

The geochemical behaviour of W, Nb-Ta, and Zr-Hf during mid ocean ridge melting

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Tungsten is traditionally regarded as one of the most incompatible trace elements during mantle melting, similar to Th. However, previously reported W/Th data indicate that the Earth's mantle has a lower W/Th (0.19) compared to the Earth's crust (0.26), suggesting that W is more incompatible than Th. In order to assess the behaviour of W relative to Th and other HFSE during mantle melting, we analysed a suite of MORB glasses from the 7°30'S and 11°30'S section of the Mid Atlantic ridge (MAR South) for their W-Nb-Ta-Zr-Hf compositions, employing isotope dilution and MC-ICPMS. Trace element compositions of the MAR South rocks nearly cover the whole range of MORB (e.g. Zr/Nb from 9-115).

Whereas contents of highly incompatible elements in the MAR South samples vary by more than an order of magnitude (9-220 ppb W, 30-1300 ppb Th), Nb/Ta and W/Th only show little variation (14.0-16.9 and 0.16-0.21, respectively). In marked contrast, Zr/Hf ratios vary from 28-39 and are positively correlated with contents of moderately incompatible trace elements. Nb/Ta ratios decrease slightly with Zr/Nb but are decoupled from Zr/Hf, similar as found in a previous high precision study on MORB samples [2]. These findings appear to be inconsistent with results from experimental studies, predicting that for mantle melting $D_{Nb} < D_{Ta}$ and $D_{Zr} < D_{Hf}$ (e.g., [3]).

The contrasting behavior of W-Th-Nb-Ta with respect to Zr and Hf is explained by the different bulk partition coefficients for each element group, dominated by cpx. Zirconium and Hf are much more compatible during mantle melting (e.g., [3]), leading to a much stronger fractionation of Zr/Hf in melts, even at relatively large melting degrees. Conversely, modelled W/Th and Nb/Ta ratios approach those of the mantle sources already at melting degrees of ca. 5%, thus providing a good estimate of the average W/Th and Nb/Ta in the mantle source regions. As these source regions of the MAR South magmas are variably depleted, the partition coefficients for Th and W must be similar to within ca 10%. Alternatively, both elements might rather be hosted at grain boundaries [4] and not in the pyroxene crystal lattice.

The new estimate for W/Th in the depleted upper mantle (0.18 ± 0.3 , 2σ) indicates that W/Th is not significantly fractionated during dry peridotite melting, tentatively suggesting that the fractionated W/Th in the continental crust reflects a different behaviour of the two elements during subduction zone processes.

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[2] Münker *et al.* (2003), *Science* **301**, 84-87.

[3] Mc Dade *et al.* (2003), *Phys. Earth Planet. Int.* **139**, 129-147.

[4] Hiraga, T. *et al.* (2004), *Nature* **427**, 699.

Magmatic paragonite: Vapour saturation of hydrous arc magmas at high pressure?

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Exposed deep roots of island arcs (e.g. Kohistan arc, Pakistan; Talkeetna; Alaska) are key for understanding continental crust growth mechanisms. Igneous lower arc crust, however, is faced with high-temperature conditions prevailing for a long time, and thus apparent granulite facies 'metamorphic' textures often mask the igneous crystallization history of intermediate to high-pressure arc plutonic rocks. Trace element modeling cannot really discriminate between dehydration melting and high-pressure igneous crystallization when both result in the removal of a small liquid fraction at similar conditions and mineralogy. Besides thermal considerations, one of the keys is that dehydration melting leaves mostly anhydrous residues, while high-P igneous crystallization concentrates H₂O in residual liquids, until (eventually) saturation and exsolution of volatiles occurs. We explore phase relations and textures in lower arc crustal rocks from the Jijal sequence of the Kohistan paleo-island arc (NE Pakistan), to constrain the dehydration melting vs igneous hypothesis.

We studied a sequence of ultramafic and mafic rocks which shows locally cyclic cumulate units (websterites, dunites, garnet clinopyroxenites), pyroxene-bearing garnet hornblendites, garnet gabbros, dissected by patches of paragonite-epidote-garnet gabbros and by garnet-bearing felsic veins. Petrography, phase relations, and thermometry are inconsistent with a dehydration melting hypothesis of the Jijal complex, because of (i) the presence of pg-epi-gar gabbros, with a very uneven distribution in the field indicating late stage localized H₂O-rich melt pods, (ii) wormlike intergrowths of epi+qtz and hbl+qtz, a typical cotectic crystallization feature, (iii) the overall composition of cumulus minerals, garnet in particular, (iv) oxide, gar-hbl and gar-cpx thermometry approaching/exceeding temperatures of 1000°C. Whole rock major and trace element data demonstrate that garnet gabbros and epi-pg-gar gabbros have \pm identical compositions indicating that the Jijal complex fractionated from low-K, hydrous, calcalkaline magma(s). However, the pg-epi-gar gabbros have lower SiO₂, Na₂O, Sr, and Ba, indicating loss of these elements by fluid exsolution upon final crystallization. Thus paragonite and epidote in gabbros are not indicative of retrogression but texturally and mineralogically testify local H₂O saturation of hydrous arc magmas at high pressures