Reconciling mantle rare gas geochemistry with tomographic evidence of whole mantle convection

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High-resolution seismic tomography clearly shows that lithospheric plates penetrate the 670 km discontinuity (e.g. van der Hilst *et al*, 1997). A common view defended by geochemists (Turekian, 1959 ; Allègre *et al.*, 1996) holds that the isotopic composition of He and Ar is incompatible with geophysical evidence because (a) the inventory of terrestrial radiogenic argon requi-res that the lower mantle is largely undegassed and (b) recycling of outgassed lithospheric material should destroy the primitive isotopic composition of helium and argon in the lower mantle.

It is first shown, however, that the 'argon problem' is largely a 'potassium problem' that results from the assumption that the terrestrial K/U ratio is 12,500 (Jochum *et al.*, 1983). In view of the large variability of this ratio amongst telluric objects (from 3,000 in the Moon to 60,000 in chondrites), of the volatile character of alkalis demonstrated by the Sr isotope geochemistry of chondrites and terrestrial material, and of the uncertainties on the K/U fractionation during melting, such a value value cannot be taken for granted. In addition, earlier geochemical models of steady-state He and Ar cycles (e.g. O'Nions and Tolstikhin, 1996) are shown to be inadequate. The common concept of residence time is inappropriate for multiple reservoir systems. An unwanted artifact resulting from the assumption that an isotopically heterogeneous system is time-invariant, is actually a strong reduction of mass fluxes between reservoirs, with, in particular, a small exchange rate between the lower mantle and the upper mantle.

The view that tomography reflects a present-day snapshot while the Earth's mantle was essentially layered until recently, requires some unsubstantiated serendipity. A regime of intermittent layering (avalanches) is geochemically indistinguishable from whole mantle convection and, as such, does not solve the dilemma.

A time-dependent model with four reservoirs (lower and upper mantle, crust, atmo-sphere) is evaluated, in which elemental fractionation upon transfer and variable rate of crustal growth, atmosphere extraction, and lithosphere production are taken into account. Vigorous lithosphere production early in the history of the Earth enhances the degassing of the upper mantle in agreement with the very radiogenic character of $^{4}He/^{3}He$ and $^{40}Ar/^{36}Ar$ ratio in MORB. The preferential reinjection into the lower mantle of lithospheric material that lost its component rich in lithophile elements to the continental crust has been underestimated by previous modelers. Recycling of oceanic lithosphere stripped of its rare gases, but more importantly of its U, Th, and K, into the lower mantle preserves the primitive isotopic signature of the rare-gas inventory of this reservoir. Accumulation in the lower mantle of ancient plates essentially barren of U, Th, and K, but nevertheless showing isotopic evidence of plate-tectonic processes in the less incompatible elements (Nd, Hf, Sr), can account for the isotopic composition of rare gases in hot-spot basalts.

A prominent effect of plate tectonics and whole mantle convection is to clutter and dilute the lower mantle with old barren lithospheric debris. The geochemistry of the lower mantle is therefore expected to show characters that somehow conflict with conventional views. Although the incompatible element content of the lower mantle has been diluted with respect to the bulk silicate Earth (BSE), the fractionation of elements, and in particular parent-daughter pairs such as Sm/Nd and Rb/Sr, is still intermediate between that of BSE and that of the upper mantle. For such a model to be acceptable, melting should reverse the relative level of enrichment of melts relative to that of their mantle source. OIB should be produced by very small degrees of melting of relatively barren lower mantle material and MORB by large degrees of melting of a relatively fertile upper mantle, regardless of the apparent 'depletion' or 'enrichment' indicated by the isotopic systems and trace element patterns. The outgassed character of the upper mantle was probably acquired during the early Archaean when mantle activity was intense and is still being enhanced by the fluxing of K, U, and Th from the descending lithospheric plates.

The view of the mantle offered by seismic tomography is therefore not incompatible with the isotopic evidence provided by terrestrial rare gases.

References

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