Forum Comment

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Kimberlites and the start of plate tectonics

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Stern et al. (2016) have well documented the Neoproterozoic onset of modern-style plate tectonics on Earth, signaled by the first appearance of high-pressure, low-temperature (HP/LT) rocks such as oceanic blueschists (e.g., lawsonite- and jadeite-bearing rocks) ± LT eclogites, and ultrahigh-pressure (UHP) intracontinental sialic complexes + kimberlite diatremes. These phase assemblages are genetically associated with modern-style subduction zones—deep-seated realms of relatively cool, steeply descending lithospheric plates. However, Stern et al. then postulate that, reflecting formation of such high-density rocks and minerals, plate tectonics only began in the Neoproterozoic (<1.0 Ga). Other workers have suggested a substantially older onset of terrestrial plate tectonics involving at least shallow subduction, based on ancient production of ophiolite complexes, high-temperature eclogites, diamond pipes, and/or phase equilibria data coupled with thermal modeling (Ernst, 1972; Davies, 1992; Dilek and Polat, 2008; Shirey and Richardson, 2011; Shirey et al., 2013; Hastie et al., 2016).

If the process is defined by lithospheric underflow, then primitive plate tectonics evidently began in Hadean time soon after the magma ocean solidified (Condie, 1980, 1982; Sleep et al., 2014). Thin lithospheric slabs must have bounded the surface of the pre-Archean solid Earth, as required by the existence of zircons derived from granitic rocks as old as ca. 4.3 Ga (Compston and Pigeon, 1986; Condie, 2005; Harrison, 2009; Hopkins et al., 2008). Granites have low-pressure dry melting temperatures of ~950 °C, far below the ~1300 °C solidi of the refractory upper mantle (Ernst, 2007). Water oceans may even have partly covered the Hadean lithosphere (Wilde et al., 2001; Mojzsis et al., 2001; Watson and Harrison, 2005). At less than half their solidi, primordial rocky materials were present as thin plates in the near-surface Hadean Earth. Stagnant-lid convection (O'Neill and Debaille, 2014) may have occurred, but was at least episodically overwhelmed by shallow plate subduction, because heat transfer required vigorous mantle overturn in the early, hot planet.

Earth's heat escapes most effectively by convection (Davies, 1980; Sleep, 2000, 2007). Initial mantle circulation might have been chiefly bottom up (plume-driven), but as Earth cooled, top-down overturn (plate subduction) began to dominate its thermal evolution (Anderson, 2001; Anderson and Natland, 2014). Thus, early subduction of small, warm plates passed by degrees to the underflow of large, sinking lithospheric plates. Attending cooling (Korenaga, 2008; Herzberg et al., 2010), P-T conditions associated with the subducting plates must have evolved toward higher-P/lower-T values, accounting for the Neoproterozoic emergence of a modern-style subduction regime and the generation of HP/LT blueschist-eclogite rocks, diamond pipes, and UHP intracontinental sialic complexes (Stern et al., 2016; Ernst et al., 2016).

Concluding that terrestrial plate tectonics began in the Neoproterozoic arbitrarily defines mantle-driven convective processes as only the most recent stage of an evolutionary continuum transitioning from small-warm-shallow to large-cool-steep plate descent. Lithospheric subduction (plate tectonics) apparently has operated episodically or continuously (?) since consolidation of the Hadean magma ocean.

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