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Isopycnicity, Thermal State and Secular Evolution of Cratonic Mantle Keels

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The lithosphere-asthenosphere boundary (LAB) beneath ancient continental nuclei (cratons) is thought to be anomalously deep (> 200 km) due to the presence of cold, compositionally distinct mantle keels that are readily identifiable as high-velocity features in global tomographic models. The empirical concept of isopycnicity, which holds that a pervasive state of near-neutral buoyancy is created by offsetting thermal and compositional effects on density, is oft invoked to explain the long-term stability of cratonic mantle keels and general absence of an accompanying long-wavelength gravity signature. Although the concept is appealing, the mechanisms by which an isopycnic state can be sustained over geological time are not clear. For example, on a billion-year (Gyr) timescale, secular cooling of a mantle keel could induce a gradual departure from isopycnicity. This scenario is examined by thermal and rheological modeling of a cold cratonic keel starting from various initial conditions. Our models assume that the temperature of the LAB intersects the mantle adiabat, and consider secular cooling (40 K per Gyr) as well as gradual loss of radiogenic heating in the lithosphere. Several compositional scenarios corresponding to 'average' Archean and Proterozoic mantle compositions are considered and used to predict seismic and gravitational observables. Our results confirm that, under similar thermal conditions, less-depleted mantle keels of 'Proterozoic' composition are less buoyant than Archean keels, but are indistinguishable based on seismic wave velocity. In general, cratonic keels are predicted to founder isostatically at about 1 km / Gyr, which should produce a testable epeirogenic signal in the core regions of continents.