Evidence for global control of boron isotopes in arc magmas by fore-arc interaction during magmatic ascent

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Boron isotopes serve as a potential tracer of water through subduction zones, because the processes which structurally bind water into oceanic plates invariably lead to boron enrichment, and because B is particularly fluid mobile across the range of P-T conditions expected during devolatilization of the slab. Models of slab dehydration based on numerical simulations and experimental petrology indicate that most of the water bound in subducting sediments and the upper layers of the ocean crust will be released beneath the fore-arc. We build on previous models which incorporate the expected stability of phengite and constraints on B isotope fractionation to verify that most of the boron in the upper slab lithologies is extracted in the fore-arc in shallow slab fluids, and that the boron remaining in the slab beyond the fore-arc is unable to account for the high $\delta^{11}B$ of arcs. Arc boron is thus derived either from the fore-arc directly, or else delivered from lithologies deeper below the slab surface.

Boron isotope measurements from Southern Chile show that this arc segment is globally the lowest $\delta^{11}B$ end-member, and that the boron erupted in Chilean arc-front volcanics may be delivered from the deep slab. Globally, the $\delta^{11}B$ values of arc-front volcanoes vary from 0‰ to 15‰, with correlations between $\delta^{11}B$ and the slab dip angle, convergence rate, trench distance, and sub-arc Moho depth. The relationships between these parameters and $\delta^{11}B$ are not consistent with variable delivery of B from deep slab lithologies, however. Models which propose that boron is transported from the fore-arc to the sub-arc mantle via "down-dragging," suffer from lack of experimental support at the P, T, and bulk compositions realistically expected along the slab surface. Instead, we suggest that boron is incorporated into arcs in the mantle wedge. This occurs during ascent of magmas through regions of the mantle which, absent magmatism, would fall within the antigorite stability field. We mine existing thermo-mechanical simulations and apply a simple machine learning algorithm to predict the relationship between subduction parameters and the geometry of this field, and show it is highly predictive of the $\delta^{11}B$ compositions of arc volcanoes. We then explore the implications of this finding for volatile cycling through arcs.