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Speculations about a revival of the layered mantle

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The one-time standard geochemical model of the Earth featured a permanently layered mantle, with very limited mass transport across the 670 km seismic discontinuity. It was based on geochemical crust-mantle mass balances and the apparent evidence that mantle plumes sample a largely primitive deep-mantle reservoir, characterized by chondritic Nd isotopes and primordial/solar He and Ne isotopes. Some early experimental mineral-physics evidence also supported this model. This "standard model", while being kept alive by some, has been abandoned by most workers because of seismic evidence for very deep subduction and geochemical evidence that plume sources such as Hawaii have sources with non-primitive Nd isotopes and strongly fractionated trace element patterns. Consequently, single-layer, "whole-mantle" convection and evolution models were designed to somehow account for the undeniable survival of primordial noble gases in mantle hotspots. Recently, Tolstikhin & Hofmann (2005) and Boyet & Carlson (2005), on the basis of independent evidence from xenon and ^{142}Nd isotopes, respectively, proposed a new layered-mantle model, where the lowermost, so-called D" layer consists of a near-primordial, crust, subducted and stored at the base of the mantle. It is enriched in incompatible elements, thus obviating the need for a very large, chemically and isotopically "primitive" lower mantle, and it stores most of the primordial noble gas budget. O'Neill & Palme (2008) proposedan alternative model with a non-chondritic Earthand a single, partly depleted mantle reservoir,which lost its primordial crust to space by collisional erosion. However, this otherwise attractive model does not address the noble gas constraints. Using Pb isotopes, I show that all early Archean crustal rocks are derived from mantle reservoirs with superchondritic (time-integrated) Th/U ratios. Subsequently, the mantle gradually evolved to a chondritic Th/U. This is explained by a chondritic Earth model in which the earliest mantle is differentiated by downward segregation of dense partial melt with a low Th/U ratio, leaving an upper-mantle residue with high Th/U. Following solidification, the deep layer is then gradually consumed by convective entrainment, leaving the present-day D" layer as a remnant and the bulk of the crust-mantle system with a near-chondritic Th/U ratio. It is still an open question under which circumstances Ca-perovskite can exist as a residual solid in the lower mantle, but Ca-perovskite appears to be the only deep-mantle phase capable of effecting the required large-scale Th-U fractionation (Hirose et al, 2004; Corgne & Wood, 2005).

Tolstikhin & Hofmann (2005),Phys. Earth Planet Inter.148, 109-130; Boyet & Carlson (2005),Science 309, 576-581; O'Neill & Palme (2008), Phil. Trans. R. Soc. A, 366, 4205-4238; Hirose et al. (2004), Phys. Earth Planet. Int. 146, 249-260; Corgne & Wood (2005), Contrib. Min. Pet. 149, 85-97.