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The Argon Constraint on Mantle Structure Re-visited: Whole Mantle Convection with a K and Ar Rich Core

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Recent tomographic models clearly document that oceanic lithosphere subducts to the core-mantle boundary. Mineral physics models using the latest thermoelastic data demonstrate that a uniform pyrolite composition can satisfy the radial profiles of density and velocity throughout the whole mantle when calculated along a self-consistent adiabatic geotherm whereas chemically layered models with an mid-mantle thermal boundary layer cannot. Thus, plumes must originate at the core-mantle thermal boundary layer. Both results are consistent with a simple picture of whole mantle flow. This view conflicts with the traditional isotopic and rare gas interpretations that the mantle is chemically and convectively layered with the 660 km discontinuity being a boundary to flow. In this scenario, the lower mantle is a chemically distinct reservoir rich in K, U, Th and ^{40}Ar. In this model, the Bulk Earth is depleted in potassium (250 ppm) relative to a C1 chondrite composition, but the lower mantle is enriched in K (150 ppm) relative to the depleted upper mantle (40 ppm) reservoir. It is argued that the atmospheric content of ^{40}Ar reflects contributions from the crust and depleted upper mantle, but that the largest contribution comes from the lower mantle.

However, this interpretation of a layered mantle cannot produce sufficient heat to satisfy the global heat flux constraint and hence cannot be correct. Furthermore, it is not possible to transfer the lower mantle ^{40}Ar to the atmosphere using accepted flux rates for a layered mantle. In this study, the atmospheric ^{40}Ar budget (66 x 10^1grams) is re-investigated with a new U, Th, and K mass and heat flux balance model where the crust, lithosphere, depleted mantle, and core reservoirs are considered. The whole mantle was treated as uniform to first order with the depleted mantle concentrations applying throughout. The successful model distributes the full C1 chondrite abundance of U and Th within the silicate Earth, but requires 1,420ppm K in the core. Potassium is sequestered in the core during core formation when K forms a stable high pressure metal alloy with the downward percolating Fe-Ni liquid metal. Over 4.5Ga, the mass of ^{40}Ar produced in the core is 369.4 x 10^1grams. It is not possible to account for the present day atmospheric ^{40}Ar budget from ^{40}Ar contributions from only the continental crust and depleted mantle reservoirs; the core must contribute the bulk of the atmospheric ^{40}Ar (51.5 x 10^{18} grams). Consideration of the ^{40}Ar/^{36}Ar ratios of ocean-island basalts indicates that the plume source region, which is the core in the model advocated here, is not, however, dominated by ^{40}Ar, indicating that the core must also have formed with a substantial concentration of ^{36}Ar.