

Why are mantle-derived noble metal alloys rhenium-free and what can they tell us about mantle melting?

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Owing to differences in compatibility between Re and Os, the decay of ^{187}Re to ^{187}Os is an exceptional tracer of melting in the Earth's upper mantle. There is a wide consensus that the mantle displays Os isotopic heterogeneity at the grain scale, which is exemplified by large variations of $^{187}\text{Os}/^{188}\text{Os}$ in oceanic basalts. Most remarkably, the decoupling of the Re-Os isotopic system during mantle melting, appears to be solely controlled by two minute accessory phases – alloys and sulfides. Alloys remain at the source and develop non-radiogenic Os isotopic ratios, as they have very low Re/Os. On the other hand, sulfides have high Re/Os and develop more radiogenic $^{187}\text{Os}/^{188}\text{Os}$ over time. However, not much is understood on the timing and conditions at which the decoupling of the Re-Os isotope system takes place. Alloy model ages calculated using Os isotopes can be as old as 4.1Ga, with the implication that alloys crystallize in the absence of Re. The relative long-lived nature of these alloys indicates that these phases are extraordinarily resilient to isotopic re-equilibration despite being hosted by mantle lithologies. Sulfides on the other hand, have model ages that are broadly younger than alloys and are vulnerable to low-T metasomatic re-equilibration. In order to provide constraints on the high-T stability of Os-rich alloys as well as their compositional distribution, we have carried out a series of experiments at pressures between 1 bar and 20 kbar, over a range of temperatures (1573 to 2000K) as well as alloy (Ru, Re, Os and Ir) and sulfide melt compositions (Fe, Ni and Cu). Results show that the compositional variability of alloys in the mantle is intimately related to large-scale melt extraction, coupled with desulfurization of the mantle source. Furthermore, we show that Re, Os and Ir form a complete solid solution in the alloy at high temperature, and that alloys are always more Re-rich than the sulfide melt in equilibrium with them. Depending on the initial proportions of Re, Os and Ir that one considers, alloy-sulfide pairs will develop different $^{187}\text{Os}/^{188}\text{Os}$ over time. Our results preclude equilibration of Os-rich alloys and sulfides in the mantle at temperatures exceeding 1700K, as alloys would inevitably be richer in Re than what is shown by natural alloys, which have only a maximum of a few hundred ppm Re. Based on our results, natural alloys, which are Re-poor, would have to be isolated from mantle sulfides for periods of up to several billion years, with implications to our understanding of mantle melting and melt extraction in the Early Earth.