Powering Earth's dynamo with magnesium precipitation from the core

JOSEPH G. O'ROURKE[1] & DAVID J. STEVENSON[2]

[1,2]Division of Geological and Planetary Sciences, California Institute of Technology, Pasadena, CA 91125, USA (Email: [1]jorourke@caltech.edu; [2]djs@gps.caltech.edu)

Earth's global magnetic field arises from vigorous convection within the liquid outer core. Paleomagnetic evidence shows that the geodynamo has operated for at least 3.4 billion years, possibly since the early Archean or even Hadean. Available power sources in standard models include compositional convection (driven by the solidifying inner core's expulsion of light elements), thermal convection (from slow cooling), and maybe heat from the decay of radioactive isotopes like potassium-40. However, recent diamond-anvil cell experiments and first-principles calculations imply that the thermal conductivity of iron is two or three times larger than typically assumed in these models. This presents a problem: a large increase in the conductive heat flux along the adiabat (due to the higher conductivity) implies that the inner core is young (less than one billion years old), but thermal convection and radiogenic heating alone have difficulty sustaining the geodynamo during earlier epochs unless core-mantle heat flow was at least tripled somehow.

Here we demonstrate that the precipitation of magnesium-bearing minerals from the core could have served as a sufficient power source. Metal-silicate equilibration at high temperatures after giant impacts allows a small amount of magnesium (one or two weight percent) to partition into the core. Using a Markov chain Monte Carlo technique, we show that equilibration of ~5 to 10% of Earth's core at these extreme conditions still produces the observed abundances of siderophile elements in the mantle and avoids an excess of silicon and oxygen in the core. The transport of magensium as oxide or silicate from the cooling core to underneath the mantle is an order of magnitude more efficient per unit mass as a source of buoyancy than inner-core growth. For every 100 K of core cooling, roughly 0.5% of the initial mass of the core should precipitatie. We integrate the corresponding release of gravitational energy and the associated entropy production into parametrized models of the energetics of the core, alongside estimates of the core-mantle heat flow permitted by mantle dynamics. Ultimately, for liberal estimates of ohmic dissipation, we conclude that Earth's dynamo would survive throughout geologic time even if core radiogenic heating were minimal or absent and core cooling were always ~15 to 20 TW, roughly the present-day value.