The Salton Trough and Eastern California Shear Zone: an EarthScope Target Area for Fault-System Studies

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Introduction

Not the least of the EarthScope goals should be a far better understanding of the workings of active fault systems: not just how isolated faults behave, but how deformation of a whole region expresses itself through fault slip and other strain over a range of temporal scales. We believe that in order to adequately study this phenomenon, EarthScope should include several target areas in which systems with a high degree of activity can be studied for both their current and long-term behavior. The region running north from the Salton Trough in southern California up through the Eastern California Shear Zone offers a unique opportunity to study a strike-slip fault system in this way, because the region, being arid and unpopulated, provides excellent exposures of the faults, and opportunities for detailed studies of recurrence that cannot be obtained elsewhere—most notably, in the urban areas which are now the focus of much hazard study. Geologic studies in this region can thus add a temporal depth that will be important in seeing, for example, the possible extent of long-term changes in rates of deformation. (We leave it to others to propose similar study areas appropriate for systems of thrust or normal faults.)

Seismotectonic Setting

The Salton trough is formed where the Pacific/North-America plate boundary comes on land from the south: one of the few on-land analogs to an oceanic spreading center, and the only one in the U.S. South of the U.S. border the boundary consists of a major transform fault (the Cerro Prieto fault), from which a number of other faults splay off into northern Baja California. The seismicity indicates a step to the northeastward at Cerro Prieto, which is generally assumed to be an onshore spreading center. However, geologic and microseismic data indicate that some of the Cerro Prieto slip continues directly across the border and farther north, tying into the southern San Jacinto fault zone via a step-over at Heber geothermal field. The best-known part of the boundary, the Imperial Fault, continues northwards from the northeast end of the step and crosses the U.S. border near Mexicali. (We appreciate that the border is an artificial division of a unified tectonic province. However, it is relevant logistically. We also have chosen not to discuss deployments south of the border because it is likely these could be funded by the NSF Margins program.)

The Imperial fault is the only transform along the plate boundary that has ruptured more than once in historic time, in 1940 and 1979. The inferred moment rate is commensurate with nearly the entire plate motion (40 mm/yr) being accommodated across it, and strain rates in the Imperial Valley are among the highest in the conterminous U.S. However, paleoseismic studies indicate a lesser rate, only about half of the inferred 40 mm/yr, with the balance likely accommodated by the Cerro Prieto extension fault and other unrecognized structures (possibly with northeast strikes).

As shown by the seismicity, the Superstition Hills strand of the San Jacinto fault splays off from the Imperial fault close to the border (although it is not clear whether the San Jacinto strain really makes it onto the Imperial fault north of the border), carrying several mm/yr of slip. The balance of San Jacinto strain appears to be fed directly by the Cerro Prieto fault.

The Imperial fault continues northwestward from the border but eventually dies out at a point where the trend of the seismicity becomes more northerly. This NNW-trending belt of seismicity is termed the Brawley Seismic Zone (BSZ), and the region between it and the San Jacinto fault is marked by narrow bands of seismicity which indicate NE-trending cross-faults. Where the BSZ crosses the Salton Sea is an area of very high heat flow characterized by Quaternary volcanism, usually assumed to be another spreading center: the only one on land in the U.S.

The BSZ ends abruptly just at the location where the San Andreas fault (SAF), itself aseismic, becomes geomorphically evident (or, looking from the north, terminates). This southern section of the San Andreas fault, is in many ways quite enigmatic. Its geomorphic expression is extremely clear so it is certainly active in some way; trenching near Indio has found evidence for several large slip events between
1000 and 1700 AD. The seismicity is low, and not on the fault. Geodetic measurements show deep slip across this segment of the fault of about 20 mm/yr, and it is an area of active, although minor, surface fault creep. It also has long been known to undergo both steady creep (at 1-2 mm/yr) and triggered slip at the times of nearby large earthquakes: most recently from the 1999 Hector Mine shock.

As the San Andreas curves to the west into the eastern Transverse Ranges, about 10 mm/yr of the plate-boundary motion splays off (in structures not yet well understood) into the Eastern California Shear Zone (ECSZ), a region of largely strike-slip faults extending across the Mojave Desert to the Garlock fault, and then northward into the Owens Valley. In the last 10 years the southern part of this zone has produced by far the largest seismic moment release in the conterminous U.S., namely the Joshua-Tree-Landers/Hector-Mine earthquake sequence. Paleoseismic studies in the wake of these earthquakes show recurrence times of typically 5,000 to 10,000 years for most of these structures, with the Hector Mine rupture occurring on a fault that may only rupture every several tens of thousands of years. Further, paleoseismic evidence indicates that past earthquakes have clustered in time and that the current seismicity comes after most of the other ECSZ faults have failed (in the past 1-2 ka). Interestingly, the primary bounding fault to the north, the Garlock fault, appears to be in phase with the ECSZ, in spite of its much greater slip rate, having produced four large events during the past 2000 years and only two before that back to 7000 years. Also enigmatic is that the current GPS-observed rates across the ECSZ are high, near 10 mm/yr, but the observed slip rates on individual faults generally fall in the 0.5 to 0.75 mm/yr range. The combined cumulative rates of all faults in the ECSZ falls short by nearly a factor of two of the currently observed geodetic rates. Thus, the excellent exposures and lack of dense population make the ECSZ perhaps the best natural laboratory in the U.S. to study both fault interaction and temporal variations in strain rates.

Preliminary work indicates that large (M>7) earthquakes have also clustered in the Salton Trough during the past 1000 years. The last major cluster occurred about 1680-1725 A.D. and involved at least the southern San Andreas, south-central San Jacinto, Superstition Mountain, and Imperial faults. Similarly, at least the southern San Andreas and south-central San Jacinto faults ruptured in around A.D. 1500. All of these faults were quiet after ca 1700 until the 1940 rupture of the Imperial fault, and many have suggested that both the San Andreas and San Jacinto (Anza Gap) are ripe for large earthquakes.

The Salton trough and ECSZ are also interesting because they form the edge of this continental plate boundary: east of both, there is little seismicity and few mapped active faults. (Though as the Hector Mine earthquake showed, our mapping of active faults may not be totally complete.) Farther north, of course, the edge of the boundary (the Basin and Range) is much broader: this eastern edge thus offers a location in which we can examine the consequences and causes of differing long-term deformation rates.

**Questions to be Addressed**

The range of deformation rates (from very high to essentially zero), the plate-boundary geometry (for example, on-land spreading centers and cross-faults) and the ease of collecting geologic data, make the Salton Trough and ECSZ a natural focus area for several components of EarthScope. Some of the questions that can be addressed are:

- **Spreading centers:** How does deformation occur at a spreading center, and how episodic is it? Back-arc spreading centers in continental crust, such as the Taupo Volcanic Zone in New Zealand, are notoriously episodic in their rate of deformation, not always in ways reflected by the seismicity. Should we expect similar behavior for the spreading center beneath the Brawley Seismic zone which directly loads the southern San Andreas fault? (As with the Taupo Zone, deformation measurements are complicated by subsidence caused by geothermal power production.)

- **Cross faults:** What role do cross-faults play in ongoing deformation? The seismicity bands which show these faults are actually aftershock zones of earthquakes in 1979, 1981 and 1987. Do these zones of seismicity correspond to any interseismic concentration of strain, as is true for the major faults? Also, how do such faults absorb deformation over longer times? Do they subtract from the seismic slip rates on the major northwest-striking faults? Do they potentially provide a trigger for large San Andreas ruptures, as the 1987 Elmore Ranch rupture apparently did for the Superstition Hills fault?

- **Earthquake clustering and fault interaction:** Are plate margins and their subsidiary deformation zones, characterized by clusters of seismic moment release? How do short and long-term variations in strain accumulation affect strain release? The aridity of the region (except for the irrigated
farmland covering part of the Imperial fault) provides excellent fault exposures; and the relatively long recurrence times of the ECSZ provide (given the errors of dating methods) a better chance to resolve temporal patterns of seismicity than the more active San Andreas fault. In the Salton Trough
the presence of sediments from the several late Holocene highstands of Lake Cahuilla may provide a tool in correlating events between faults that cross the shorelines. Potentially, combining lake correlations with C-14 dating may provide an unprecedented level of precision in dating past earthquakes on a regional basis. If we can understand all the phenomena of clustering and temporal changes in this area, then we may hope to apply this knowledge to other regions, in which the data are not so rich—for example, the Los Angeles metropolitan area, which is too built-up to allow the required detail in geologic studies.

• Transition behavior: What are the specifics of the deformation, and hence the mechanics, of the junction of the BSZ and the San Andreas fault—which is very nearly a ridge-transform junction?
• Fault junctions: How does slip splay off from active fault? The splay of the San Jacinto from the Imperial fault appears to be relatively simple based on the seismicity, and hence is a candidate for addressing this question. What makes it particularly interesting is that the San Jacinto slip apparently does not make it onto the Imperial fault, or at least it hasn’t during the past 500 years. Also, the transition to the ECSZ is another, more complex, region to study.
• Plate-boundary transition: As noted above, this region is effectively one well-defined edge of the plate boundary—the other one being under the Pacific.
• Postseismic relaxation: The large ECSZ earthquakes of the 1990’s have very likely produced one of the largest postseismic relaxation signals we will have to study—and the location is at one edge of the plate boundary, which means that this signal can be measured with little contamination from the ongoing plate motion.

Proposed Measurements.
We believe this region is a candidate for most of the aspects of EarthScope. The PBO component should include both GPS measurements (to densify the relatively sparse SCIGN network density in this non-urban area), and strainmeters to measure the shorter-term fluctuations in deformation rates. These measurements will help to address many of the questions described above. In addition, a program of fault kinematic histories (through both remote sensing and targeted fault trenching) will be essential to look at rates over a longer time scale. A focused seismic deployment, especially to the east of the ECSZ, will help indicate any variations in crustal structure or seismic anisotropy associated with the change from deforming to stable material, and might aid in forming viscosity models for measurements of postseismic deformation.