The streaky-mantle alternative to mantle plumes and its bearing on bulk-Earth geochemical evolution

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ABSTRACT

Standard geochemical models of the Earth envisage a layered mantle structure, with the depleted-mantle source of mid-ocean ridge basalts (MORB) as a residue from formation of the continental crust and subducted oceanic crust isolated in thermal boundary layers that serve as the source of mantle plumes. In the streaky-mantle model, subducted oceanic crust is mixed with a residue (unbuffered mantle) from crustal extraction to make the depleted mantle; hence the depleted mantle cannot be the geochemical complement of the lithospheric crust. Mantle evolution in the streaky-mantle model is controlled by the relative importance of slab melting and slab dehydration processes at convergent margins through time. Slab compositions after melting have low Ce/Pb, low U/Pb, and high Sm/Nd, and their recycling suppresses the Pb isotopic evolution of the mantle while leading to high ´$_{Nd}$ relative to the recycling of dehydrated slabs that have high Ce/Pb, high U/Pb, and low Sm/Nd. A transition from subduction dominated by slab melting to subduction dominated by slab dehydration in the Middle Archean may therefore be recognized from a shift in initial $^{206}Pb/^{204}Pb$–$^{207}Pb/^{204}Pb$ isotopic signatures above the m = 8 single-stage growth curve and a reduction in ´$_{Nd}$ values in depleted mantle–derived rocks. Ancient streaky mantle buffered by melted slabs was not overprinted, but constitutes the matrix into which younger recycled dehydrated crust was mixed. Both streaky-mantle components are present in the source of MORB in approximately equal proportions, with end-member compositions tapped during the generation of seamount basalts. Ocean island basalts (OIB) can be generated from recycled dehydrated oceanic crust in the same mantle section by invoking a “plum-pudding” or statistical upper mantle assemblage–style distribution of recycled components or preferential melting of dehydrated oceanic crust on account of greater retention of volatiles during the recycling process. The common component between MORB and OIB is thus recycled dehydrated oceanic crust, and differences between the basalt types should be viewed as a consequence of the involvement of the ancient mantle component rather than as resulting from the introduction of enriched components into a depleted reservoir by mantle plumes. Application of the two-stage evolution model to the modeling of Nb/U, Ce/Pb ratios yields a best estimate of the amount of sediment subducted into the mantle of 56% of the present mass of lithospheric continental crust. Allowance for this extra crustal budget in mass balance calculations requires processing of 82% of the mantle and indicates a boundary between depleted and primitive mantle at 2025 km depth, which is in agreement with seismic tomographic models advocating a change in mantle convection regime in the lowermost 1000 km of the mantle.