

Fractionation of highly siderophile elements in the lower oceanic crust at ODP Site 735b, SW Indian Ridge

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Compared to the mantle, abundances of some HSE in gabbroic oceanic crust and ocean ridge basalts are lower by a factor of 1000 or more, with Re, Au and Pd being more abundant than Os, Ir, Ru, or Rh. It has been suggested that the highly variable abundances may reflect sulfide fractionation processes in the deeper oceanic crust [1]. Samples from ODP site 735b, legs 118 and 176, a 1500 section of tectonically exhumed middle to lower oceanic crust were analyzed for abundances of HSE and Os isotopic composition. For reconnaissance study, 30 samples characterized by little alteration were selected to cover a range of lithologies, including olivine gabbro, gabbro, troctolitic gabbro, troctolite and disseminated oxide gabbro and oxide gabbro. 2.5 g of powder was digested in inverse aqua regia in a high pressure asher at 320°C. HSE separation and analyses methods follow those established in our lab. In a Re-Os isochron diagram, the most radiogenic samples (with large errors) plot along a 11 Ma reference line, in good agreement to the crustal age of site 735b [2]. Two troctolitic gabbros and 3 olivine gabbros with ¹⁸⁷Os/¹⁸⁸Os of 0.14 - 0.24 display a different linear trend that yields an apparent age of 244 ± 77 Ma with an initial ¹⁸⁷Os/¹⁸⁸Os of 0.126 ± 0.022. CI-chondrite normalized abundances of HSE in the lower crustal rocks cover a wide range (at the most extreme 10⁻³ to 10⁻⁷ x CI chondrite for Os), with relatively high abundances of all HSE in some troctolitic gabbros to more fractionated HSE patterns and much lower abundances of Os, Ir, Ru, Rh and Pt in other lithologies. Re is the least variable, with typical abundances in gabbros of 0.2 – 0.5 ppb, considerably lower than in most MORB. Au concentrations in most analyzed samples are typically <0.1 ppb. Au is more strongly depleted than Re compared to MORB [3] and most mantle rocks. This would imply that Au is more incompatible than Re during fractional crystallization, at least in this section of oceanic crust. From HSE abundance and ratio data, it appears that olivine gabbros behave as a coherent group, whereas troctolitic gabbros may reflect other processes. HSE abundances, Au/Ir, Pd/Ir and Os/Ir in “primitive” olivine gabbros reach values >100 and decrease substantially with decreasing Mg#, Cr, Ni and MgO. The progressive depletion of HSE in olivine gabbros may be related to fractional crystallization from progressively evolved basic melts. This process appears to result in a strong increase in Re/Os from olivine gabbro via gabbro to leuco gabbro and in a decrease of Au/Ir, Pd/Ir and Os/Ir. Consequently, while Re/Os in melts increase during fractional crystallization, Au/Ir, Pd/Ir and Os/Ir decrease. The evolution of troctolitic gabbros, increasing Au/Ir and Pd/Ir with decreasing Mg# and Cr, follows different trajectories and implies more complicated processes, presumably, hybridization of ultramafic cumulates or mantle tectonites by basic melts..

[1] Hertogen et al. (1980) *GCA* **44**, 2125 – 2143.

[2] Dick et al. (1991) *Proceedings of the ODP, Scientific Results* **118**, 439 – 538.

[3] Keays and Scott (1976) *Economic Geology* **71**, 705 – 718.

Control of copper enrichment in Lau Basin magmas by sulfide segregation and sulfur degassing

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Lau Basin magmas show how magma ascent, crystallization and degassing can lead to either enrichment or depletion of Cu (and other chalcophile elements) in differentiated magmas. In these magmas, S degassing is correlated with H₂O degassing. Dissolved S occurs almost entirely as sulfide (S²⁻) in analyzed glasses.

Glasses from the northern part of Eastern Lau Spreading Center (ELSC), located in the backarc, far from the active Tofua arc, are similar to MORB. They have not degassed H₂O, and their dissolved S contents are high and correlated with Fe. They have not degassed much S but have segregated immiscible sulfide liquids which leads to a MORB-like trend of decreasing Cu with decreasing MgO. Further south, ELSC (and its continuation, Valu Fa Ridge:VFR) is shallower and only 35-60 km from Tofua arc. Its magmas include a greater subduction component, especially H₂O which has degassed. Low S contents show that they have also degassed variable amounts of S. Cu contents are slightly elevated compared to northern ELSC and MORB, and Cu decreases with decreasing MgO.

In contrast, the small seamounts located a few km from the ELSC-VFR axis have Cu contents that *increase* with decreasing MgO, and reach much higher values than ELSC-VFR. They have degassed large amounts of H₂O and almost all of their Sulfur. Most seamounts are more primitive than the nearby spreading axis. A few analyzed glasses from the nearby Tofua volcanic arc are similar to the seamounts in their behavior of S and Cu.

We propose that Cu contents in differentiated magmas are controlled by immiscible sulfide liquid segregation and S degassing. Like MORB, glasses from northern ELSC undergo sulfide segregation that depletes Cu from residual liquids, while very little S is lost by degassing. Magmas from southern ELSC and VFR start crystallizing at moderate depths (6-8 km) where they segregate some sulfide liquid, and lose Cu. They also undergo degassing of H₂O and S as they crystallize and ascend to shallower levels, limiting the amount of formation of sulfide liquids and its consequent Cu depletion. In contrast, seamount (and arc) magmas ascend rapidly to shallow levels and degas H₂O and S before they have a chance to segregate immiscible sulfide liquid. Cu remains in the silicate liquid and its concentration increases in differentiated magmas.

An alternative mechanism to account for high Cu in some magmas is that during larger extents of partial melting beneath the arc and seamounts (caused by high H₂O in the source), sulfide in the mantle source is exhausted, releasing all Cu into the melt. However, low Cu in primitive seamounts suggests elevated Cu results from differentiation, not melting.