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The effect of different mantle convection regimes on the long-term thermochemical evolution of the Earth’s core.

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The Earth's palaeomagnetic record reveals the existence of a global magnetic field persisting for at least 3.4 billion years. This geomagnetic field is generated by thermochemical convection, driven by the cooling of the Earth's core. Efficient cooling of the core is crucial to sustaining the magnetic field. The solid mantle plays thus a critical role in regulating the core's long-term evolution. Notably, efficient mantle cooling resulting from plate tectonics is important for sustaining the magnetic field observed in the geological record up to the present day.

However, the timing of the onset of modern-style plate tectonics remains an open question. It may have been active since the Earth's formation (~4.5 billion years ago), or since the Archean (4 – 3 billion years ago), or emerged much more recently (<1 billion years ago). When and how plate tectonics began are major scientific questions in Earth science because of their profound implications for Earth's thermal and magnetic history. The convection regime that preceded plate tectonics remains unclear. Observations of other planetary bodies in the solar system such as Mars, Mercury, and the Moon suggest that a stagnant lid regime—characterized by a single and immobile plate—is the norm. This raises the possibility that early Earth operated under a stagnant lid regime, which is significantly less efficient at dissipating heat. Such inefficient cooling would limit the capacity to sustain a long-lived magnetic field, unlike the plate tectonics regime.

Our study aims to constrain the mantle-core co-evolution by investigating the impact of these two convection regimes—stagnant lid and plate tectonics (i.e. mobile lid)—and their transition during Earth's geological evolution. To achieve this, we developed a coupled model that integrates two one-dimensional evolution frameworks. One model describes the core's thermochemical evolution, including inner core crystallization and the potential formation of a thermally stratified layer. The other describes mantle dynamics, allowing for either stagnant lid or mobile lid behaviour.

We systematically explored a wide range of mantle parameters such as mantle viscosity, the relative efficiency of stagnant - versus mobile-lid regimes, the timing of plate tectonics onset, and the mantle's and core initial temperatures. For the core, we focused on two end-member scenarios to account for the low and high thermal conductivity of iron whose precise determination remains controversial. We compared the resulting model predictions with key constraints, including the present-day inner core size, the palaeomagnetic record, the evolution of the mantle potential temperature, and the present-day thickness of a thermally stratified stable

layer at the top of the liquid core. This integrated approach sheds light on the interplay between mantle dynamics and core processes since the time of Earth’s formation.