A Quantitative Link Between Recycling and Osmium Isotopes

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Formation, subduction, and incomplete mixing of oceanic crust produces chemical and isotopic heterogeneity in Earth's mantle (*1*, *2*). The signature of these processes in the mantle over time and the importance of recycling in explaining the origins and compositions of volcanic rocks remain major questions. Recently, osmium isotopes have proved to be an important tracer (*3*, *4*). Basaltic ocean crust has much higher Re/Os ratios than mantle peridotite, from which it is derived through partial melting, because osmium remains mostly in the solid (mantle residue), whereas Re preferentially enters the melt. The decay of long-lived ^{187}Re to stable ^{187}Os therefore generates increased $^{187}Os/^{188}Os$ ratios in such crustal rocks. Elevated $^{187}Os/^{188}Os$ values have been recently found in Icelandic basalts, where they are correlated with the relative abundances of other isotopes (*5*, *6*). These data support the notion that the mantle source of Icelandic basalts contains oceanic crust that has been recycled by subduction and mantle convection (*7*). However, it has been difficult to assess this model because independent estimates of the proportions of components and their Os isotopic compositions were lacking.

Sobolev *et al.* (*8*, *9*) recently proposed that the abundances of Mn and Ni in early-formed olivine crystals in oceanic basalts such as Hawaii and Iceland can provide these estimates. The method makes use of fundamental differences in chemical composition, mineralogy, and melting behavior between recycled (oceanic) crust and mantle. Whereas mantle peridotite invariably contains large proportions of olivine, recycled (eclogitic) crust reacts with the surrounding peridotite and forms an olivine-free hybrid, pyroxenite (*8*). A similar hybrid component, a mixture of ancient recycled crust and peridotites, was also proposed on the basis of Os-He isotope relationships in Icelandic picrites (*6*). Because olivine and pyroxene partition Ni and Mn differently (olivine prefers Ni and pyroxene, Mn), Ni and Mn abundances in equilibrium melts formed from these contrasting lithologies will retain the memory of their respective source compositions. When a source contains both peridotite and pyroxenite, both lithologies contribute to the resulting melt, and their proportions can be reconstructed by using Mn/Fe or Ni/(Mg/Fe) ratios in olivine phenocrysts formed from these hybrid melts.

We combined data for averaged compositions of olivine phenocrysts for olivine-rich lavas and bulk rock $^{187}Os/^{188}Os$ ratios from Iceland to obtain the proportion of pyroxenite-derived melt by both Ni excesses and Mn deficits in olivine (Fig. 1). These parameters indeed show strong linear correlations, and this permits quantitative assessment of the end-member isotope ratios: peridotitic mantle ($X_{px} = 0$) and pyroxenite from recycled crust ($X_{px} = 1$). The best correlation based on Ni (Fig. 1A) yields a (peridotitic) intercept of $^{187}Os/^{188}Os = 0.126 \pm 0.002$ (2σ), similar to estimates of present-day oceanic mantle $^{187}Os/^{188}Os = 0.125$ (*4*). The calculated isotopic composition of pyroxenite is $^{187}Os/^{188}Os = 0.140$ to 0.155. The analogous correlation based on Mn (Fig. 1B) is consistent with this result, although the scatter is slightly greater. These values can be modeled as 1.1- to 1.8-billion-year-old oceanic crust reacted with present-day oceanic peridotite shortly before final melting (*10*). The calculated age range for recycled component in Icelandic mantle is consistent with similar age estimations from Pb isotopes (*11*) and Os and He isotope relationships (*6*). The obtained isotopic compositions of the peridotitic and pyroxenitic components for Iceland also support independently "olivine-based" estimates of source proportions (*9*), as well as the qualitative idea of the presence of ancient recycled materials in Icelandic mantle sources (*5*–*7*, *11*).

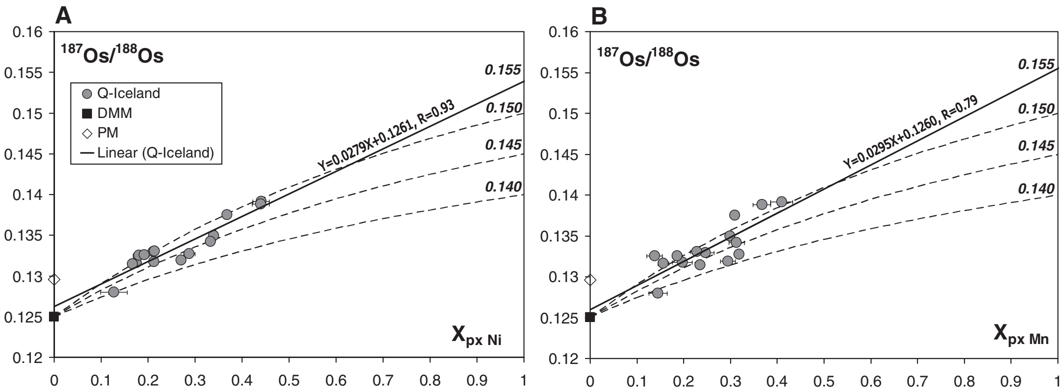

Fig. 1. (**A** and **B**) Measured bulk rock $^{187}Os/^{188}Os$ versus estimated proportion of pyroxenite derived melt (X_{px}) (table S1). X_{px} is defined as a following linear functions of average olivine composition (*10*): $X_{px\ Ni} = 10.54 \times NiO/(MgO/FeO) - 0.4368$; $X_{px\ Mn} = 3.483 - 207.139 \times (Mn/Fe)$. Solid lines represent linear regression with parameters shown. DMM and PM stand for depleted and primitive present day mantle estimates, respectively (*4*). Dashed lines indicate mixing of melt derived from peridotite with $^{187}Os/^{188}Os = 0.125$ and from pyroxenite with $^{187}Os/^{188}Os$ ratio indicated in italics (*10*).

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Materials and Methods
Table S1
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