Symmetry and stability of Earth's magnetic field

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Geophysicists have suggested various parameters that may correlate with time-averaged geomagnetic reversal rate, including the dipole, axial dipole, equatorial dipole, non-dipole and non-axial dipole field strengths, various of their ratios, and the amplitude of secular variation. Merrill and McFadden (1988) proposed a more subtle relationship between reversal rate and symmetry of the geomagnetic field, and McFadden et al. (1991) used paleosecular variation data from lavas to demonstrate that this correlation exists. We show that geodynamo simulations also exhibit such a correlation between field symmetry and stability. The more stable simulation cases of Glatzmaier et al. (1999) have a ratio of time-averaged spectral energy of the equatorially antisymmetric (n+m odd, and excluding the axial dipole) to equatorially symmetric (n+m even) spherical harmonic terms of the field at the core-mantle boundary that is significantly larger than the less stable cases. For instance, for the simulations with equatorially symmetric zonal heat flux at the core-mantle boundary, the ratio of odd to even spectral energy for the case that never reversed is more than ten times that for the case that reversed most frequently.

Most intriguing is a simulation with uniform heat flux and smaller inner core only one-quarter of its present radius, as was probably true long ago in Precambrian time (Roberts and Glatzmaier, 2001). The odd/even spectral energy ratio for this case is about 7000 times larger than the uniform heat flux case with today's inner core. This is 40 times larger than the most stable case mentioned above, implying that the reversal rate may have been much lower early in the history of the geomagnetic field. Paleomagnetic evidence from rocks older than 1 Ga, though sparse, appears to favor this hypothesis. This includes:

1. a 2775-2715 Ma sequence of basalts, tuffs, felsic volcanics, and clastic sediments from Western Australia that records only three chrons, including one of minimum duration 26 Ma;
2. the ca. 2465 Ma Matachewan dike swarm of Canada, which fed a flood basalt that spans at least a few and perhaps as much as 30 million years and is interpreted to record only one reversal (by contrast 8-10 reversals are recorded in the 17-6 Ma Miocene Columbia River Basalt);
3. the 1468-1401 Ma North American Belt-Purcell Supergroup silt, sandstone and lava flows that record four main chrons, one of about 30 Myr, with only two short subsequences that have multiple reversals;
4. the 1100-1050 Ma North American Grand Canyon Supergroup and Keewanawan rocks that appear to record just one reversal;
5. a 1100-1050 Ma Siberian 50-meter composite section micritic limestones and shale that exhibits 16 reversals (perhaps these rocks are not truly coeval with those of 4);
6. 1020-820 Ma uplifted and slowly cooled rocks of the North American Grenville orogen that record just four main polarity chrons.

The older the rock the more difficult are the problems of magnetic overprinting, accurate dating, and obtaining relatively continuous sections of rocks of suitable age. Thus it is not possible at present to obtain a quantitative average reversal rate for this period of time. However, taken collectively these results suggest a low reversal frequency. Even the highest frequency indicated in (5) above, one per 3 Myr, is six times lower than the rate over the past 150 Myr.

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