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The Origin of HFSE Anomalies in Subduction Zone Magmas: Evidence from Hf-Nd Isotope and Element Covariations

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The best-known (and ubiquitous) geochemical feature of subduction-derived magmas is the low concentrations of the high field strength elements (HFSE) relative to the large ion lithophile elements (LILE), which produces negative HFSE anomalies on trace element patterns. The relative contribution to these anomalies of the dehydration of the subducting slab, melting of the subducting slab, melting of the mantle wedge and melt-mantle interactions has long been the subject of debate. Because Hf is one of the few incompatible HFSE with a readily-measurable isotope ratio, and because Hf and Nd differ considerably in their ionic potential but only slightly in their bulk distribution coefficients, Hf-Nd isotope and element covariations are particularly effective for studying HFSE anomalies in detail.

In a recently published paper (Pearce et. al., 1999), we demonstrated that subduction-related fractionation of Hf and Nd produces a correlation between the magnitude of a Hf anomaly on extended chondrite-normalized REE diagrams and the isotopic shift relative to the appropriate MORB-OIB array on a Hf-Nd isotope plot. Both the anomaly and the isotope shift can be expressed mathematically as functions of the Hf/Nd ratios in the subduction component and the mantle, and of the mass fraction of the subduction component in the mantle wedge. In our study of the Izu-Bonin-Mariana arc-basin system, we demonstrated that the Hf anomaly and the isotope shift did correlate significantly and thus that the anomaly could be explained by selective mobilization of Nd during the subduction process. The data were further used to demonstrate that Nd/Hf ratios in the subduction component were high (>40) to infinite and that pelagic sediment was less significant than volcanogenic sediment as a source of the excess Nd.

These results were in marked contrast to the Lesser Antilles and Banda systems (White and Patchett, 1984) where there is neither a marked shift from the MORB-OIB array nor a significant negative Hf anomaly. In this case, fusion (rather than dehydration) of subducted materials and/or assimilation of terrigenous sediments are required to explain the Hf-Nd systematics.

We have now extended our arc data set to the Tonga-Fiji-Vanuatu arc-basin systems. Interpretation of the isotope data in terms of subduction processes is complicated by the variations in mantle provenance from Pacific to Indian to Samoan-plume influenced (Kempton et al., this volume), in contrast to the consistently Indian provenance for the Izu-Bonin-Mariana system. Taking this into account, however, there is still a significant correlation in the arc lavas between the magnitude of the negative Hf anomaly and the isotope shift, implying a subduction origin for the anomalies. For Tonga, the main component of variation within the Central Tofua arc, and within the northern Tofua arc, lies parallel to the Nd axis of the Hf-Nd isotope diagram (Fig. 1 of Kempton et al., this volume), implying extremely high Nd/Hf ratios in the subduction component. Vanuatu is less clear because some Vanuatu arc lavas have low Hf and Nd isotope ratios. However, a plot of Hf isotope ratio against Hf/Yb shows that these samples follow an IOB, not a crustal contamination trend (as the Lesser Antilles and Banda arcs). In Vanuatu as well as Tonga, therefore, the new data also indicate a subduction-related HFSE anomaly.

The inference that the negative Hf anomalies observed in many arc lavas can be attributed primarily to fractionation of Nd from the less mobile Hf in the subducting plate also indicates the relative importance of slab dehydration rather than fusion in these samples. Modelling shows that both Hf and Nd may be partitioned into sediment and crustal melts so that negative Hf anomalies are rarely produced (although Nb anomalies may be). Our studies also show that variations due to mantle wedge processes may have local and periodic significance, as in the case of the positive Hf anomalies formed by shallow mantle wedge melting during subduction-initiation (Pearce et al., 1999). Globally, however, fractionation during subduction processes is of greatest significance.

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