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Partial separation of halogens during the subduction of oceanic crust

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Incompatible elements, such as halogens, have the potential to act as key tracers for volatile transport processes in Earth and planetary systems. The determination of halogen abundances and ratios in different mantle reservoirs gives us the ability to better understand volatile input mechanisms into the Earth′s mantle through subduction of oceanic crust.

Halogen partition coefficients were experimentally determined between forsterite, orthopyroxene and silicate melt at pressures ranging from 1.0 to 2.3 GPa and temperatures ranging from 1500-1600°C, thus representing partial melting conditions of the Earth′s mantle. Combining our data with results of recent studies (Beyer et al. 2012; Dalou et al. 2012) shows that halogen partitioning between forsterite and melt increases by factors of about 1000 (fluorine) and 100 (chlorine) between 1300°C and 1600°C and does not show any pressure dependence. Chlorine partitioning between orthopyroxene and melt increases by a factor of about 1500 for a temperature increase of 100°C (anywhere between 1300°C and 1600°C), but decreases by a factor of about 1500 for a pressure increase of 1.0 GPa (anywhere between 1.0 GPa and 2.5 GPa). At similar P-T conditions, a comparable effect is observed for the fluorine partitioning behaviour, which increases by 500-fold for a temperature increase of 100°C and decreases with increasing pressure.

Halogen abundances in mid-ocean ridge basalts (MORB; F=3-15, Cl=0.5-14ppm) and ocean island basalts (OIB; F=35-65, Cl=21-55 ppm) source regions were estimated by combining our experimentally determined partition coefficients with natural halogen concentrations in oceanic basalts (e.g. Ruzié et al. 2012).

The estimated chlorine OIB source mantle concentration is in almost perfect agreement with primitive mantle estimates (Palme and O′Neill 2003). If we expect an OIB source mantle slightly depleted in incompatible elements, this suggests that at least small amounts of chlorine are recycled deep into the mantle through subduction of oceanic crust, possibly via marine pore fluids (Sumino et al. 2010). The OIB source region is, however, significantly enriched in fluorine relative to the primitive mantle by a factor of 1.4-3.6, which indicates that significantly larger amounts of fluorine are transported deep into the Earth′s mantle through subduction. An explanation for the partial separation of chlorine and fluorine during subduction is that the heavy halogens are more likely to escape from the subducting slab in hydrous fluids at an early subduction stage whereas significant amounts of fluorine are likely to remain in the slab, possibly incorporated in the lattice of hydrous amphibole or mica, or in anhydrous high-pressure phases of eclogite.

The MORB source mantle is degassed in fluorine (17-88%) and chlorine (22-99%) relative to primitive mantle estimates. Preliminary data suggest that the bromine partitioning behaviour between forsterite and melt is roughly comparable to the behaviour of fluorine and chlorine. If true, this would imply that the Earth′s upper mantle is presumably degassed of all halogens despite the more likely escape of heavy halogens from the slab at an early subduction stage, implying that these halogens are at least partly accumulating in the crust after leaving the slab.

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