

# **Mantle composition control on the likelihood of plate tectonics on rocky exoplanets**

**BRADFORD FOLEY<sup>1</sup> AND PHIL SKEMER<sup>2</sup>**

<sup>1</sup>The Pennsylvania State University

<sup>2</sup>Washington University in St. Louis

Catalogs of rock forming element abundances in stars show significant variation from our sun, and by extension, Earth. If these stellar composition variations map to rocky exoplanets, then a wide range of exomantle mineralogies are possible: from sub-equal mixtures of olivine and pyroxene (like Earth's roughly 60% olivine, 40% pyroxene upper mantle) to mantles composed almost entirely of olivine or pyroxene, to even mixtures of olivine and magnesiowustite or pyroxene and quartz. Such compositional variation could have a major impact on exoplanet geodynamics and tectonics, with implications for habitability and interpreting atmospheric observations.

We show that the operation of plate tectonics is strongly favored for planets with subequal mixtures of two or more minerals, like Earth, while plate tectonics is highly unlikely on planets with nearly monomineralic mantles. Plate tectonics requires the formation of narrow, weak shear zones where deformation is localized, separating strong, stable plate interiors. A mantle with a subequal mixture of two or more minerals facilitates weak shear zone formation by grain size reduction, because grain size reduction sufficient to induce rheological weakening can only occur for polymineralic rocks where the mineral phases can mix at small scales. Mixing slows grain growth and enhances grain size reduction but is impeded for mantles dominated by a single mineral phase.

We combine scaling laws for mantle convection developed from numerical simulations with a theory for grain size reduction and phase mixing, grain-damage theory, that is calibrated to rock deformation experiments. We show that as the major mineral phase fraction exceeds  $\sim 0.8$ , weak shear zone formation is impeded such that a "sluggish lid" style of tectonics prevails, rather than plate tectonics. As major phase fraction approaches 1 grain size reduction is severely inhibited, leading to stagnant lid convection. We map the plate tectonic, sluggish, and stagnant lid regimes as a function of major phase fraction, surface temperature, and planet size, and find that phase fraction is of similar importance to the other factors in controlling tectonic regime. Plate tectonics is favored for planets with cool surface temperatures and subequal mixtures of mineral phases.