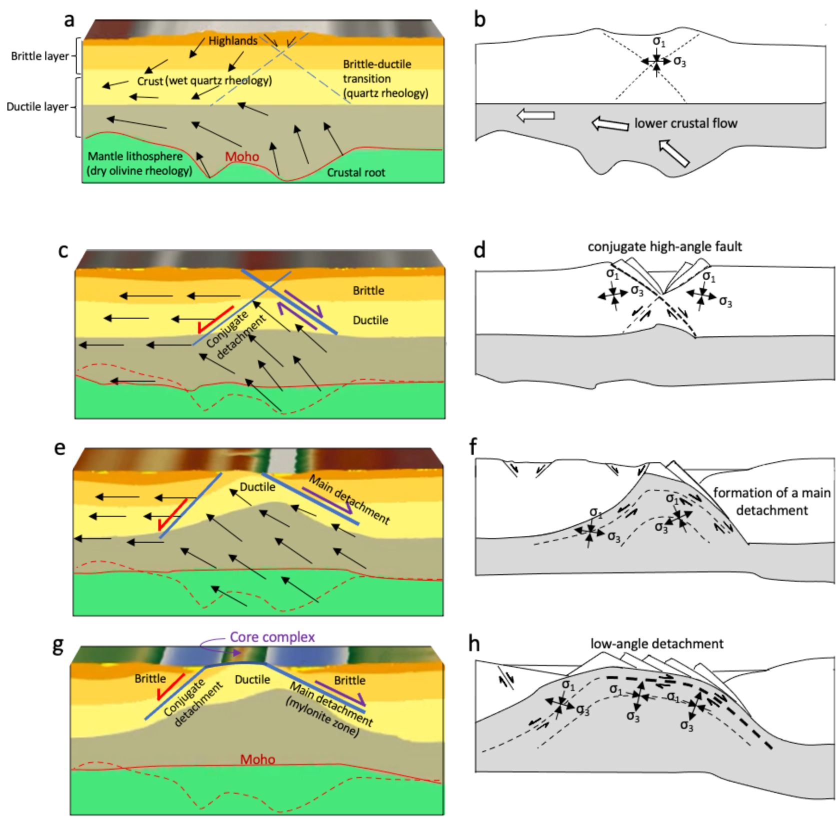
The plate tectonic paradigm enables us to understand how mass is transported horizontally and vertically, both internally and on the Earth's surface, based on simple principles of physics, such as conservation of momentum, energy, and mass. Yet many geological observations continue to challenge our understanding of kinematic and dynamic processes. The Basin and Range Province of the southwestern North America is the result of shear and extension following a protracted phase of crustal shortening and mountain building (155–60 Ma). Since ~40 Ma the tectonic history of the southwestern North America involves a complex transition from early shallow- to flat-subduction of the east dipping Farallon slab along the western margin to its present transtensional environment. Through this evolution of changing boundary forces, topography and crustal thicknesses were dramatically altered from high elevations of orogenic plateaus and corresponding thick crustal welts to the current Basin and Range system. The topographic collapse resulted in significant exhumation of deep crustal rocks exposed in metamorphic core complexes of the southwestern North America.

We develop time-dependent geodynamic models of lithosphere evolution in southwestern North America constrained by seismic data, paleo-topography and crustal thickness contrasts, kinematic estimates that incorporate both land-based geological observations and the history of the plate boundary zone (plate motion boundary conditions), volcanism, and changing material properties of the lithosphere. Our geodynamic models predict the extension and shear history and explain changes in strain localization through time. Our results show that high gravitational potential energy of a mountain belt (the Nevadaplano and Mogollon Highlands) relative to a lower Colorado Plateau is required to match the extension directions and stress magnitudes in the belt of core complexes in Arizona and Nevada during the Late Eocene to Early Miocene. Our numerical models demonstrate that the gravitational body forces generated by realistic surface and Moho topography can cause an upward flow pattern of the ductile lower and middle crust, which is facilitated by a detachment surface that evolves into low-angle normal fault.



Schematics of the main mechanisms responsible for formation of the metamorphic core complexes at the lithospheric scale. a,b, Zones of high gravitational body forces are highly affected by lower crust flow which causes the topographic collapse; c,d, The flow pattern associated with crustal root rebound and topographic collapse, combined with applied horizontal boundary conditions on the left side together with the formation of a high-angle conjugate fault. The counterclockwise rotation of the velocity field, as it transitions from upward ascent to horizontal flow, is accommodated along a main detachment surface and a nearby conjugate detachment; e,f, The relaxation of the crustal root generates an upward transport and doming of middle crust that is primarily accommodated along the main detachment zone; g,h, A final configuration of the core complex involving an exhumed low-angle detachment within the domal region. Black arrows on the right panels represent principal axes of stresses on the conjugate fault and detachment surface.