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Article abstract

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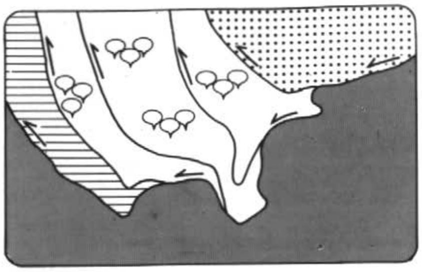

Alkaline rocks from a Proterozoic volcanic island in the Cape Smith Thrust Belt, New Quebec

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Summary

In the Cape Smith Belt, a highly alkaline sequence of volcanic rocks overlies the tholeiitic basalts of the Povungnituk Group. This sequence consists of basanites/nephelinites and phonolites. All lavas display high Zr, Nb, Ti values, and the mafic lavas contain primary titaniferous clinopyroxene. Crystal fractionation models indicate that the evolution of the mafic lavas was dominated by clinopyroxene fractionation. The phonolites are most reasonably interpreted as products of extensive fractionation of feldspar from a basanitic parent.

The Cape Smith alkaline suite is similar to Phanerozoic undersaturated lava suites and is interpreted as part of an alkaline volcanic island developed on the continental margin of an opening oceanic rift basin. The chemistry of the alkaline rocks from the Cape Smith Belt suggests similar processes for the generation alkaline melts in the Proterozoic and Phanerozoic mantle.

Résumé

Dans la bande du Cap Smith, une séquence de roches volcaniques fortement alcalines surmonte localement les basaltes tholéitiques et les sédiments du Groupe de Povungnituk. Cette séquence se caractérise par des basanites/néphélinites et des phonolites montrant des valeurs élevées en Zr, Nb, Ti. Les laves mafiques contiennent essentiellement des clinopyroxènes titanifères primaires. Les modèles de cristallisation fractionée indiquent que l'évolution des laves mafiques fut dominée par le fractionnement du clinopyroxène. Les phonolites sont interprétées comme résultant du fractionnement extensif de felspath, à partir d'un liquide parent basanitique.

La suite alcaline de Cap Smith est similaire aux suites sous-saturées du phanérozoïque. Elle semble avoir formé une île volcanique alcaline developpée sur la marge continentale d'un océan en cours d'ouverture. La géochimie de ces laves suggère que les liquides alcalins ont été formés par des processus similaires dans les manteaux protérozoïque et phanérozoïque.

Introduction

Relatively few occurrences of alkaline volcanic rocks have been documented to date in the Archean and Proterozoic. Those identified in the Archean appear to be closely related to calc-alkaline sequences and are generally interpreted as shoshonitic assemblages or lamprophyres associated with the final stages of convergent margin volcanism (Picard and Piboule, 1986; Wyman and Kerrich, 1989). To our knowledge, no definitive alkaline volcanic complex representative of intraplate alkaline volcanism has been identified in the Archean or Proterozoic. Thus, the presence of alkaline extrusive rocks, probably related to a volcanic island, and associated with the rifted continental margin assemblage in the Early Proterozoic Cape Smith Thrust Belt is of great interest. The volcanic island constitutes a basanite/nephelinite - phonolite assemblage that is essentially identical to many Phanerozoic silica-undersaturated alkaline volcanic island assemblages. The geochemistry of these volcanic rocks can be used to constrain both the magmatic evolution of this Early Proterozoic volcanic belt, and the evolution of magma sources in the Precambrian.

Petrography

The southern portion of the Early Proterozoic Cape Smith Belt preserves a northward-facing continental rift margin, comprising dominantly tholeiitic basaltic volcanic rocks and continental sediments (Povungnituk Group), followed by a sequence of komatiitic and tholeiitic volcanics (Chutokat Group). The petrogenesis and tectonic significance of these volcanic sequences have been described by Hynes and Francis (1982), Francis *et al.* (1983) and Picard *et al.* (1989 - this issue, p. 130-134).

The alkaline lavas overlie the tholeiitic basalts and sediments of the Povungnituk Group and are described by Picard (1986, 1989). Both mafic and felsic alkaline units are present. The mafic alkaline volcanics are dominated by pyroclastic rocks (80-90%) with minor intercalated lavas. Clinopyroxene with rare apatite inclusions (titaniferous augite, Table 1) is the dominant phase in the mafic rocks (20% as phenocrysts and 20% as microcrysts in the matrix). In addition, microphenocrysts of Fe-Ti oxide, apatite and spinel are observed. The felsic lavas overlie the mafic lavas. They contain rare alkali feldspar phenocrysts in a trachytic martrix mainly composed of plagioclase.

Rounded xenoliths are observed in the mafic lavas and vary in diameter from a few millimetres to several centimetres. The xenoliths are clusters of equigranular brown hornblende intergrown with clinopyroxene which is replaced by actinolite; some xenoliths are devoid of amphibole. Apatite, sphene and opaques may represent up to 20% of the xenoliths, either as inclusions within the clinopyroxene and amphibole, or as discrete phases. The texture observed in the xenoliths suggests that they are magmatic cumulates (Lloyd, 1987). However, because of the absence of primary clinopyroxene, it was not possible to confirm their cognate nature.

Geochemistry

Representative analyses of the lavas are given in Table 1. When plotted on a $NaO_2 + K_2O$ *versus* SiO_2 diagram, the lavas display values which are too low to be considered typical of highly undersaturated magmas. Similarly, normative calculations yield results that fall both in the undersaturated and the saturated fields. However, when plotted on a diagram of SiO_2 *versus* Zr/TiO_2 (Figure 1) the lavas show a strong alkaline affinity. The mafic lavas fall in the most undersaturated basanite/nephelinite field for mafic rocks and the felsic rocks in the phonolite field. This highly alkaline affinity is further supported by the high abundances of TiO_2 (3.92-6.70 wt.%), Nb (110-170 ppm) and Zr (500-730 ppm) in the mafic lavas and Zr (550-1700 ppm) and Nb (100-250 ppm) in felsic lavas.

The difficulty in classification of the lavas is a result of the loss of alkalies due to alteration. This is particularly evident for Na_2O which is even lower than would be expected in tholeiitic lavas, and in the "spider diagram" (Figure 2) where Sr values are lower than in equivalent alkaline lavas. Both K_2O and Rb seem to be reasonably representative of their primary abundance (Figure 2).

Although these alkaline rocks have been altered, primary magmatic trends are observed in which MgO, CaO, FeO, TiO_2, Ni, Cr and V decrease with increasing SiO_2. A gradation from mafic to felsic lavas is present, but a compositional gap (Figure 1) leaves the relationship between the magmas uncertain.

The rare earth elements (REE) in the mafic lavas are strongly fractionated with $(La/Yb)_n$ ratios of 28 and La abundances varying between 180 and 500 relative to chondrite. There is a parallel enrichment in REE to the felsic lavas, which show well-developed Eu anomalies. The La abundances of the felsic lavas range from 300 to 800 relative to chondrite.

The basanites/nephelinites from the Cape Smith Belt have been compared to Phanerozoic alkaline mafic rocks in the "spider diagram" (Figure 2). Relative to basanite/nephelinite assemblages from suites such as Cameroon (Fitton and Dunlop, 1985) and Fort Selkirk (Francis and Ludden, in press), the Cape Smith least evolved basanite/nephelinite lies between the basanite and nephelinite trends (Figure 1) and the more evolved basanite/nephelinite just below the evolved Etinde nephelinite lava from Cameroon (Figure 2a).

Magma evolution

Based on major element abundances, the more fractionated basanite/nephelinite (Ni = 49 ppm, Cr = 77 ppm) can be derived from the most primitive one (Ni = 412 ppm, Cr = 671 ppm) by approximately 60% fractional crystallization. Least squares modelling (Wright and Doherty, 1970), indicates fractional crystallization of the following phases: clinopyroxene (51%); titanomagnetite (6%); apatite (2%); with 40% residual liquid. The most important implication of this result is that fractional crystallization in the nephelinites/basanites is dominated by the extraction of clinopyroxene. This is typical of some Phanerozoic nephelinite/basanite assemblages (*e.g.*, Peterson, 1989). The clinopyroxene phenocrysts present in the mafic lavas are low in Al_2O_3 (Table 1) and Al(VI), which is characteristic of those formed during low pressure fractionation (Duda and Schmincke, 1985).

The phonolites are most reasonably explained by fractionation of plagioclase and potassic feldspar. This is consistent with the Eu anomaly observed in the felsic lavas. The phonolites probably represent the final stage of crystallization of the alkaline magma.

Geodynamic consequences

The Cape Smith alkaline series is essentially identical to Phanerozoic highly alkaline lava series. Its association with a proto-rift sequence may indicate a continental margin-type environment, such as for the Cameroon. The Cape Smith alkaline rocks are thought to have accumulated on thinned continental crust overlain by continental sediments and continental tholeiitic basalts of the Povungnituk Group (Picard *et al.*, 1989 - this issue, p. 130-134). The alkaline series may document the construction of a volcanic island at the transition from continental to oceanic lithosphere.

Table 1 Microprobe analyses of clinopyroxene phenocrysts and representative whole rock analyses of the Cape Smith alkaline lavas. (Oxides are in %; elements in ppm)

Oxides	cpx-core	cpx-rim	Bas/Neph	Bas/Neph	Phon
SiO_2	50.70	48.63	41.24	46.50	63.04
Al_2O_3	3.36	3.38	10.36	14.47	18.55
TiO_2	1.06	2.81	6.73	3.91	0.45
MgO	12.78	13.54	9.07	5.83	1.19
CaO	20.65	21.95	15.72	11.99	3.11
FeO_3^t	10.46	9.04			
FeO^t			14.99	13.40	2.06
Na_2O	0.72	0.44	0.37	1.74	1.50
K_2O	0.00	0.01	0.21	1.24	9.91
MnO	0.25	0.17	0.26	0.23	0.06
P_2O_5	0.03	0.05	1.05	0.70	0.14
Cr_2O_3	0.13	0.04			
LOI			2.71	2.16	2.82
Nb			93	146	82
Zr			580	703	570
Cr			390	75	15
Ni			280	48	38

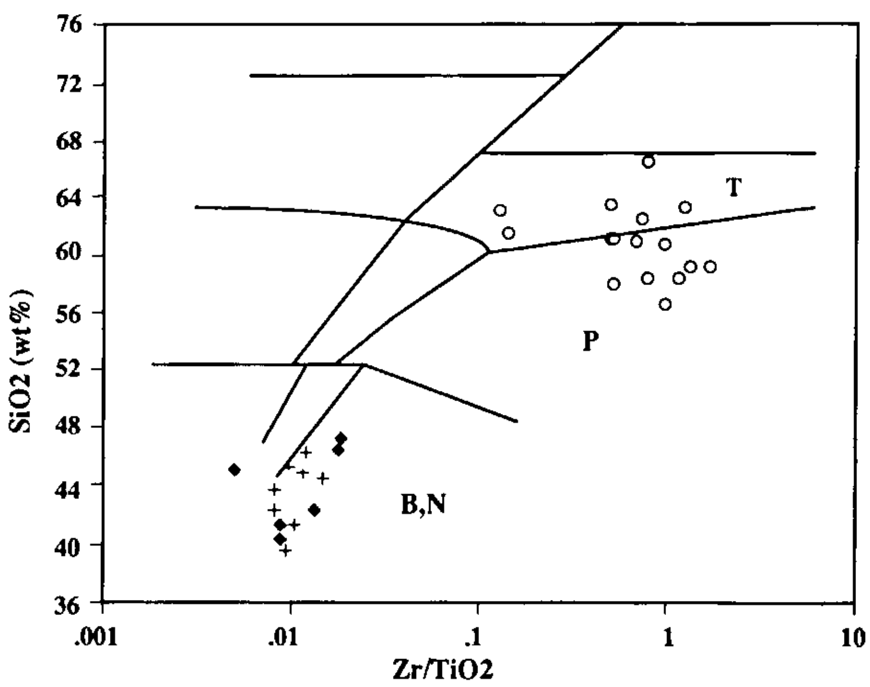

Figure 1 *SiO_2 versus Zr/TiO_2 diagram as defined by Winchester and Floyd (1977). Crosses - volcanoclastites; full diamonds - basanites/nephelinites; open circles - phonolites.* ***P****, phonolite field;* ***B,N****, basanite and nephelinite field,* ***T****, trachyte.*

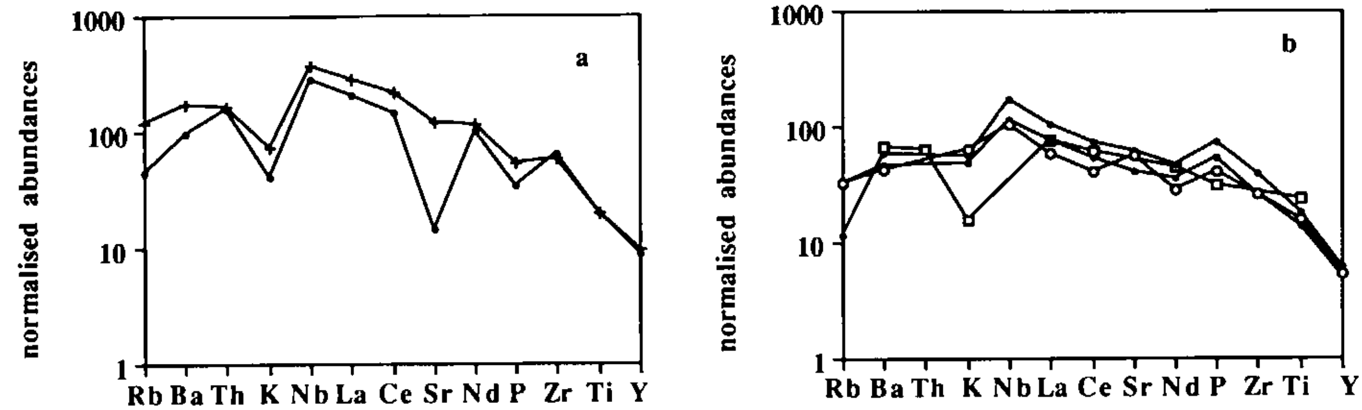

Figure 2 *Spider diagram showing:* **(a)** *evolved nephelinite from Cape Smith (squares), and Etinde nephelinite from Cameroon (crosses) (Fitton, 1985);* **(b)** *primitive nephelinite from Cape Smith (open squares), nephelinites from Fort Selkirk (filled squares), and basanite from Fort Selkirk (open circles) (Francis and Ludden, in press). Values normalized to values for primordial mantle given by Wood* et al. *(1981).*

To our knowledge, the alkaline lavas in the Cape Smith Belt appear to be the oldest and most convincing example yet described of an alkaline assemblage emplaced on a continental margin environment. They overlie the Povungnituk Group basalts and are cut by the Delta intrusions (Picard, 1989) which are co-magmatic with the Romeo sill (Thibert *et al.*, 1989 - this issue, p. 140-144). Phanerozoic alkaline magmas have been ascribed to enriched mantle reservoirs caused by various processes, such as primordial deep mantle, veined mantle and percolation of fluids through the depleted mantle. The Cape Smith alkaline lavas require the presence of such an enriched mantle source region and the operation of processes comparable to those of the Phanerozoic in the Early Proterozoic.

Conclusions

Alkaline lavas in the Povungnituk Group of the Cape Smith Belt comprise a basanite/nephelinite and phonolite assemblage. These volcanic rocks erupted through thinned continental crust formed during ongoing continental rifting. Their petrological characteristics are identical to Phanerozoic alkaline volcanoes and they attest to the presence of similar mantle sources for alkaline volcanism in the Phanerozoic and Early Proterozoic.

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