Recognizing recycled osmium

Elisabeth Widom
Department of Geology and Environmental Earth Science, Miami University, Oxford, Ohio 45056, USA

Understanding the behavior of noble metals like Os in Earth systems is important from both scientific and economic standpoints. The abundances of noble metals in the mantle have significant implications for our understanding of the Earth’s evolution. The relative abundances of these strongly siderophile elements in the mantle potentially preserve a fingerprint of core formation, which likely scavenged much of the Earth’s budget of these elements, as well a record of the latest stages of accretion history, during which time the Earth’s mantle may have been re-enriched in these elements (e.g., Walter et al., 2000). Understanding processes that can modify these signatures in the Earth’s mantle is fundamental to such models. In addition, documenting environments under which noble metals are mobile, and those under which they become scavenged and concentrated, are critical for understanding the formation of precious metal ore deposits and developing strategies for prospecting. For example, many economic Au deposits are associated with magmatism at convergent margins, yet the source of the Au and the behaviors of other noble metals are generally not well constrained (McInnes et al., 1999).

The paper by Suzuki et al. (2011, p. 999 in this issue of Geology) contributes important new results regarding the mobility of Os in subduction settings. The Re-Os isotope system, involving the decay of $^{187}$Re to $^{188}$Os with a half-life of ~42 Ga, serves as a potentially invaluable tracer for understanding the mobility of noble metals during subduction and the ability of subduction processes to overprint the mantle signature. The Re-Os isotope system is distinct from other radiogenic isotope systems in that the parent element (Re) is moderately incompatible, and the daughter element (Os) strongly compatible during mantle melting (Shirley and Walker 1998). The large parent-daughter fractionation produced during melting have resulted, with time, in $^{187}$Os/$^{188}$Os isotopic differences between crustal and mantle reservoirs that are more extreme than other isotope systems. Upper continental crust, seawater, and sediments (Peucker-Ehrenbrink and Jahn, 2001; Sharma et al., 2007) generally have $^{187}$Os/$^{188}$Os ratios nearly an order of magnitude more radiogenic than the depleted mantle (Staidish et al., 2001; Walker et al., 2002). Furthermore, due to the very high Re/Os ratios in crustal material, radiogenic Os isotope signatures can develop over very short time periods (e.g., $10^8$–$10^9$ yr; Gannoun et al., 2007); hence, even relatively young crustal materials are likely to be significantly more radiogenic in Os than depleted mantle-derived melts.

The extreme disparity in isotopic signatures between the depleted mantle and crustal materials makes the Os isotope system a particularly sensitive tracer of crustal involvement in magma petrogenesis. A longstanding observation has been that many arc lavas are significantly more radiogenic in Os than the depleted upper mantle (Alves et al., 2002), but it has proven challenging to determine whether this is due to addition of radiogenic slab-derived Os to the mantle wedge by fluids or melts, or to assimilation of crust during magma ascent (Woodhead and Brauns, 2004), or both. This stems from two fundamental issues: Os abundances are extremely low in most arc magmas (often less than a few tens of parts per trillion) making them highly sensitive to even very minor (percent level or less) crustal assimilation (Chesley et al., 2004); and compared to many lithophile elements, relatively little is known about the geochemical behavior of Re and Os during subduction. Previous attempts to understand the behavior of Re and Os during subduction have been pursued on several fronts. Experimental measurements suggest that Re may be mobile in hydrous fluids, especially when oxidizing and Cr rich, as expected in subduction-related fluids, but Os appears to be substantially less fluid mobile (Xiong and Wood, 1999; Xiong and Wood, 2000). Comparisons of samples thought to represent subduction processed oceanic crust (meta-basalts and meta-gabbros) with their respective protoliths agree qualitatively with these results, and suggest that as much as 40%–60% of the Re, but inconsequential amounts of Os, may be liberated in slab fluids (Becker 2000; Dale et al. 2009). Perhaps the most direct way to assess potential slab-derived Re and Os addition to the mantle wedge is to analyze mantle samples from subduction settings. Mantle xenoliths hosted in arc lavas are relatively rare, but some samples from southwestern Japan and the Izu-Bonin arc have unradiogenic Os signatures that have been interpreted as ancient, strongly melted mantle fragments for which any potential slab contribution would be largely masked (Parkinson et al., 1998; Senda et al., 2007). In contrast, other mantle xenoliths from the Cascades (North America), Japan, Kamchatka (Russia), and Papua New Guinea have Os isotopic compositions slightly to moderately more radiogenic than depleted upper mantle, and have been attributed to addition of radiogenic slab-derived fluids (Brandon et al., 1996; McInnes et al., 1999; Widom et al., 2003; Saha et al., 2005).

Mass balance considerations pose significant difficulties in calling on the addition of slab fluids or melts to explain radiogenic Os signatures in arc mantle. Given that Os concentrations in most crustal materials are ~10–1000 times lower than mantle peridotite, modifying the mantle Os isotope signature by addition of a metasomatic slab-component would require either much greater mobility of Os than that documented experimentally or evidenced in subduction metamorphosed crust as described above (Chesley et al., 2004), or a very high fluid:rock ratio or some mechanism to concentrate Os from a slab-derived fluid. In general, sub-arc mantle xenoliths are strongly melt depleted, so even if some Re were added by a slab fluid or melt, Re/Os ratios are far too low to generate the radiogenic Os due to radiogenic ingrowth (Brandon et al., 1996; Widom et al., 2003; Chesley et al., 2004). One observation that mitigates the mass balance problem to some extent is that in general, the more radiogenic Os isotope signatures are found in mantle xenoliths with lower than average mantle Os abundances. This relationship has been attributed to scavenging of the original mantle Os budget by infiltration of oxidizing slab fluids, such that this “cleansed” mantle wedge becomes more susceptible to overprinting by continued infiltration and reaction with radiogenic slab-derived Os (Brandon et al., 1996; Widom et al., 2003; Saha et al., 2005).

So far, there have been very few data from arc lavas to substantiate such a model. As discussed above, arc lavas generally have very low Os abundances, and minor crustal assimilation will swamp any potential slab-derived radiogenic Os in their mantle sources. The novel study of Suzuki et al. (this issue) takes advantage of the properties of Cr-spinel, an early crystallizing mineral phase that incorporates Os with concentrations upward of 10 pph, comparable to mantle peridotite and substantially higher than arc lavas. Critically, the Cr-spinels in this study also trapped inclusions of the arc magmas from which the crystals grew, providing some assurance that the magmas were relatively primitive and apparently unaffected by
crustal assimilation prior to precipitating the Cr-spinels. The Os isotopic signatures of the Cr-spinels thus reflect that of primitive arc magmas, and presumably the mantle wedge from which they were derived (Fig. 1). Although such Cr-spinels exist only as trace mineral phases in arc lavas, Suzuki et al. took an innovative approach in collecting Cr-spinels from beach sands in the Bonin Islands (Japan), from which separation of sufficient Cr-spinel is facilitated. These samples thus represent a regional composite of crystals that grew from primitive arc magmas in three of the Bonin Islands. Two Cr-spinel samples, crystallized from boninitic lavas (high-Mg andesites) formed in the earliest stages of the Izu-Bonin arc, have Os isotopic signatures within the range of normal depleted mantle, thus lacking any evidence for slab-derived Os. In contrast, one Cr-spinel sample from a more recent tholeiitic stage of the Izu-Bonin arc exhibits an Os isotope signature significantly more radiogenic than depleted upper mantle, and potentially documents for the first time the Os isotopic composition of primitive arc magma and the signature of the slab fluid-fluxed mantle wedge from which it was derived. In concert with previously proposed mechanisms for imparting radiogenic Os isotopic signatures to arc mantle (Brandon et al., 1996; Widom et al., 2003; Saha et al., 2005), Suzuki et al. ascribe their findings to progressive oxidation of the mantle wedge by infiltrating slab fluids or melts, which after several millions of years of evolution may have oxidized the wedge sufficiently to allow migration of radiogenic slab-derived Os, and overprinting of the original wedge signature in the zone of arc magma generation.

An additional important finding of the Suzuki et al. study is that, compared to the Cr-spinel samples, lava samples from the respective islands were all significantly more radiogenic in Os, arguing strongly that they have experienced crustal assimilation, despite at least one with a relatively high Os concentration (86 ppb). The method of Suzuki et al. thus offers great promise for further evaluating both mantle and crustal processes in arc magma generation in other subduction zones, and should be especially powerful when combined with chemical analysis of melt inclusions in chromites to ensure that they trap truly primitive and uncontaminated arc magmas.

REFERENCES CITED


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