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Long Lived Compositional Reservoirs: Their Evolution in a Cooling Earth and Hypothesis Tests for their Existence

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Seismic observations increasingly hint at large-scale compositional heterogeneity in Earth's lower mantle, particularly within the tomographically-observed large, low shear velocity provinces (LLSVPs) beneath Africa and the Pacific. If compositional heterogeneity takes the form of long-lived, geochemical reservoirs, as hypothesized from geochemical surface observations, it will play a controlling role in the thermal and mass transport throughout Earth's mantle. Therefore, our understanding of mantle convection, plate tectonic driving forces, and thermal and chemical evolution all hinge upon constraining the mode of large-scale thermochemical convection that exists in the deep mantle. We first examine how mantle cooling affects the evolution and stability of compositional reservoirs. We find that mantle cooling acts to inhibit the formation of thermochemical, plume-like instabilities and instead, it promotes the existence of long-lived thermochemical piles that remain in the lowermost mantle for geologic timescales. We then examine how seismic observations of core-mantle boundary (CMB) topography and ultra low velocity zones (ULVZs) can constrain the existence and geometry of long-lived compositional reservoirs. We show that compositional reservoirs will produce a unique signature of CMB topography in which the CMB is upwarped along a narrow ridge along their perimeters. Furthermore, we find that ULVZs will preferentially accumulate along these regions of upwarped CMB topography. Most importantly, we conclude that compositional reservoirs produce ULVZs with an asymmetrical shape, thinner on the inside perimeter and thicker on the outside. In conclusion, high resolution seismic studies that constrain CMB topography and ULVZ presence and geometry along the perimeters of the LLSVPs provide a hypothesis test for the existence of long-lived compositional reservoirs.