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Evolution of crustal faulting during the transition from orthogonal to oblique continental extension

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The rate and angle of continental extension imposes first order controls on the style of brittle and ductile crustal deformation. For example, crustal structures in the Gulf of California and Walker Lane Region often record a transition from orthogonal, Basin and Range style extension to highly oblique transtensional deformation. Here, we use 3-D numerical models to examine how deformation evolves with such variations in the orientation of continental extension.

We model thermal-mechanical deformation of the continental lithosphere with the Eulerian-Lagrangian, finite-element code SULEC. The spatial domain spans 250 km and 400 km in the horizontal directions, and extends vertically to 100 km depth. Outflow along the model sides drives deformation, while a free surface allows topographic relief to develop along normal faults. Deformation takes into account non-linear viscous and brittle rheologies and is initialized via random perturbations in the brittle field. We focus on crustal deformation during the initial stages (< 20 Myr) of continental rifting.

We first model a 5-10 Myr phase of purely orthogonal extension. As deformation initializes along random brittle perturbations, normal faults are both distributed and asymmetric, rather than concentrated along a single symmetric horst-graben structure. Along the model length, normal faults link together and often strike obliquely to the extension direction, particularly in transfer zones between large-offset faults. Continued extension (10-20 Myr) localizes deformation onto a single horst-graben structure that varies in orientation along the length of the model. The second model phase focuses on how distributed normal faulting patterns evolve during a transition from orthogonal to oblique extension. These experiments systematically vary the extension angle following 5-10 Myr of orthogonal extension and compare the resulting structures to observations of transtensional deformation in the Western United States and Gulf of California.