# Geochemical evidence for magma generation above subduction zones

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## Introduction

In this work, we use high-precision (ICP-MS) trace element analyses of basalts from a series of island arcs and peridotites from supra-subduction zone ophiolites to constrain models for melt generation in the mantle wedge above subduction zones.

## Theory of trace element behaviour in subduction systems

Evaluation of geochemical data from the world's arc-basin systems indicates that the mantle wedge contains two types of element: *conservative* elements, which owe their concentration predominantly to the nature of the mantle in the wedge; and *non-conservative* elements, which are added to the mantle during subduction. The most conservative elements are usually high field strength trace elements such as Nb, Ta, Hf, Zr, Ti, Y, *HREE*, V, Sc, Ga. Most major elements are also effectively conservative because they are buffered by their high concentrations in the mantle wedge. Non-conservative elements comprise elements of low to moderate ionic potential such as the alkali and alkaline earth elements, mono- and divalent transition metals, some lanthanides (*L-MREE*) and actinides (Th and U), together with elements of very high ionic potential such as P and S.

Conservative and non-conservative elements can be distinguished using plots such as M/Yb v Nb/Yb, where M is the element in question and Nb is treated as the most conservative element. If M is conservative, the data form a trend within the MORB array; if M is non-conservative, the data plot above the MORB array. These plots emphasise that the high field strength elements are mobile only when hot crust in subducted, in which case partitioning into the residues from slab melting may be more important than ionic potential in determining the composition of the slab component.

Investigation of the conservative elements shows that their behaviour largely depends on incompatibility during melting. Thus, Nb, Ta, Hf and Zr ($D < 0.05$) can be termed very highly incompatible (VHI), Ti, Y, *HREE* ($D = 0.05-0.15$) can be termed highly incompatible (HI), and V, Ga, Sc (D-0.15–0.5) can be termed moderately incompatible (MI). When normalized to fertile MORB mantle (FMM) and plotted in order of incompatibility, the conservative elements form patterns that vary systematically according to the degree of enrichment or depletion of the mantle and the degree of melting (Pearce and Parkinson, 1993).

## Evidence for the nature of supra-subduction zone mantle

The conservative elements in arc basalts form FMM-normalized patterns which indicate a range of mantle compositions from enriched (VHI elements > HI $\geqslant$ MI), through MORB-like ($VHI \geqslant HI \geqslant MI$) and moderately depleted ($VHI < HI = MI$) to strongly depleted ($VHI < HI < MI$). In general, the most depleted sources are associated with intraoceanic arcs with active back-arc basins (e.g. South Sandwich, Tonga-Kermadec), MORB-like sources are associated with intraoceanic arcs without active back-arc basins (e.g. Lesser Antilles, Aleutians), and enriched sources are assocated with active continental margins (e.g. Andes). However, there are significant variations within arcs. For example, many oceanic arcs contain enriched segments (Central Vanuatu, Southern Lesser Antilles) and continental arcs (e.g. Southern Chile) can contain MORB-like segments. There is some evidence that the mantle wedge becomes more depleted with proximity to the trench.

## Evidence for the degee of partial melting

The degree of partial melting is difficult to separate from source variations and fractional crystallization in lavas, although relationships between conservative VHI and HI elements do help distinguish the two variables. Results confirm that the highest degrees of melting take place beneath intraocanic arcs on thin lithosphere and during arc rifting, and the lowest take place beneath continental arcs on thick lithosphere. Trace element analyses of peridotites from supra-subduction zone ophiolites provide an alternative insight into the melting process. These contain lower contents of incompatible elements such as Ti and Y compared with peridotites from mid-ocean ridges, and their spinels are, as is well-known, more Cr-rich. Modelling suggests that this difference can be explained by 5–10% extra melting beneath supra-subduction ridges compared with mid-ocean ridges. Given that decompression melting and melt extraction are likely to be similar in supra-subduction and mid-ocean ridges, the implication is that this additional melting is due to the input of subduction fluids. The value obtained is also consistent with inferences based on experimental data. We thus conclude that some 5–10% of melting in the mantle wedge is caused by addition of fluids from the subducting slab, but up to 15–20% by decompression, the value of the latter depending on lithospheric thickness.

## Evidence for the causes of mantle wedge depletion and enrichment

Depletion of the mantle wedge in oceanic arcs has one of two probable origins: it could originate at back-arc spreading centres, in which case depleted mantle would advect into the wedge prior to fluid addition from the subducting slab; or it could take place within the mantle wedge melting column, in which case depletion would post-date fluid addition. These two possibilities are easily distinguished on plots such as M/Yb-Nb/Yb where M is a non-conservative element. On such a plot, depletion in the melting column gives a trend parallel to the MORB trend, whereas depletion in the back-arc basin gives a trend in which the most depleted source is (by virtue of mass balance) the most affected by the slab component. In most intra-oceanic arcs, MORB-parallel trends are observed, demonstrating that at least some mantle depletion can be explained by loss of small melt fractions in the melting column after addition of the slab component. This implies that pooling of melt in the mantle wedge may be significantly different from pooling of melt at mid-ocean ridges, probably because of the added effect of corner flow in the former. By contrast, some early arc (boninitic) volcanics and some continental arc volcanics follow a trend consistent with enrichment and depletion prior to fluid addition. In these situations, the slab component may be added to vertically-zoned mantle lithosphere with relatively enriched compositions at the base and relatively depleted compositions at shallow levels.

## References

Pearce, J.A. and Parkinson, I.J. (1993). *Geol. Soc. Lond. Spec. Publ.* **76**, 373–403.