Has Earth’s Plate Tectonics Led to Rapid Core Cooling?

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Earth’s mantle and core are convecting planetary heat engines. The mantle convects to lose heat from secular cooling, internal radioactivity, and core heatflow across its base. Its convection generates plate tectonics, volcanism, and the loss of ~35 TW of mantle heat through Earth’s surface. The core convects to lose heat from secular cooling, small amounts of internal radioactivity, and the freezing-induced growth of a compositionally denser inner core. Until recently, the geodynamo was thought to be powered by ~4 TW of heatloss across the core-mantle boundary. More recent determinations of the outer core’s thermal conductivity (Pozzo et al., 2012; Gomi et al., 2013) would imply that >15 TW of power should conduct down its adiabat. Secular core cooling has been previously thought to be too slow for this, based on estimates for the Clapeyron Slope for high-pressure freezing of an idealized pure-iron core (cf. Nimmo, 2007).

The ~500-1000 kg m^{-3} seismically-inferred jump in density between the liquid outer core and solid inner core allows a direct estimate of the Clapeyron Slope for the outer core’s actual composition which contains ~0.08±0.02 lighter elements (S,Si,O,Al, H,…) mixed into a Fe-Ni alloy. A PREM-like 600 kg m^{-3} density jump yields a Clapeyron Slope for which there has been ~774K of core cooling during the freezing and growth of the inner core, cooling that has been releasing an average of ~21 TW of power during the past ~3 Ga. If so, core cooling could easily have powered Earth’s long-lived geodynamo. Another implication is that the present-day mantle is strongly ‘bottom-heated’, and diapiric mantle plumes should dominate deep mantle upwelling. This mode of core and mantle convection is consistent with slow, ~37.5K/Ga secular cooling of Earth’s mantle linked to more rapid secular cooling of the core (cf. Morgan, Rüpke, and White, Frontiers, 2016). Efficient plate subduction, hence plate tectonics, is a key ingredient for such rapid secular core cooling.

We also show how a more complete thermodynamic version of Birch’s accretional energy calculation predicts that accretion with FeNi-sinking-linked differentiation between an Earth-like mantle and core could naturally generate a core that, post-accretion, was both hotter than overlying mantle and ~1000K hotter than today.

Keywords: core heat loss, mantle convection, plate tectonics, subduction, accretion energetics

