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Plate-tectonic boundary formation by grain-damage and pinning

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Shear weakening in the lithosphere is an essential ingredient for understanding how and why plate tectonics is generated from mantle convection on terrestrial planets. I present continued work on a theoretical model for lithospheric shear-localization and plate generation through damage, grain evolution and Zener pinning in two-phase (polycrystalline) lithospheric rocks. Grain size evolves through the competition between coarsening, which drives grain-growth, with damage, which drives grain reduction. The interface between phases controls Zener pinning, which impedes grain growth. Damage to the interface enhances the Zener pinning effect, which then reduces grain-size, forcing the rheology into the grain-size-dependent diffusion creep regime. This process thus allows damage and rheological weakening to co-exist, providing a necessary shear-localizing feedback. Moreover, because pinning inhibits grain-growth it promotes shear-zone longevity and plate-boundary inheritance. This theory has been applied recently to the emergence of plate tectonics in the Archean by transient subduction and accumulation of plate boundaries over 1Gyr, as well as to rapid slab detachment and abrupt tectonic changes. New work explores the saturation of interface damage at low interface curvature (e.g., because it is associated with larger grains that take up more of the damage, and/or because interface area is reduced). This effect allows three possible equilibrium grain-sizes for a given stress; a small-grain-size high-shear state in diffusion creep, a large grain-size low shear state in dislocation creep, and an intermediate state (often near the deformation map phase-boundary). The low and high grain-size states are stable, while the intermediate one is unstable. This implies that a material deformed at a given stress can acquire two stable deformation regimes, a low- and high- shear state; these are indicative of plate-like flows, i.e, the coexistence of both slowly deforming plates and rapidly deforming plate boundaries.