Implications of early dynamos for the evolution of Earth and Venus

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Global magnetic fields may strongly affect the surface habitability and atmospheric properties of terrestrial planets. Vigorous motions in electrically conductive fluids with substantial radial extent are required to sustain a dynamo. In particular, convection in Earth-like cores is possible if the heat flow across the core/mantle boundary exceeds a critical value that depends on available sources and sinks of entropy. Spacecraft visiting Venus over the past few decades have failed to find evidence of an internally generated magnetic field. Whether Venus always lacked a dynamo is still uncertain absent convincing detection of crustal remnant magnetism. Paleomagnetic data from Earth clearly indicates that our geodynamo has survived for at least ~3.5 billion years. Detrital zircons from the Jack Hills of Western Australia are proposed to record a global magnetic field that operated throughout the Hadean, although many samples may have suffered more recent remagnetization. Here we present coupled simulations of mantle/core differentiation and later thermochemical dynamics to show how complete histories of dynamo action or inaction on Earth and Venus would tightly constrain the divergent evolution of these celestial siblings.

Equilibration in the high-temperature aftermath of giant impacts delivers light components like magnesium-bearing minerals and silicon dioxide to the core. Subsequent precipitation may provide enough chemical buoyancy to sustain convection for billions of years prior to the nucleation of Earth's inner core. The presence or absence of a Hadean dynamo would reveal the timescales for the initial cooling and saturation of the core, alongside erosion of any primordial gradient in composition (with implications for the geometry and energetics of the Moon-forming impact) and solidification of a basal magma ocean. Sluggish mantle convection in Venus would suppress convection today in an identically Earth-like core unless thermal conductivity is lower than most recent estimates and an inner core exists within a narrow range of radii. Only certain scenarios for the linked surface/interior evolution, however, are compatible with any crustal remnant magnetism produced in the past. Therefore, detecting such signals is perhaps the best test of whether Venus and Earth formed through similar processes.