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Testing the geomagnetic dipole and reversing dynamo models over Earth's cooling history

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Continental drift reconstructions rely on the assumption that Earth's mean magnetic field has been a geocentric axial dipole over geologic time. However, the coupled dynamics of mantle and core convection may have had profound effects on the magnetic field in the distant past. Previous dynamo models have linked differences between polar and equatorial mantle heat flow to apparently anomalous paleomagnetic fields, and changes in reversal frequency. Here we use the inclination test (Evans, 1976) to interpret observational magnetic field models and polarity-reversing numerical dynamos representing various convective states of the mantle and core. Dynamo models with uniform buoyancy flux represent three convective states of the mantle and core: (1) present era Earth, driven thermo-chemically at the inner core boundary; (2) mantle overturn, with elevated heat flux at the core–mantle boundary, and (3) ancient Earth prior to inner core nucleation, with buoyancy production solely at the CMB. Consistent with Earth's present magnetic field, dynamos driven by buoyancy due to inner core growth are nearly dipolar. In contrast, elevated CMB heat flow yields small to moderate inclination flattening due to a persistent octupole that reverses synchronously with the dipole. For the ancient Earth models the relatively strong octupole component tends to stabilize the dynamo and decrease the reversal frequency. Our results, along with evidence of a young inner core, imply that an entirely liquid core contributed to shallow inclinations in Precambrian time. We also run models with latitudinally variable heat flux boundary conditions to further investigate the relationship between dynamo flow fields, the octupole component, magnetic inclinations and reversal frequency. For models with increased polar CMB heat flux we find that the relative strength of the octupole component increases in proportion to latitudinal heat flux variation. On the other hand, models are very sensitive to enhanced equatorial CMB cooling, which rapidly leads to unstable, multipolar dynamos with high reversal frequencies. This asymmetry in sensitivity to latitudinal variations in CMB heat flux implies that such variations are likely to yield only small inclination anomalies.