The EarthScope (ES) project is providing an exceptional amount of Earth's surface motion measurements and is imaging the subsurface with unprecedented resolution across the North American continent. These new data will help resolve important questions in tectonics, including the relationship between active flow at depth and fracture at the surface. These new data will help address the coupling or decoupling that takes place between the brittle crust and the deeper lithosphere in zones of wrench deformation. Another major contribution of ES data is to better understand the differential motion of deep crust relative to shallow crust, particularly in areas of extension; here I focus on observational, conceptual, and modeling results regarding the behavior of partially molten crust during orogenic evolution.

The North American Cordillera exposes a series of metamorphic complexes that are cored by migmatite domes. Within the domes, complex structural overprints and decompression metamorphic paths indicate large-magnitude horizontal and vertical flow of partially molten crust relative to mantling rocks. No matter how the crust reached partial melting (thermal relaxation and/or heating) during continental under-thrusting, crustal thickening, lithosphere foundering, slab break-off, or slab window, the end result is one of an orogenic crust that contains a low viscosity layer at depth. This layer is mobile and opportunistic: it flows laterally and therefore helps keep a flat Moho; it may flow from a thick plateau and thicken the foreland region (mechanism of plateau growth); it fills gaps that open in the upper crust and therefore enhances orogenic collapse by transferring material from deep to shallow levels; ultimately, flow of this layer stabilizes the crust and may bring the end of orogeny.

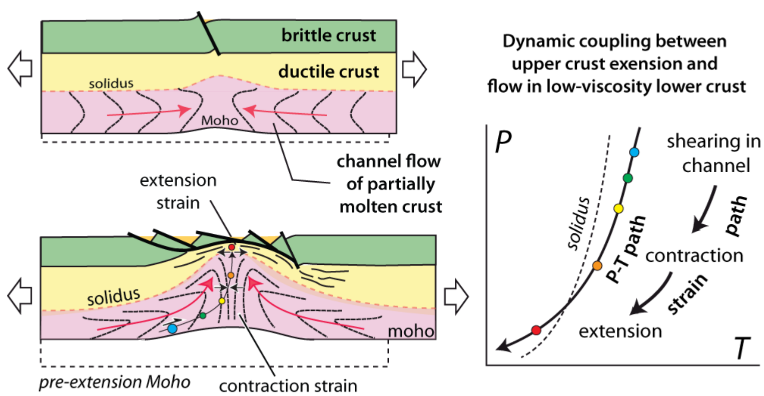

Figure: Extension of layered crust in which flow of the low-viscosity lower crust is dynamically coupled to extension in the upper crust.

Thermal and mechanical numerical modeling can help evaluate quantitatively the relative importance of crust thickness, geothermal gradients, and tectonic boundary conditions in the evolution of orogenic systems. In the simple case of steady extension of a layered crust, results show that upper-crust extension is dynamically linked to lower crustal flow until much of the lower crust material is drained or until boundary conditions change. Therefore, a typical crustal section of a collapsing orogen involves partial convection of material where extension of upper crust (divergent motion) is underlain by lateral flow (convergent motion) and exhumation (upward flow) of the deep crust.

This general concept explains the complex structures within gneiss domes (i.e. upright folds overprinted by vertical shortening) that develop as a result of flow while the upper crust is pulled apart steadily and is dissected by a simple array of normal and detachments faults. Implications include better understanding of (1) heat and mass transfer in orogens; (2) the role of (oblique) divergence in the development of migmatite domes, including the dynamics of melt migration and development of anatectic granite sheets; and (3) coeval contraction and extension at various levels of orogens.