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Plates, slabs, and keels: Deciphering Earth's convective history from seismology, mineral physics and geodynamics

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Earth's tectonic activity is governed by the surface expression of mantle convection, plate tectonics. Typically, mantle dynamics is analyzed in terms of thermal convection where the major components, plate-scale flow and subduction, interact with minor effects such as plumes. However, we now understand better how compositional and rheological heterogeneity (continents on top, dense piles at the bottom) have first-order effects on intra-plate deformation, mantle flow and thermal evolution. In the upper mantle, an integrated approach using mineral physics, seismology, and geodynamics indicates that seismic anisotropy can put quantitative bounds on flow and mantle rheology. A synoptic picture from lab-samples to plate-scales indicates how deformation over the last tens of million years is recorded underneath oceanic plates, while Wilson-cycle collisions are frozen into old continental lithosphere and keels. Oceanic plates self-organize between continents, moving relatively faster over a weakened asthenosphere, and the importance of convective plate-driving forces varies laterally. Strength contrasts also partially explain the net rotation of the lithosphere as observed in hotspot reference frames; trench rollback behavior and slab stirring may explain the rest. Statistical analysis of seismic tomography yields further evidence for a dynamic subdivision of the mantle into tectosphere, slab, and pile-dominated regions. In the surrounding mantle, plumes connecting to hotspots are mapped in places where flow models predict that their conduits should be. While plates, slabs, and keels can therefore be identified as the major tectonic players, important challenges for mantle convection models remain. These include understanding the interplay between conti-

nents and plate formation, improving global subduction models, and quantifying the time-dependence of plate tectonics. An applied geodynamics approach that emphasizes the exchange between disciplines and comprehensive tests of realistic forward models seems promising.