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Past Mantle Dynamics Revealed by Net Characteristics of Surface Plate Motions

Clinton Conrad (1,5), Bernhard Steinberger (2,3,5), Trond Torsvik (3,4,5)

(1) Department of Geology and Geophysics, SOEST, University of Hawaii at Manoa, Honolulu, HI 96822, United States (clintc@hawaii.edu), (2) Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences, 14473 Potsdam, Germany, (3) Physics of Geological Processes, University of Oslo, 0316 Oslo, Norway, (4) Centre for Geodynamics, Geological Survey of Norway, NO-7491, Trondheim, Norway, (5) Center for Advanced Study, Norwegian Academy of Letters & Sciences, 0271, Oslo, Norway

Although convection in the Earth's mantle ultimately drives much of Earth's geological evolution, constraints on the history of mantle flow are difficult to obtain because the geometries and magnitudes of past driving forces are difficult to estimate. However, plate tectonic reconstructions, which are becoming increasing well-constrained, should contain information about the underlying mantle flow that drove plate motions in the past. Although the motions of individual plates can be affected by the specific details of individual plate forces, which can vary significantly in both space and time, long-wavelength forcings on plates may be reflected in patterns of plate motions occurring over length scales longer than those of individual plates. To test this, we measured the dipole and quadrupole moments of present-day plate motions and compared their orientations to the analogous moments of the basal tractions exerted on plates in a mantle flow model driven by tomographically-inferred mantle density heterogeneity. We found that both plate motions and net tractions converged in a net sense toward a dipole located in Asia. Similarly, both vector fields indicate quadrupole divergence in both Africa and the equatorial Pacific and quadruple convergence in southeast Asia and eastern South America. These similarities in dipole and quadrupole orientations indicate that the net characteristics of surface plate motions are reflective of global mantle flow patterns. To constrain temporal variations in mantle flow patterns, we measured the dipole and quadrupole moments of surface plate tectonics as a function of time for three different plate tectonic reconstructions dating as far back as 250 Ma. In all three, we found remarkable stability in the orientations of both the dipole moment and the divergence component of the quadrupole moment, indicating that the locations of net upwelling flow in the Earth's mantle have remained relatively fixed, at least throughout the Cenozoic and Mesozoic.