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Mantle Dynamics, Plate Structure and the Earth's Long-Term Rotational Stability

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The long term (10-100 Ma) rotational stability of a dynamic, evolving Earth is a classic problem in geophysics framed by a series of seminal studies (e.g., Gold, 1955; Goldreich and Toomre, 1969). Gold (1955), for example, considered the stability of a hydrostatic planet subject to an imperfectly compensated (internal or external) load. In this case, the hydrostatic bulge provides no long-term rotational stability and the reorientation of the pole, or so-called true polar wander (TPW), would be governed solely by the location of the load. Gold's (1955) arguments were extended by Goldreich and Toomre (1969) who demonstrated that a group of anomalous masses moving randomly on the surface (the classic set of scurrying beetles) could drive rapid (relative to the speed of the masses) reorientation of the rotation pole. This inherent instability of the rotation axis appears to be at odds with observational evidence for a relatively stable rotation axis over the last 200 Ma. Previous studies have attempted to explain this stability through some combination of a high viscosity (sluggish) lower mantle and/or a relatively fortuitous distribution of mantle heterogeneity. We demonstrate that including the stabilizing effects of heterogeneous lithosphere in our simulations can also significantly affect predictions of long-term TPW. Our simulations are based on a suite of three-dimensional convection models initiated using seismically-inferred mantle heterogeneity and they illustrate, for Earth-like conditions, the potential role of a "lithosopheric filter" on the rotational stability observed for the post-Jurassic Earth.