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Continental Lithospheric Strength in Actively Deforming Regions

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It has been agreed for nearly a century that a strong, load-bearing outer layer of the Earth is required to support mountain ranges, transmit stresses to deform active regions, and store elastic strain to generate earthquakes. But the depth and extent of this strong layer remain controversial. We use evidence from post-seismic transient and earthquake cycle (EC) deformation, reservoir loading, glacio-isostatic adjustment (GIA), and lithosphere isostatic adjustment to large surface and subsurface loads (LIA) to infer the distribution of lithospheric strength in the active western US from seismic to steady-state timescales. The nearly perfectly elastic behavior of the Earth's crust and mantle at the timescale of seismic wave propagation evolves to that of a strong ∼elastic crust and weak, ductile upper mantle lithosphere at both earthquake cycle (EC, ∼10–10,000 years) and glacio-isostatic adjustment (GIA, ∼10,000–100,000 years) timescales. Topography/gravity field correlations indicate lithosphere isostatic adjustment (LIA) on ∼1-10 million year timescales occurs with most lithospheric stress supported by upper crust which overlies a very much weaker ductile substrate. These comparisons suggest the upper mantle lithosphere is weaker than the crust at all timescales longer than seismic. In contrast, the lower crust has a chameleon-like behavior, strong at EC and GIA timescales and weak for LIA and steady-state deformation processes. However, lower crust might take on a third identity in regions of rapid crustal extension or continental collision, where anomalously high temperatures may lead to large-scale ductile flow in a lower crustal layer locally weaker than the upper mantle. Modeling of lithospheric processes in active regions thus cannot be done using a one-size-fits-all prescription of rheological layering (relation between applied stress and deformation as a function of depth) but must be tailored to the timescale and tectonic setting of the process being investigated.