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Lithospheric Rheology and Stress and the Dynamics of Plate Tectonics

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Plate tectonics is a kinematic theory that describes relative motions of Earth′s surface tectonic plates. However, with the subduction of cold lithosphere into mantle interiors, plate tectonics has profound implications on the thermal and dynamic evolution of planets. Earth appears to be the only planetary body in the solar system that has active plate tectonics. The cause of plate tectonics remains one of the most important unresolved questions in Earth and planetary sciences. The recent discovery of a large population of exoplanets further raises the question on how common plate tectonics is to planetary bodies and what causes plate tectonics. In this presentation, I will discuss two issues that are important to understanding the origin of plate tectonics: lithospheric rheology and stress. Lithospheric rheology is important for understanding crustal and lithospheric dynamics, and the conditions for plate tectonics. For example, numerical modeling studies suggest that plate tectonics emerge from the dynamics of mantle convection when a small coefficient of friction μ (<0.1) or small yield stress for lithosphere is used [Moresi and Solomatov, 1998]. However, both in-situ borehole stress measurement (to ~10 km depth) and laboratory studies suggest that μ~0.6 [Kohlstedt et al., 1995; Zoback and Townend, 2001]. A recent study that models the seismically observed elastic flexure and seismicity at Hawaiian islands in response to volcanic loading indicates μ>0.25 [Zhong and Watts, 2013]. The loading study [Zhong and Watts, 2013] also suggests that lithospheric rheology related to low-temperature plasticity is significantly weaker than laboratory studies [Mei et al., 2010] and that lithospheric stress at Hawaiian islands is 100-200 MPa, possibly largest lithospheric stress on the Earth, given that Hawaiian islands represent the largest uncompensated surface loads on the Earth. These studies highlight the importance to understand the evolution of lithospheric stress and rheology from plate interiors to plate boundaries, in order to understand the cause of plate tectonics. I will also discuss the convection-driven stress in the top thermal boundary (lithosphere). Convection-driven stress scales with Rayleigh number and hence mantle viscosity. A larger mantle viscosity or smaller Rayleigh number leads to a larger viscous stress in the lithosphere in mantle convection models. Some recent mantle convection studies for plate tectonics generation reported >500 MPa stress in lithosphere. It is important to develop independent observable measures to examine the relevance of modeled lithospheric stress. I will discuss possible measures that may be developed and used in this context.

Keywords: Mantle Convection, Plate Tectonics, Lithospheric Stress, Lithospheric Rheology, Brittle Deformation