Geochemical evidence for plume-arc interaction in the generation of the proto continental Superior Province

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Archaean greenstone belts from the northern Superior Province, ranging in age from 2.9 to 3.0 Ga, comprise an association of komatiite-tholeiite sequences intercalated with arc-related felsic volcanic rocks. These belts are distinct from their southern counterparts in at least four ways: (1) several of the komatiite sequences are characterised by a compositional signature of contamination; (2) there is evidence for older crustal basement to some of the greenstone belts; (3) several of the komatiites possess positive peaks of Sc and V relative to *HREE*, and (4) they extend to greater ages than their southern counterparts.

Komatiites and komatiitic basalts were sampled from three 2.9–3.0 Ga assemblages within greenstone belts of the Uchi subprovince, Canada. Komatiites from the Balmer assemblage of the Red Lake belt have MgO contents of 22–37 wt.% and Al_2O_3 of 3–9 wt.%, with elevated Ni (450–1860 ppm). They vary from weakly *LREE* enriched to strongly depleted (La/Sm_n = 0.36–1.6) in conjunction with variably fractionated *HREE* (Gd/Yb_n = 0.8–1.2; Fig. 1). In general the magnitude of the Nb anomaly increases with the degree of *LREE* enrichment. The majority of both the komatiites and komatiitic basalts are characterised by high V/Yb and Sc/Yb ratios (277–360 and 58–76 respectively) which are reflected in positive V and Sc peaks relative to the *HREE*.

Tholeiitic flows intercalated with the komatiites typically display flat *REE* patterns with variable Nb anomalies and high Th/Ce ratios, consistent with minor degrees of contamination. Two suites of felsic volcanic rock have been recognised intercalated with the komatiite-tholeiite sequences. Both types display pronounced *LREE* enrichment and negative Nb and Ti anomalies, but Type 1 has strongly fractionated *HREE* patterns, whereas Type 2 *HREE* are generally flat in conjunction with elevated compatible element contents (e.g. Mg#, Ni, Cr). The predominant Type 1 rhyolite is directly comparable to southern Superior Province examples associated with oceanic arc sequences, and are comparable to Archaean high Al, high La/Yb_n TTGs; they indicate a subduction-related origin for the northern examples. Type 2 rhyolite geochemical signatures may result from mixing of Type 1 rhyolites with tholeiitic magmas or variations in the mantle source.

Komatiites from these 2.9–3.0 Ga greenstone belts all have the conjunction of negative Nb anomalies with trends of increasing SiO_2, La, La/Sm_n and Th/Ce with decreasing Mg# and Ni, indicative of contamination by a felsic component. Modelling of simple mixing between the least *LREE* enriched Ball komatiite and a representative felsic composition from that assemblage, can account for the high Th contents, Th/Ce ratios and enriched *LREE* of the more evolved compositions, with as little as 5% felsic contaminant.

The high V/Yb and Sc/Yb ratios and associated positive kicks at V and Sc on a primitive mantle normalised diagram observed in ultramafic flows of the Ball and Balmer assemblages are unique amongst Archaean komatiites. Pearce and Parkinson (1993) have proposed that high V/Yb and Sc/Yb ratios may be produced by melting a previously depleted mantle source. There are at least three possible causes for this signature of prior melting in the komatiites: (1) they have been contaminated by a felsic component, (2) dynamic melting within a mantle plume whereby mantle components are continually remelted, or (3) interaction with depleted sub-arc mantle possibly comparable to the source of boninitic rocks.

Contamination by a felsic component explains the Th, Nb, *LREE* systematics but cannot account for the *HREE*-V-Sc characteristics, given the low abundance

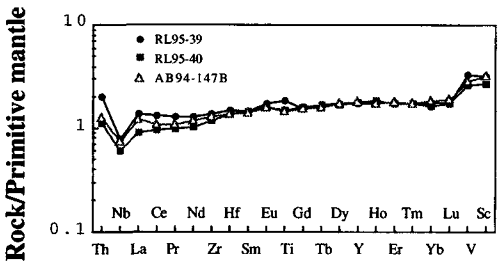

FIG. 1. Representative primitive mantle normalised trace element patterns for typical ultramafic flows of the 2.9–3.0 Ga northern Superior Province.

of these elements in local Archaean felsic rocktypes. The absence of comparable Yb-Sc-V systematics, in high MgO picritic rocks associated with dynamic melting in mantle plumes suggests that this process can not account for the distinctive characteristics of northern Superior Province ultramafic rocks (c.f. Kerr *et al.*, 1996).

Boninitic rocks associated with island arcs feature variably fractionated *MREE* and *HREE*, high Al_2O_3/TiO_2 ratios and many have high Sc/Yb and V/Yb ratios (Cameron, 1989). Further, normalized V-Sc enrichments versus *HREE* are characteristic of mafic rocktypes derived from previously depleted mantle sources and occur, to some degree, in most mafic arc volcanic rocks. We suggest that a depleted source component may account for the distinctive *HREE*-V-Sc systematics of the komatiites and, along with the presence of intercalated arc-type felsic rocks, argues strongly for interaction with subduction influenced mantle.

Evidence of interaction between plumes or plateaus and subduction zones is increasingly recognized in the geologic record. Plume influence on active subduction zones has been identified in the SW Pacific (Lau Basin; Pearce *et al.*, 1995) and direct plume impingement on subduction zones has been suggested in the case of the mid-Cretaceous Marie Byrd Land plume on the Pheonix Plate subducting beneath Antarctica (Weaver *et al.*, 1994) and an Abitibi plume acting upon a pre-existing 2720 Ma arc (Wyman *et al.*, 1997).

Collectivley, the geochemical, geochronologic and stratigraphic evidence from the northern Superior Province greenstone belts provide strong evidence for both a spatial and temporal association of mantle plumes and subduction zones during generation of the proto-continent nucleus to the Superior Province.The geological evidence for the contemporaneous eruption of plume- and arc-related volcanic rocks argues strongly for the interaction between plume-plateau and island arcs at the margins of the USG over a 100 m.y. interval. However, unlike many plateau obduction models applied to specific Archaean or younger terranes, we propose that an active plume (or plumes) is required to account for the coeval eruption of komatiitic and TTG-like volcanic flows.

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