Inverse correlation between radiogenic isotopes and trace element enrichment in subduction rocks from New Zealand: the case for a four component model

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Chemical variations in subduction-related rocks reflect the interplay of multiple sources in plate collision systems including the mantle wedge beneath the arc as well as fluids and melts derived from the subducting plate. Element transport from the subducting slab to the mantle wedge in most recent arc systems is the consequence of two major processes: (1) melting of subducted sediment, and (2) dehydration of the MORB portion of the slab (Nichols *et al.*, 1994; Miller *et al.*, 1994). This study presents evidence for mixing of at least four components, mantle wedge - subducted sediment melt - MORB derived fluid - MORB derived melt, in the mantle sources of subduction related magmas.

A well preserved Cambrian arc system of the Takaka Terrane from New Zealand (Münker and Cooper, 1995) has been chosen for this case study. Although overprinted by very-low grade metamorphism, this arc system displays a complete assemblage of interbedded low- to high-K type arc rocks, back-arc rocks and boninites. A coherent dataset was obtained analysing both whole rock samples (XRF, ICPMS) and fresh clinopyroxene and amphibole separates (Sr-Nd-Pb isotope ratios). In marked contrast to many recent arc systems studied, volcanic rocks of the Takaka Terrane show increasingly depleted Sr-Nd isotope ratios (at 500 Ma) with increasing enrichment of incompatible elements (e.g. Th/Yb, La/Yb) (Fig. 1). La/Yb values range from 1 (boninites, back-arc rocks) to 30 (high-K type arc rocks) as corresponding εNd vary from −4 to +6.

The coupling of isotope and trace element ratios (Fig. 1) rules out a partial melting control on trace element variations. Constant εNd and $^{87}Sr/^{86}Sr$ at variable Mg# (40-70) within single volcanic groups preclude any significant influence of crustal contamination on the isotope compositions. This is consistent with extremely radiogenic Pb isotope compositions in the volcanic rocks which cannot be explained by admixture of Takaka Terrane sediments, since the sediments show much less radiogenic Pb compositions (all at 500 Ma). Taken together, such patterns suggest that the isotope variations in the volcanic rocks were produced by addition of subducted sediment to the mantle wedge. Palaeogeographic constraints (Münker, 1997) suggest this subducted sediment to be derived from Archaean cratons with extremely radiogenic $^{207}Pb/^{204}Pb$ and unradiogenic εNd. This sediment composition makes Pb-Nd isotopes a particularly sensitive tracer for subducted sediment contribution.

Modelling of simple two component mixing between depleted mantle wedge and melt derived from subducted sediment (Fig. 2) cannot explain the observed Nd-Pb co-variation in the volcanic rocks: calculated Pb isotope ratios are too high at given εNd. Admixture of a third component, MORB-derived fluid with a high Pb/Nd ratio and mantle like Pb composition, can satisfactorily explain the observed isotope patterns (Fig. 2). Addition of up to 0.5% sediment melt and 3% MORB-derived fluid to the mantle wedge is required, consistent with mixing

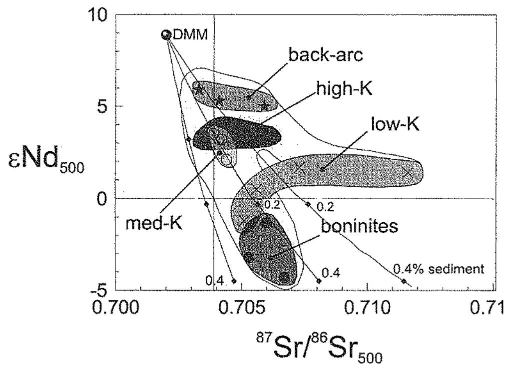

FIG. 1. $^{87}Sr/^{86}Sr$ *vs* εNd (both recalculated at 500 Ma).

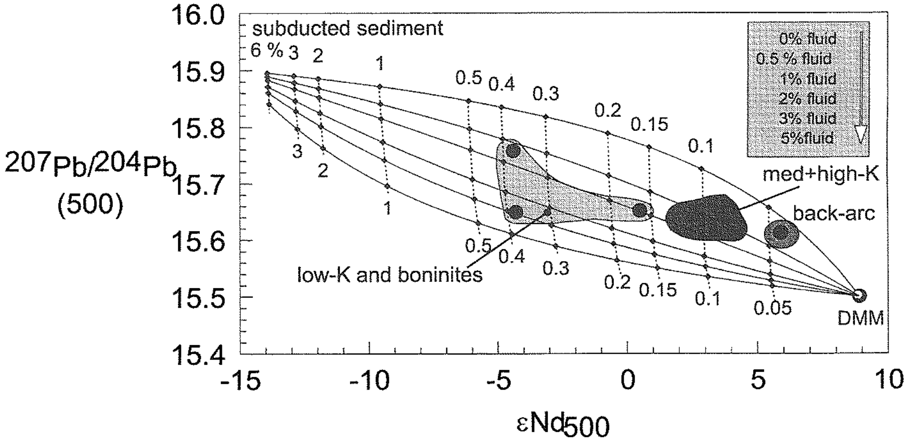

FIG. 2. Nd-Pb isotope mixing curves between depleted mantle (DMM) - sediment melt - MORB derived fluid.

proportions obtained for recent arc systems (e.g. White and Patchett, 1984; Miller *et al.*, 1994).

The above three-component model, however, still fails to explain the concomitant increase of εNd and La/Yb as particularly observed between low- and medium-/ high-K rocks (Fig. 3). Mixing of depleted mantle with sediment-derived melts alone would cause a decrease in εNd with increasing La/Yb. MORB-fluid addition cannot contribute sufficient amounts of light rare earth elements and Th to the mantle wedge in order to explain the observed compositions. Addition of melts derived from the MORB portion of the slab (high εNd) can explain this feature. Figure 3 shows mixing curves of depleted mantle with melts from both the MORB and sediment portions of the slab. The εNd-La/Yb compositions of the medium- and high-K rocks can be explained by addition of up to 10% of a slab melt which consists of 10–20% sediment derived and 80–90% MORB-derived melt (Fig. 3). Uncertainties in the trace element compositions of the slab melts, however, limit the accuracy of calculated slab melt addition to ±50%, i.e. from 5 to 20%.

The inferred role of MORB derived slab melts during the petrogenesis of the medium- to high-K rocks is in agreement with an earlier approach (Münker, 1998) where Nb/Ta ratios were used to constrain the role of slab-derived melts. Only the medium and high-K rocks have chondritic or higher Nb/Ta (>17.6), indicating admixture of rutile-equilibrated slab melts (Nb/Ta > 17.6) to the mantle wedge (Nb/Ta < 17.6). The low-K rocks, boninites and back-arc rocks all have Nb/Ta<17.6, indicating a slab-fluid dominated regime and the absence of MORB derived slab melts.

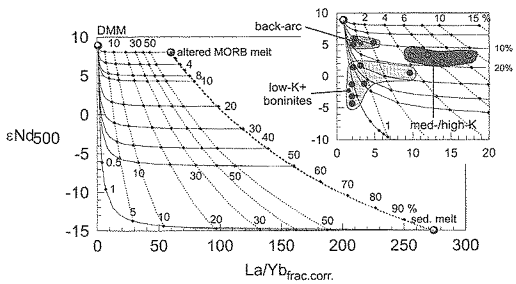

FIG. 3. εNd-La/Yb mixing curves between depleted mantle - sediment melt - MORB melt (La/Yb is fractionation-corrected).

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