GPS and Strainmeters in the Salton Trough

Duncan Agnew, Frank Wyatt, Greg Anderson

Seismotectonic Setting

The Salton trough is where the Pacific/North-America plate boundary comes on land from the south. 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 (see the proposal by Bennett et al.). The fault ends at Cerro Prieto, where the seismicity indicates a step to the northeastward, this step generally being assumed to be an onshore spreading center. From the northeast end of this step, the boundary continues north as the Imperial fault, which crosses the U.S. border.[1] The Imperial fault is the only one along the plate boundary that has ruptured more than once in historic time, in 1940 and 1979—commensurate with nearly the entire plate motion (40 mm/yr) being accommodated across it: the strain rates in the Imperial Valley are among the highest in the conterminous U.S.

As shown by the seismicity (Figure 1) another fault, the San Jacinto, splays off from the Imperial fault close to the border, carrying about 10 mm/yr of slip. The Imperial fault continues northwestward but eventually dies out at a point where the trend of the seismicity becomes more northerly. This NNW-trending belt of seismicity is 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 (and geothermal power production), 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, running along one side ot the Coachella Valley and the Salton Sea, 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 four large slip events between 1000 and 1700 AD. The seismicity is low, and not on the fault (Figure 1). Geodetic measurements show deep slip across this segment of the fault of about 20 mm/yr. and it is an area of active (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 earthquakes: most recently from the 1999 Hector Mine shock.

The main long-base strainmeter at Durmid Hill (DHL—see Figure 2) after about 4 years of tracking the secular strain, with no unusual events, detected anomalous deformation episodes starting in the summer of 1999; these were corroborated by the other (earth-tide) long-base strainmeter at the site. Following the Hector earthquake (which triggered slip on the SAF and earthquakes in the BSZ) the strain rate changed substantially, though

[1] 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.

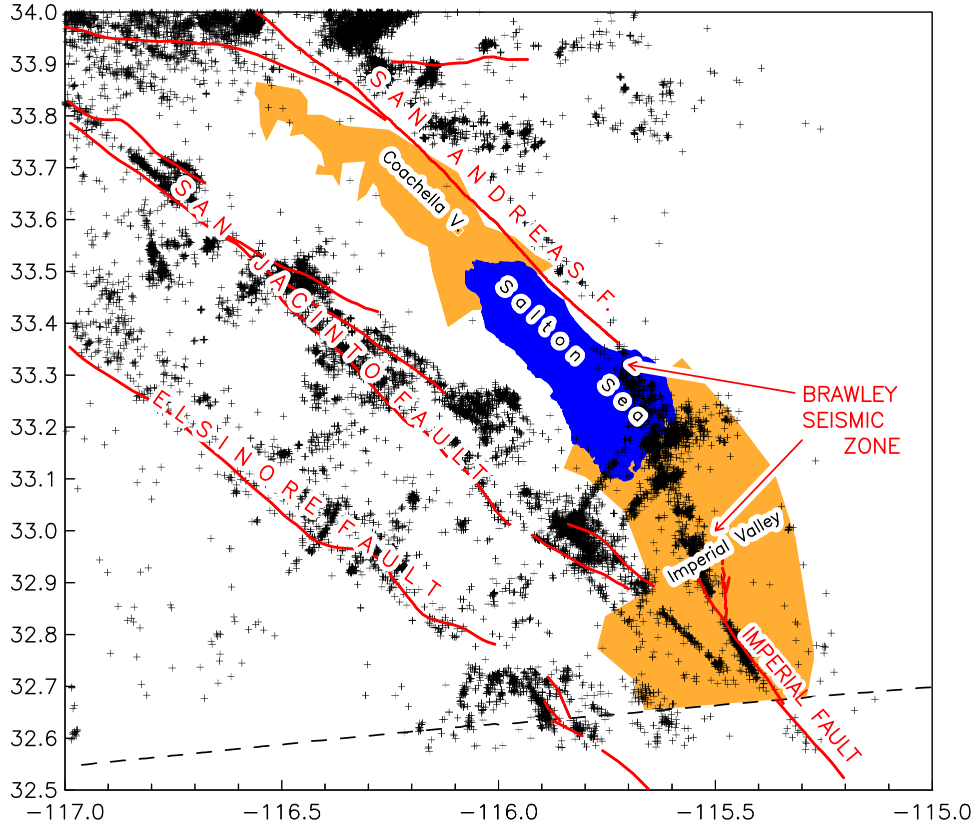

Figure 1. Major faults and seismicity in and around the Salton Trough. Epicenters from the relocation by Richards-Dinger and Shearer.

it has now returned to its original rate.

In addition to the laser strainmeter observations InSAR data (D. Sandwell, personal communication) shows extensive slip all along the SAF from the Coachella Valley south almost to DHL; we assume that this is the source of the transients seen at DHL.

Questions to be Addressed

We believe that the high deformation rate, and the unique plate-boundary geometry (on-land spreading centers) of the Salton Trough make it a natural focus area for the PBO. Some of the questions that can be addressed by measurements there are

1. Spreading Centers: How does deformation occur, and how episodically, at a spreading center? 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; and we may expect similar behavior for the spreading center beneath the Brawley Seismic zone—though, as with the Taupo Zone, deformation measurements are complicated by subsidence caused by geothermal power production.

2. Cross faults: What role do cross-faults play in ongoing deformation? The two seismicity bands in Figure 1 which show these faults are actually aftershock zones of

earthquakes in 1981 and 1987. Do these zones of seismicity correspond to any interseismic concentration of strain, as is true for the major faults?

3. Transition Behavior: What is the deformation, and hence the mechanics, of the junction of the BSZ and the San Andreas? This is one of three places along the SAF where a transition between seismic and aseismic behaviors occurs (the others are the two ends of the creeping section in central California).

   Beyond the purely scientific issue of understanding this junction, there is also the practical interest that it is a possible initiation point for the next large earthquake on this most ‘‘overdue’’ part of the SAF.

4. Creep: How episodic is the surface creep of the SAF? And, is it confined to the shallow sediments, or does it extend deeper on the fault? A possibly related feature is the the local (1 km scale) uplift seen by A. Sylvester on two level lines crossing this section of the fault— the mechanism for this is unknown.

5. Fault junctions: How does slip splay off from one active fault? As the seismicity in Figure 1 shows, the splay of the San Jacinto from the Imperial fault appears to be relatively simple, and hence is a candidate for addressing this question.

Proposed Measurements

Figure 2 shows the measurements we propose—heavily affected by the restrictive local setting. While the BSZ is an ‘‘on-land’’ spreading center, it is, for deformation studies, almost as badly located as if it were at sea (indeed, part is underwater). Because the Salton trough is spreading and subsiding, it is nearly all sediments: around the edges alluvial fans, and in the middle it is lake sediments, mostly irrigated and farmed. The brown areas in Figures 1 and 2 show the irrigated areas (and in the north, urbanized ones): these are not suitable for any kind of strain measurement though well-anchored GPS measurements should be satisfactory. The existing long-base instrument at DHL is on older, semi-consolidated lake-bed deposits (clays), and works quite satisfactorily in this setting. The kind of harder rock needed for good-quality borehole strain measurement is located only towards the edges of the trough; near the SAF/BSZ junction nearly all available outcrops are well inside the Chocolate Mountains Aerial Gunnery Range—not an accessible location.

In view of these restrictions we have proposed the deployment shown in Figure 2 of 25 GPS stations (open triangles), 4 long-base strainmeters—two would go at the existing site at DHL, to make this a complete three-component system, and the other two as single-component installations in new locations (open stars)—and six borehole instruments: one at a possible site on the edge of the Gunnery Range, and five others along the more northern portion of the San Andreas. Again, we have proposed a higher ratio of long-base to borehole instruments for this area than anywhere else because the surface geology, weak as it is, we know to be adequate for the former type. We assume that operation of the existing SCIGN GPS stations shown (not very dense), and the long-base instruments at DHL and PFO, would be supported as part of PBO operations. (It would certainly be odd to end them as this program of strain monitoring begins.)

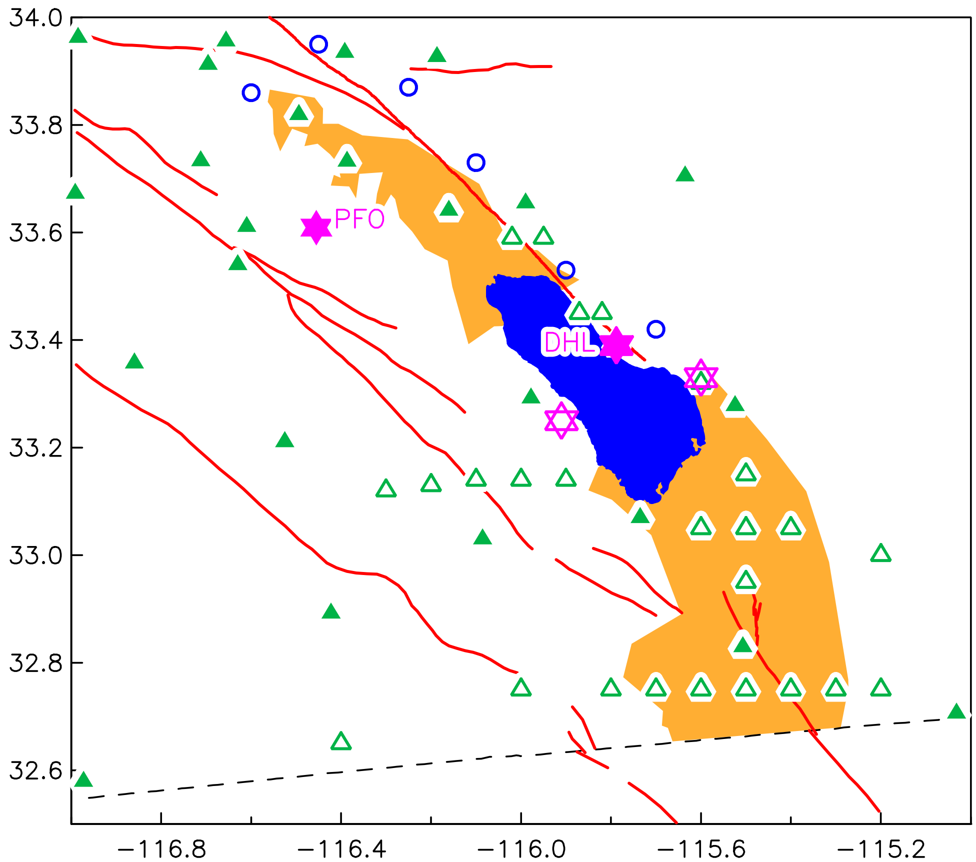

Figure 2. Existing (solid) and proposed (open) deformation measurements in the Salton Trough. Continuous GPS is green triangles, long-base strain purple stars, borehole strain blue circles.

The long-base strainmeters should, between them, provide the best measure available of transients around the SAF/BSZ junction. It is clearly important to have a three-component measurement, and doing this at DHL makes the best use of our existing investment there. The 4 GPS installations north of DHL are intended as ‘‘GPS creepmeters’’—at 1 km spacing, they can detect the full vector displacement across the SAF to better than 1 mm. This will provide vector information at two points to help interpret the InSAR line-of-sight data. These GPS pairs and the borehole strainmeters will help to determine the depth of creep on this part of the fault. The GPS installations south of DHL are set up as several transects to elucidate the geometry of deformation in this complex area, the northern one being extended to the west to cover the active San Jacinto fault, as the southern one does close to the junction with the Imperial fault.