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Surface expression of lithospheric deformation on time-scales ranging from years to millions of years: The evolution of the East California Shear Zone and associated structures by propagation

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Do continents deform in a continuum fashion or is deformation localized? This debate has raged for 30 years. Central to the debate has been the role of major structures such as the North Anatolian and Altyn Tagh faults. Evidence that these features have evolved by propagation suggests that, in a broad sense, their associated lithosphere behaves in an elasto-plastic fashion.

A similar evolution by propagation is proposed for the western USA for the last 6-8 Ma when the San Andreas fault jumped inland. This modified the extension and right-lateral shear to which the Basin and Range province had been subject to for $\sim$17 Ma. Although the exact location of this deformation is not well defined, in the later phases an important part passed through the location of the present Death, Panamint and Owens valleys and extended to the south along the Soda, Bristol and Cadiz lake valleys to the east of the present Mojave block. The inland jump caused material to escape from the compressional "Big Bend". Upward and downward motion resulted in lithospheric thickening and the rapid uplift of the Transverse Ranges and the Mojave block extruded laterally to the east. By 3-4 Ma this had suppressed the earlier extension along the Soda, Bristol and Cadiz lake valleys and increasing opening rates in Death, Panamint and Owens valleys. This reactivation resulted in increased volcanism and over the next few million years the increased opening rates and volcanism propagated to the north and was manifest in such features as the Long valley volcanic

activity. At about 1 Ma the system again changed with the lithospheric weakness resulting from the opening allowing increased right-lateral shear to extend from the Death, Panamint and Owens valleys in the south to the Verdi Range, Honey Lake and Black Rock desert region west and north of Reno. At the same time oblique extension propagated into the Stillwater, Shoshone Range and Crescent Valley faults in the Carson Sink-Dixie valley region. Strike slip motion also initiated across the Mojave block.

The processes described are similar to those associated with the extrusion of Anatolia into the Aegean. Understanding the processes in the western USA is less straight forward, since two phases of propagation have occurred and these must be distinguished from deformation prior to 6 Ma. Our findings are also compatible with recent short-term results coming from satellite geodesy as well as the distribution of historic seismicity. However the model for the evolution is simple and provides a large-scale framework within which to place existing observations. Furthermore it suggests new approaches to understanding the mechanical evolution not only of the western USA, but of continental lithosphere in general. The results of our analysis illuminate the importance of integrating various geological, geophysical, and geodetic data over time scales ranging from a few to several millions of years. We conclude that (1) deformation rates vary even on short time scales (tens of ka), and that (2) the initiation or reactivation times of faulting rather than the average fault slip rate is the most important measurable parameter. Thus, the challenge for determining the correct fault system geometry and kinematics is to recognize whether a fault system deforms steadily, or whether it has an actively propagating deformation front. The latter is inherently difficult to recognize at the earth's surface, because such structures tend to be very young (Quaternary in age) and hence small. Recent advances in the precision of spatial mapping techniques and Quaternary geochronometers, combined with careful field work, will lead to significant improvements in the observational basis for models of lithospheric deformation and evolution of topography in general.