

## Fluids in subduction zone magmatism: implications of boron geochemistry

W. P. Leeman

Department of Geology & Geophysics, Rice University, Houston  
TX 77005 USA

S. Tonarini

Istituto di Geocronologia e Geochimica Isotopica, CNR, 56127  
Pisa, Italy

The roles of fluids, sediments, and slab melts in convergent margin magmatism are difficult to quantify and likely vary from one arc to another. Decoupling of trace elements with differential fluid- and melt-mobility can illuminate specific subduction processes; the fluid-mobile element (FME) boron is particularly useful in this regard.

Variable B-enrichment (up to  $> 100\times$ ) in arc compared to within-plate lavas can be attributed to direct subduction contributions (as implied by correlations with  $^{10}\text{Be}$ -enrichments in arc suites). The fact that B enrichment is decoupled from that of fluid-immobile elements (*REE*, Zr, Ti, Nb, etc.) but parallels that of fluid-mobile elements (Pb, As, Sb) implies dominant transfer of the latter elements into arc magma sources via aqueous fluids rather than melts. B commonly is decoupled from or poorly correlated with Ba, Sr, and alkalis - suggesting that these elements are subject to more complex controls. In general, element mobility must be considered in light of element partitioning between all stable mineral, fluid, or melt phases.

Enrichments of B (e.g. relative to Zr) vary widely from one arc to another, and generally correlate with such factors as 'slab length' or 'age of subducting crust', both of which are manifestations of slab thermal state. Locally, in cross-arc transects, B-enrichment is strongest at the volcanic front (VF) and diminishes toward back-arc (BA) regions. Coupled with data for metamorphic suites that indicate progressive B-depletion with increasing grade, such trends suggest that B is mobilized from subducting slabs due to progressive slab dehydration. Thus, B-enrichment in arc basalts appears to reflect the thermal evolution of subducted slabs. B-enrichment also appears to be correlated with degree of U-isotope disequilibria. Available B isotopic data for arc lavas tend to show both regional and local variations consistent with the above.

Different ranges in boron isotopic composition of siliciclastic sediments ( $\delta^{11}\text{B}$ :  $-5 \pm 5\%$ ), altered

oceanic crust ( $\delta^{11}\text{B}$ :  $4.3 \pm 5.4\%$ ), and peridotite ( $\delta^{11}\text{B}$ : 8 to 13%) an covariations between degree of B enrichment,  $\delta^{11}\text{B}$ , and  $^{87}\text{Sr}/^{86}\text{Sr}$  isotopic data may be used to discriminate the relative contributions of hydrous fluids vs. sediments to arc magma sources. In western Pacific arcs (old, cold slab), elevated  $\delta^{11}\text{B}$  ( $> +3\%$ ) in VF lavas is consistent with derivation of excess B from subducted seawater-altered oceanic crust rather than sediments, whereas low  $\delta^{11}\text{B}$  and elevated  $^{87}\text{Sr}/^{86}\text{Sr}$  in some arc lava suites (Lesser Antilles, Aeolian) point to sediment or crustal involvement as well. Moreover, inter-arc variations in  $\delta^{11}\text{B}$  could in part reflect progressive decrease in  $\delta^{11}\text{B}$  of the subduction component during devolatilization of subducted slabs, with less intense metamorphism and lower  $^{11}\text{B}$ -loss in cold subduction zones and vice versa. To highlight the relative importance of these processes in arc-magma genesis we have analysed volcanic rocks from arcs with different geological settings and subduction zone thermal structures. Tonarini & Leeman (this volume) discuss the behaviour of B in specific arcs.

Overall,  $\delta^{11}\text{B}$  varies widely (between  $-10\%$  and  $+21\%$ ) in arc lavas; the highest values apparently occur in lavas derived from highly depleted sources that are easily modified by the subduction component (Fig. 1). The B/Nb-B systematics similar to those of the Izu and Kuriles arcs (Ishikawa and Nakamura, 1994; Ishikawa and Tera, 1997) are sometimes observed in subsets of our data, but overall relations are more complex. Also,  $^{87}\text{Sr}/^{86}\text{Sr}$  is correlated with  $\delta^{11}\text{B}$  inside each arc but not in general due to differing slab and sediment contributions worldwide. From plots of 'fluid-immobile element'/B ratios vs  $\delta^{11}\text{B}$ , extrapolated to zero,  $\delta^{11}\text{B}$  values for the subduction component(s) can be estimated for each arc studied. Typical values are:  $+16\%$  for the South Sandwich arc (and perhaps locally in Tonga [Hunga Ha'apai]);  $+7\%$  for Tonga, Mariana, Izu (Ishikawa and Nakamura, 1994), and Kurile (Ishikawa and Tera, 1997) arcs;  $+3.7\%$  for the Aleutian arc; and

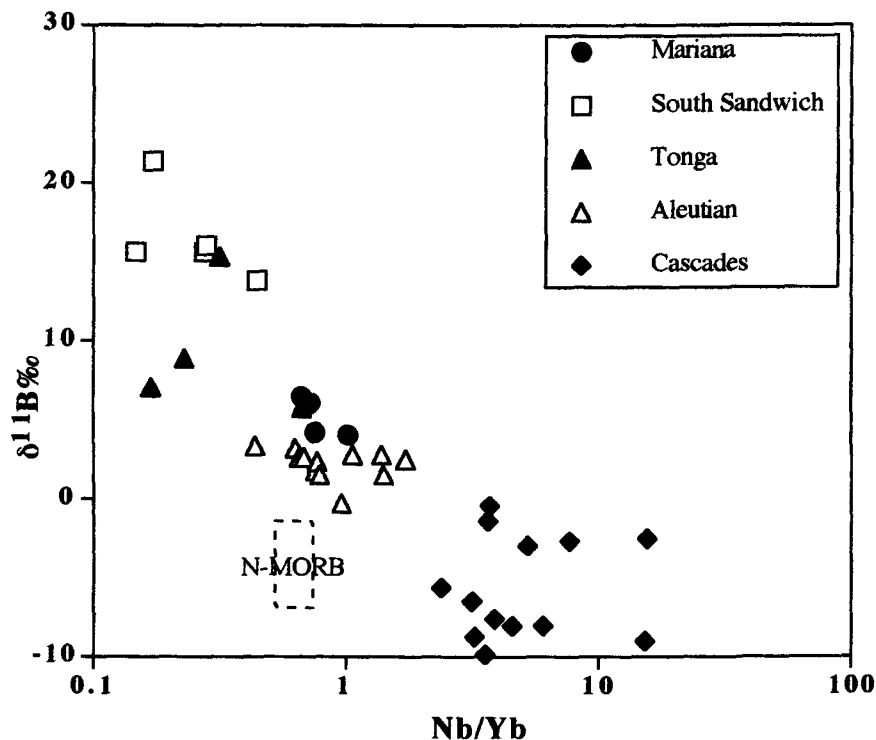


FIG. 1.  $\delta^{11}\text{B}$  vs Nb/Yb for lavas of Pacific arcs.

possibly less than 0‰ for the Cascades arc.

These variations in  $\delta^{11}\text{B}$  could reflect additions to magma source regions of fluids having site-specific compositions controlled by different proportions of sediment and altered oceanic crust in each subduction zone. The highest  $\delta^{11}\text{B}$  values (significantly greater than those typical of altered oceanic crust and peridotite) suggest that B isotope fractionation may accompany dehydration of the slab (e.g. due to selective loss of  $^{11}\text{B}$  beneath forearc regions).

Sediment contributions to subduction zone fluids may be best evaluated using other geochemical parameters such as fluid immobile element and  $^{143}\text{Nd}/^{144}\text{Nd}$  isotope ratios. We have observed almost the same range of B enrichment for

Mariana, Tonga, South Sandwich and Aleutian arcs, and roughly negative correlations between  $\delta^{11}\text{B}$  and  $^{143}\text{Nd}/^{144}\text{Nd}$  that are most significant in the Aleutian arc. A possible scenario there involves progressive reaction of small amounts of low  $\delta^{11}\text{B}$  sediments with hydrous fluid having  $\delta^{11}\text{B}$  similar to that of South Sandwich Island arc.

## References

- Ishikawa, T. Nakamura, E. (1994) *Nature*, **370**, 205–8.  
 Ishikawa, T. Tera, F. (1997) *Earth Planet. Sci. Lett.*, **152**, 123–38.  
 Tonarini, S. Leeman, W.P. (1998) This Volume.