1
Sr	144.0	26.0	97.3	143.9	132.9	183.1	291.9
V	326.0	303.0	475.0	451.0	312.0	330.0	355.0
Cr	188.8	96.5	91.0	85.5	198.4	156.7	136.8
Ni	96.0	56.0	46.0	56.0	100.0	64.0	65.0
Y	25.5	24.5	39.3	40.6	23.1	26.9	27.8
Zr	85.3	100.8	159.7	166.7	72.7	135.4	148.1
Nb	7.9	9.2	13.6	13.0	7.4	14.5	16.8
Hf	-	-	-	-	1.9	-	-
Ta	-	-	-	-	0.3	-	-

Rare Earth Elements in ppm

La	-	-	-	-	18.8	-	-
Nd	-	-	-	-	8.87	-	-
Sm	-	-	-	-	2.54	-	-
Eu	-	-	-	-	0.95	-	-
Gd	-	-	-	-	3.02	-	-
Tb	-	-	-	-	0.55	-	-
Tm	-	-	-	-	0.30	-	-
Yb	-	-	-	-	1.94	-	-
Lu	-	-	-	-	2.71	-	-
Th	-	-	-	-	0.35	-	-
U	-	-	-	-	0.10	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	FO-4	FO-15	FO-14	FO-13
Rock:	Blst	Blst	Blst	Blst
SiO_2	48.26	46.79	50.21	51.02
TiO_2	2.03	1.54	2.34	2.16
Al_2O_3	13.79	14.14	13.61	12.66
Fe_2O_3	14.07	14.33	14.64	14.77
MnO	0.22	0.21	0.21	0.21
MgO	6.31	6.75	5.62	5.13
CaO	11.68	12.81	7.61	9.57
Na_2O	2.45	2.00	4.28	3.56
K_2O	0.12	0.13	0.21	0.15
P_2O_5	0.22	0.13	0.22	0.19
LOI	1.73	1.89	1.52	1.62
Total	100.87	100.71	100.47	101.05

Trace Elements in ppm

Rb	2.9	3.2	5.3	2.6
Sr	262.4	331.0	72.7	94.7
V	355.0	330.0	360.0	389.0
Cr	125.9	153.3	129.3	111.5
Ni	52.0	83.0	65.0	63.0
Y	27.5	24.7	30.8	30.1
Zr	143.4	83.6	148.4	134.3
Nb	16.3	7.2	13.7	13.0
Hf	-	-	-	3.7
Ta	-	-	-	0.7

Rare Earth Elements in ppm

La	-	-	-	9.53
Nd	-	-	-	17.8
Sm	-	-	-	4.66
Eu	-	-	-	1.70
Gd	-	-	-	5.28
Tb	-	-	-	0.90
Tm	-	-	-	0.42
Yb	-	-	-	2.68
Lu	-	-	-	0.38
Th	-	-	-	0.77
U	-	-	-	0.22

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample: Rock:	904 Blst	916 Blst	917 Blst	918 Blst	919 Blst	920 Blst	923 Blst
SiO_2	51.69	49.01	50.55	48.43	50.53	49.74	50.81
TiO_2	1.38	1.35	1.42	1.42	1.40	1.63	1.12
Al_2O_3	15.03	14.56	14.51	14.46	13.41	14.16	14.16
Fe_2O_3	12.54	13.86	13.38	12.35	13.72	14.93	12.40
MnO	0.15	0.22	0.19	0.18	0.20	0.24	0.18
MgO	4.72	5.99	5.74	5.60	5.35	6.46	7.23
CaO	8.25	8.48	9.07	12.03	11.65	7.41	8.23
Na_2O	4.83	3.97	4.05	2.54	2.36	3.69	3.76
K_2O	0.29	0.13	0.09	0.21	0.07	0.17	0.22
P_2O_5	0.11	0.11	0.15	0.13	0.11	0.15	0.09
LOI	2.04	2.84	1.77	2.43	1.91	2.41	2.03
Total	101.03	100.51	100.92	99.77	100.71	100.97	100.24

Trace Elements in ppm

Rb	3.9	3.0	2.4	5.7	2.4	4.9	6.0
Sr	61.2	58.9	76.5	228.2	58.8	75.5	95.1
V	360.0	309.0	310.0	333.0	304.0	352.0	278.0
Cr	190.9	215.5	108.8	151.2	166.9	135.5	178.6
Ni	91.0	99.0	56.0	90.0	67.0	71.0	113.0
Y	29.0	23.5	24.3	24.0	23.9	25.3	23.6
Zr	80.1	72.5	82.3	80.4	77.0	92.0	63.1
Nb	7.4	7.1	8.3	7.3	7.2	8.5	6.0

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	924	926	931
Rock:	Blst	Blst	Blst
SiO_2	47.75	49.14	48.73
TiO_2	1.10	1.51	1.12
Al_2O_3	14.57	13.98	14.19
Fe_2O_3	12.90	13.63	13.49
MnO	0.18	0.22	0.21
MgO	6.98	6.69	7.49
CaO	12.73	11.13	9.90
Na_2O	1.90	2.76	3.26
K_2O	0.05	0.11	0.14
P_2O_5	0.09	0.09	0.09
LOI	1.95	1.73	2.08
Total	100.20	100.99	100.71

Trace Elements in ppm

Rb	1.9	2.6	4.2
Sr	188.4	258.7	105.2
V	288.0	367.0	299.0
Cr	148.5	164.2	151.2
Ni	103.0	125.0	84.0
Y	23.7	19.7	24.2
Zr	59.5	57.9	61.6
Nb	5.8	7.4	6.0
Hf	-	-	1.7
Ta	-	-	0.2

Rare Earth Elements in ppm

La	-	-	3.94
Nd	-	-	8.13
Sm	-	-	2.42
Eu	-	-	1.03
Gd	-	-	3.15
Tb	-	-	0.61
Tm	-	-	0.37
Yb	-	-	2.32
Lu	-	-	0.31
Th	-	-	0.30
U	-	-	0.09

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	8328	8329	8344	8348	8349	8350	8369
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	48.33	44.86	46.81	46.83	48.24	47.88	50.19
TiO_2	1.22	1.83	1.43	1.65	1.58	1.49	2.39
Al_2O_3	13.85	16.78	15.17	13.35	14.29	14.19	13.52
Fe_2O_3	14.43	17.39	12.97	17.43	15.43	13.57	15.28
MnO	0.20	0.22	0.18	0.27	0.22	0.20	0.21
MgO	7.16	7.55	6.26	6.72	6.52	6.86	5.23
CaO	10.66	4.06	13.46	9.75	9.01	9.15	8.93
Na_2O	2.81	4.34	2.07	2.49	3.26	3.52	2.40
K_2O	0.10	0.07	0.24	0.11	0.08	0.15	0.75
P_2O_5	0.12	0.16	0.16	0.13	0.14	0.11	0.26
LOI	1.86	4.21	1.60	2.01	2.05	2.59	1.32
Total	100.74	101.48	100.34	100.73	100.82	99.70	100.48

Trace Elements in ppm

Rb	2.7	2.3	6.5	3.1	2.5	4.2	23.1
Sr	102.1	35.3	318.9	138.0	111.5	209.7	250.3
V	310.0	387.0	307.0	392.0	356.0	321.0	416.0
Cr	162.8	199.1	149.2	73.9	123.2	124.5	76.6
Ni	83.0	89.0	50.0	69.0	71.0	76.0	51.0
Y	26.1	31.3	22.9	32.6	28.1	23.6	33.8
Zr	66.9	108.6	97.2	89.1	84.9	85.1	160.9
Nb	6.4	9.6	12.5	6.8	8.3	8.5	13.2
Hf	-	-	2.6	-	-	-	-
Ta	-	-	0.7	-	-	-	-

Rare Earth Elements in ppm

La	-	-	10.16	-	-	-	-
Nd	-	-	14.52	-	-	-	-
Sm	-	-	3.39	-	-	-	-
Eu	-	-	1.33	-	-	-	-
Gd	-	-	3.91	-	-	-	-
Tb	-	-	0.63	-	-	-	-
Tm	-	-	0.29	-	-	-	-
Yb	-	-	1.85	-	-	-	-
Lu	-	-	0.26	-	-	-	-
Th	-	-	0.93	-	-	-	-
U	-	-	0.41	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample: Rock:	15382 Blst	18793 Blst	18838 Blst	18839 Blst	18840 Blst	18841 Blst	18842 Blst
SiO_2	44.54	27.30	47.58	46.72	49.03	48.01	47.07
TiO_2	2.50	7.36	1.82	1.90	2.83	1.87	1.80
Al_2O_3	13.39	7.08	13.39	15.92	13.60	16.00	16.48
Fe_2O_3	19.57	16.61	9.81	11.67	13.32	10.45	10.82
MnO	0.26	0.26	0.17	0.16	0.18	0.15	0.15
MgO	5.37	7.81	6.51	5.73	7.23	5.40	5.81
CaO	10.24	15.08	8.41	13.08	6.72	14.73	13.94
Na_2O	2.35	1.87	4.26	2.58	4.00	2.11	2.20
K_2O	0.24	3.94	0.13	0.05	0.68	0.04	0.03
P_2O	0.09	0.52	0.39	0.22	0.35	0.22	0.21
LOI	1.92	11.58	8.15	2.07	2.60	1.68	2.06
Total	100.48	99.41	100.62	100.11	100.54	100.65	100.56

Trace Elements in ppm

Rb	5.9	124.7	2.7	3.4	9.0	2.6	2.7
Sr	175.5	881.4	371.0	1058.0	272.7	803.7	855.3
V	877.0	376.0	184.0	244.0	247.0	240.0	226.0
Cr	34.9	115.6	442.0	200.5	251.1	178.6	168.3
Ni	64.0	10.0	106.0	109.0	124.0	83.0	107.0
Y	25.9	42.8	25.0	22.6	34.4	22.8	21.2
Zr	57.1	703.4	130.6	105.3	189.7	104.2	99.0
Nb	5.2	297.9	39.6	16.7	30.5	16.9	16.6

Rare Earth Elements in ppm

La	-	232.90	-	-	-	-	-
Nd	-	235.10	-	-	-	-	-
Sm	-	36.95	-	-	-	-	-
Eu	-	10.77	-	-	-	-	-
Gd	-	29.36	-	-	-	-	-
Tb	-	3.06	-	-	-	-	-
Tm	-	0.46	-	-	-	-	-
Yb	-	2.65	-	-	-	-	-
Lu	-	0.38	-	-	-	-	-
Th	-	66.1	-	-	-	-	-
U	-	5.45	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	18843	8333	15425	18758	18774	18844	18845
Rock:	Blst	Blst	Blst	Blst	Blst	Blst	Blst
SiO_2	45.93	46.34	46.23	47.94	51.24	45.18	51.99
TiO_2	2.74	2.83	2.13	3.99	1.21	3.15	2.21
Al_2O_3	13.97	12.96	14.29	14.22	13.59	12.93	10.58
Fe_2O_3	15.28	17.81	11.36	13.32	11.39	16.38	9.70
MnO	0.21	0.36	0.13	0.14	0.17	0.23	0.12
MgO	5.07	4.93	8.59	4.32	6.42	6.56	4.94
CaO	6.40	8.35	10.62	7.62	11.82	10.30	12.74
Na_2O	3.68	2.63	1.97	4.98	3.05	2.49	3.07
K_2O	0.56	1.68	1.20	0.27	0.27	0.05	0.54
P_2O_5	0.31	1.00	0.42	0.49	0.09	0.26	0.20
LOI	6.58	1.19	2.96	2.67	1.29	2.27	4.06
Total	100.74	100.08	99.91	99.96	100.54	99.81	100.14

Trace Elements in ppm

Rb	16.6	63.1	34.0	5.0	7.0	1.8	1.7
Sr	206.9	276.0	582.0	229.7	143.6	111.9	621.9
V	325.0	156.0	252.0	350.0	283.0	394.0	260.0
Cr	73.2	40.4	770.4	82.1	232.6	178.6	364.0
Ni	53.0	13.0	158.0	70.0	94.0	100.0	180.0
Y	32.4	51.5	25.6	33.9	22.7	30.5	23.1
Zr	147.0	356.0	157.9	384.4	66.6	205.1	154.3
Nb	18.9	48.1	34.3	24.7	7.1	18.1	13.3
Hf	-	-	7.3	3.5	-	-	-
Ta	-	-	2.9	0.8	-	-	-

Rare Earth Elements in ppm

La	-	-	25.83	4.37	-	-	-
Nd	-	-	40.04	8.50	-	-	-
Sm	-	-	9.18	2.48	-	-	-
Eu	-	-	3.82	0.99	-	-	-
Gd	-	-	9.28	3.11	-	-	-
Tb	-	-	1.37	0.57	-	-	-
Tm	-	-	0.42	0.31	-	-	-
Yb	-	-	2.60	2.03	-	-	-
Lu	-	-	0.33	0.29	-	-	-
Th	-	-	3.28	1.41	-	-	-
U	-	-	0.69	0.56	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample: Rock:	18846 Blst	18847 Blst	18848 Blst	18849 Blst	23980 Blst	32534 Blst	32549 Blst
SiO_2	50.08	46.96	45.23	45.89	45.85	45.93	44.37
TiO_2	2.41	2.90	3.70	2.11	3.28	3.54	2.52
Al_2O_3	8.54	9.66	11.77	13.76	12.58	12.23	15.68
Fe_2O_3	12.68	14.88	16.44	14.57	14.85	16.66	14.83
MnO	0.16	0.17	0.20	0.22	0.21	0.27	0.22
MgO	11.47	9.71	5.48	5.24	5.08	5.29	7.24
CaO	9.40	10.25	9.86	9.53	7.45	8.82	8.89
Na_2O	2.44	1.94	2.79	3.36	3.56	3.65	2.12
K_2O	0.05	0.44	0.40	0.61	0.87	1.46	0.31
P_2O_5	0.22	0.23	0.34	0.24	0.52	0.64	0.30
LOI	2.66	2.65	4.32	4.31	5.84	1.92	3.53
Total	100.11	99.80	100.53	99.85	100.10	100.41	100.01

Trace Elements in ppm

Rb	2.2	8.9	10.0	25.0	24.4	66.0	11.4
Sr	102.5	148.3	301.2	756.4	187.3	178.2	394.7
V	285.0	356.0	419.0	338.0	334.0	323.0	272.0
Cr	584.3	730.7	61.6	202.5	158.7	57.5	74.6
Ni	228.0	243.0	73.0	77.0	39.0	20.0	68.0
Y	26.7	26.8	28.6	25.9	40.7	43.8	25.3
Zr	167.5	195.8	203.2	157.9	251.3	259.1	135.9
Nb	15.7	17.6	27.7	20.8	38.8	42.1	25.3
Hf	4.4	-	-	-	5.6	-	3.4
Ta	0.9	-	-	-	2.5	-	1.5

Rare Earth Elements in ppm

La	10.72	-	-	-	32.69	-	20.21
Nd	20.98	-	-	-	41.74	-	25.81
Sm	5.42	-	-	-	8.60	-	5.38
Eu	1.87	-	-	-	2.51	-	2.01
Gd	5.72	-	-	-	8.88	-	5.34
Tb	0.91	-	-	-	1.35	-	0.78
Tm	0.32	-	-	-	0.59	-	0.33
Yb	1.92	-	-	-	3.71	-	2.10
Lu	0.26	-	-	-	0.50	-	0.31
Th	0.25	-	-	-	3.03	-	1.51
U	0.96	-	-	-	0.66	-	0.31

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	17884	17888	17890	17895	17898	17900	
Rock:	bslt	bslt	bslt	bslt	bslt	bslt	
SiO_2	47.51	44.97	48.69	46.85	48.09	44.22	
TiO_2	2.18	3.27	1.35	2.26	1.65	2.15	
Al_2O_3	14.82	14.62	14.31	17.38	13.98	16.00	
Fe_2O_3	14.85	14.78	12.98	9.56	13.97	14.41	
MnO	0.21	0.21	0.20	0.15	0.20	0.19	
MgO	7.03	6.66	7.37	6.54	6.90	5.40	
CaO	7.29	11.99	11.11	12.45	11.16	13.49	
Na_2O	3.73	0.35	1.80	2.55	2.44	2.29	
K_2O	0.16	0.05	0.17	1.06	0.19	0.76	
P_2O_5	0.22	0.54	0.17	0.23	0.14	0.19	
LOI	2.70	3.25	2.43	1.12	1.97	1.14	
Total	100.45	100.71	100.69	100.58	100.15	100.70	100.24

Trace Elements in ppm

Rb	4.1	2.6	3.3	41.3	4.6	18.2
Sr	280.4	262.7	265.2	207.1	268.7	212.2
V	325.0	336.0	275.0	393.0	301.0	401.0
Cr	130.7	106.1	216.9	166.9	151.2	157.4
Ni	51.0	57.0	68.0	70.0	71.0	66.0
Y	28.6	40.4	22.8	28.4	22.7	31.7
Zr	154.3	230.4	98.5	162.3	84.9	132.5
Nb	16.1	32.0	11.6	17.7	10.3	14.3

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	17909	17911	17919	17920	17949	32540	AH8064
Rock:	bslt	bslt	bslt	bslt	bslt	bslt	bslt
SiO_2	47.73	42.38	43.64	41.57	43.13	44.31	46.34
TiO_2	1.72	1.66	3.62	3.74	3.93	1.75	1.50
Al_2O_3	16.60	17.82	14.72	15.01	14.23	14.48	14.17
Fe_2O_3	11.71	13.04	16.00	12.27	14.35	11.94	15.46
MnO	0.16	0.32	0.24	0.22	0.26	0.18	0.17
MgO	7.73	7.15	5.55	5.26	5.98	5.71	3.71
CaO	8.03	13.99	10.71	13.03	9.81	18.37	7.62
Na_2O	3.72	1.20	2.62	2.65	3.13	1.19	0.15
K_2O	0.29	0.40	0.37	0.60	0.47	0.07	2.44
P_2O_5	0.16	0.15	0.62	0.55	1.26	0.18	0.16
LOI	3.02	2.78	2.22	5.19	3.54	1.51	8.56
Total	100.87	100.89	100.31	100.08	100.09	99.69	100.28

Trace Elements in ppm

Rb	6.4	12.6	6.1	8.3	7.0	2.0	52.6
Sr	229.4	230.5	135.7	189.4	349.5	145.0	80.8
V	235.0	231.0	329.0	348.0	199.0	342.0	285.0
Cr	96.5	101.9	84.8	106.1	139.6	108.8	119.7
Ni	84.0	95.0	30.0	66.0	67.0	74.0	56.0
Y	21.6	20.7	42.3	41.2	39.9	26.4	24.0
Zr	77.1	76.9	257.3	257.0	307.4	96.5	115.8
Nb	13.3	13.4	40.4	40.6	73.6	11.3	14.4

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX A: COMPOSITION OF POVUNGNITUK GROUP THOLEIITES

Major element in wt%

Sample:	AH8075	AH8076	AH8077	AH8079	AH8081	AH8087	AH8093
Rock:	bslt	bslt	bslt	bslt	bslt	bslt	bslt
SiO_2	47.96	48.05	47.79	49.72	48.86	44.99	50.40
TiO_2	1.62	1.52	1.62	1.63	1.59	1.70	0.81
Al_2O_3	14.86	14.21	14.69	14.45	14.75	16.74	12.59
Fe_2O_3	14.23	13.54	14.55	13.28	12.22	15.00	10.22
MnO	0.20	0.21	0.21	0.20	0.17	0.23	0.19
MgO	5.49	6.22	6.08	5.72	5.62	6.56	10.19
CaO	11.78	12.27	10.79	11.30	11.94	9.64	9.16
Na_2O	2.25	1.91	1.78	2.17	2.61	2.65	0.49
K_2O	0.24	0.34	0.39	0.50	0.60	0.22	3.53
P_2O_5	0.19	0.18	0.19	0.19	0.19	0.19	0.07
LOI	2.04	1.87	2.42	1.85	1.72	2.87	2.64
Total	100.87	100.32	100.52	101.02	100.27	100.78	100.29

Trace Elements in ppm

Rb	5.7	7.8	8.3	10.2	12.1	5.5	81.0
Sr	446.9	426.0	380.1	388.0	432.8	162.4	89.2
V	292.0	279.0	297.0	302.0	302.0	371.0	254.0
Cr	86.9	96.5	91.7	87.6	90.3	147.1	591.1
Ni	51.0	83.0	61.0	46.0	55.0	56.0	250.0
Y	25.9	24.5	25.9	26.2	25.8	27.7	18.3
Zr	140.5	129.3	140.1	144.6	136.6	130.8	37.6
Nb	16.4	14.9	16.3	16.7	15.8	15.5	4.0

Rare Earth Elements in ppm

La	-	-	-	-	-	-	-
Nd	-	-	-	-	-	-	-
Sm	-	-	-	-	-	-	-
Eu	-	-	-	-	-	-	-
Gd	-	-	-	-	-	-	-
Tb	-	-	-	-	-	-	-
Tm	-	-	-	-	-	-	-
Yb	-	-	-	-	-	-	-
Lu	-	-	-	-	-	-	-
Th	-	-	-	-	-	-	-
U	-	-	-	-	-	-	-

APPENDIX B: Composition of Kenty Lake alkaline suite

Major Elements in wt%

Sample:	KT-6	KT-8	KT-9	KT-10	KT-11	KT-12	KT-19
Rock:	Alk	Alk	Alk	Alk	Alk	Alk	Alk
SiO_2	42.34	41.01	42.38	42.04	48.67	39.21	38.04
TiO_2	4.17	4.66	4.69	4.57	4.24	3.23	6.22
Al_2O_3	9.21	10.20	9.77	9.46	9.38	7.34	9.98
Fe_2O_3	15.68	15.88	16.13	14.30	13.13	19.82	16.77
MnO	0.29	0.26	0.26	0.32	0.25	0.39	0.36
MgO	10.64	10.93	9.42	11.82	10.21	9.74	10.84
CaO	13.31	12.18	15.29	14.08	9.68	17.11	13.57
Na_2O	0.67	0.44	0.64	1.10	2.40	0.08	0.43
K_2O	1.91	1.92	0.63	0.75	0.55	0.10	0.26
P_2O_5	0.59	0.65	0.55	0.64	0.16	0.42	0.39
Total	98.81	98.13	99.76	99.07	98.67	97.44	96.86

Trace Elements in ppm

Rb	51.9	63.9	14.2	15.2	14.2	0.4	1.3
Sr	449.6	423.4	325.9	342.0	55.7	78.3	323.7
V	331.0	352.0	350.0	355.0	324.0	254.0	499.0
Cr	691.7	691.7	689.7	749.9	666.4	496.7	515.2
Ni	403.0	427.0	367.0	408.0	349.0	253.0	261.0
Y	29.7	33.9	33.8	35.6	27.4	28.5	43.5
Zr	427.3	499.4	503.9	476.9	445.4	338.8	578.8
Nb	82.9	95.8	97.2	94.9	86.0	83.9	123.5

Rare Earth Elements in ppm

La	79.69	92.87	86.93	83.45	46.60	57.41	114.40
Nd	84.20	96.04	90.74	104.00	63.03	83.56	119.10
Sm	15.21	17.04	16.42	18.42	12.94	15.29	21.29
Eu	4.70	4.51	4.11	4.52	3.12	3.40	6.65
Gd	11.26	12.76	12.34	13.52	9.87	11.10	16.41
Tb	1.49	1.68	1.63	1.77	1.29	1.45	2.22
Tm	0.33	0.38	0.37	0.38	0.30	0.29	0.45
Yb	1.86	2.19	2.14	2.18	1.79	1.71	2.44
Lu	0.24	0.29	0.28	0.29	0.24	0.22	0.30
Th	8.57	10.33	10.18	9.29	8.55	6.54	9.87
U	1.82	2.22	2.30	1.17	1.79	1.32	2.14

APPENDIX B: Composition of Kenty Lake alkaline suite

Major Elements in wt%

Sample:	KT-20	KT-29
Rock:	Alk	Alk
SiO_2	39.51	39.34
TiO_2	5.64	5.82
Al_2O_3	9.18	11.32
Fe_2O_3	15.14	15.73
MnO	0.33	0.22
MgO	12.01	9.39
CaO	14.29	14.82
Na_2O	0.45	0.18
K_2O	0.14	0.18
P_2O_5	0.67	0.56
Total	96.91	97.56

Trace Elements in ppm

Rb	2.9	0.7
Sr	114.9	56.5
V	432.0	469.0
Cr	595.3	344.8
Ni	109.0	247.0
Y	34.0	44.4
Zr	458.8	533.6
Nb	102.4	107.8

Rare Earth Elements in ppm

La	30.62	67.06
Nd	62.00	132.30
Sm	14.44	24.05
Eu	1.62	9.43
Gd	11.74	17.72
Tb	1.54	2.38
Tm	0.36	0.48
Yb	1.97	2.65
Lu	0.25	0.33
Th	9.11	9.24
U	0.64	3.34

Appendix C: Composition of the Lac LeClair volcanic suite

Major Elements in wt%

Sample:	BLS-1	BLS-2	BLS-3
Rock:	lava	lava	lava
SiO_2	36.39	37.20	33.80
TiO_2	3.34	2.29	0.63
Al_2O_3	2.90	3.60	2.60
Fe_2O_3	12.50	12.60	10.00
MnO	0.12	0.15	0.19
MgO	25.80	28.21	28.51
CaO	3.83	1.71	4.03
Na_2O	0.03	0.03	0.03
K_2O	0.05	0.05	0.05
P_2O_5	0.39	0.43	0.30
LOI	14.42	13.54	19.67
Total	99.77	99.81	99.81

Trace Elements in ppm

Rb	5.0	5.0	5.0
Sr	130.0	40.0	85.0
V	230.0	170.0	58.0
Cr	567.9	520.0	526.8
Ni	790.0	720.0	980.0
Y	15.0	14.0	10.0
Zr	190.0	190.0	96.0
Nb	120.0	100.0	60.0

Rare Earth Elements in ppm

La	102.00	79.00	63.00
Nd	93.00	---	56.00
Sm	12.00	---	7.10
Eu	3.40	---	2.20
Gd	8.30	---	5.20
Tb	0.00	---	0.00
Tm	0.18	---	0.12
Yb	0.83	---	0.63
Lu	0.00	---	0.00
Th	14.00	---	10.00
U	1.90	---	1.60