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Earthquake swarms and aseismic slip in the Salton Trough: High-resolution imaging of the upper frictional stability transition. Collaborative proposal with Woods Hole Oceanographic Institution, Cornell University and the USGS MP

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Abstract:
Efforts to understand the relative roles of seismic and aseismic processes in controlling the build-up and release of strain along active fault zones require detailed studies of individual faults and placement of those results in a broader rock-mechanics based framework. One particularly intriguing fault zone behavior that has been observed with increasing frequency in recent years involves the interplay between aseismic slip and seismic swarm activity. Slow fault slip has been observed to trigger earthquake swarms in a variety of tectonic environments including subduction zone thrusts, volcanic systems, and continental strike-slip faults in Southern California. Detailed studies of these events offer an opportunity to connect physical properties of the fault-zone such as rock type, depth, and temperature with rock-mechanical properties such as frictional stability.

One region that provides a prime environment to study seismic swarms and aseismic creep is the Imperial Valley/Salton Trough in Southern California. Seismic swarms, large (Mw>7) earthquakes, and transient episodes of fault creep are all frequent occurrences along the plate boundary faults within the Salton Trough. Geodetic and seismic data from the Obsidian Buttes swarm, which occurred in 2005 near the southern shore of the Salton Sea, indicate that the majority of deformation occurred aseismicaly, and that the ~1000 earthquakes during the swarm were triggered by the aseismic slip. This swarm occurred in an interesting geological environment with geothermal gradients of 140-240 deg/km, and there appears to be a frictional stability transition in the 2-3 km depth range that separates the seismic and aseismic portions of the primary fault.

We propose a combination of an active source seismic study of the 2005 swarm's primary fault zone, and a more detailed analysis of the existing seismic and geodetic data. The core of our effort is a one-week seismic survey using the high-res profiling techniques developed by the USGS-Menlo Park group that will provide constraints on the details of fault-zone geometry and rigidity structure. These results will be used to improve our studies of the 2005 swarm. The combination of these studies will allow us to study the relations between rock-type, rigidity, thermal structure and frictional stability. Because shallow creep and earthquake swarms are general properties of major faults in the Salton Trough, our results will provide inputs to physics based earthquake hazard models in the region.

Outline

Our report consists of summaries of the following items:

- Field deployment and data acquisition
- Earthquake relocations
- Data processing: Initial velocity fields
- Future work

Field Deployment

Between March 15-27th, 2010, a team of researchers from the USGS, Woods Hole, and Cornell, as well as students from SCRIPPS, deployed instruments and set of active source explosive shots along two perpendicular lines crossing the location of the 2005 seismic swarm at Obsidian Buttes. Our proposed survey consisted of two seismic profiles, a 5-km-long ultra high-resolution (5-m shot and geophone spacing) P- and S-wave profile, superimposed on a 15-km-long high-resolution (20-m seismograph and 40-m shot spacing) profile. The 5-km-long seismic profile would be recorded with a series of linked multi-channel (Geometrics) seismographs (300 to 360 channels) attached via multi-channel cables to 40-Hz, single-element vertical and horizontal geophones spaced at 5-m intervals. The 15-km-long seismic profile would be recorded with stand-alone (RefTek 125A -Texan) seismographs, mated to 4-Hz vertical and horizontal geophones, spaced at 20-m intervals. We were able to meet these goals, although we had slightly shorter lines in each case.

The proposed seismic sources consisted of a combination of 400-grain Betsy Seisgun blasts, buried explosions, truck-mounted accelerated weight drops (AWD), and compressed-air and hammer shear-wave sources, spaced at 5-m intervals for the 5-km-long array and at 40-m intervals for the 15-km-long array. For the actual deployment, we used the Seisgun and buried explosives only, since the shear-wave source apparatus did not work in the field.

We had one issue with our initial line that was due to a difference in the software used by the USGS and IRIS staff – it resulted in our recordings starting several seconds late, which caused us to miss the first set of shots. Fortunately, we had extra explosives with us and were able to use the existing holes to rebury a new set and record the shots correctly. The Besty Seisgun shots went without a hitch.

Other issues involved in the deployment could potentially be valuable for later processing. The power plants located throughout the area show up as a definite large noise source along the line, which impedes interpretation of the data in the vicinity of the fault along the N-S line. However, they also present a potential source for ambient noise tomography, which we are exploring now.

Earthquake Relocations

Jeff McGuire used data from local network stations that are newly available to do a revised double-difference inversion for locations of seismicity in the region in the last several years (Figure 1). These relocations move the seismicity during the Obsidian Buttes swam slightly to the north, which is actually more consistent with the North-dipping fault that we infer from the SAR observations.

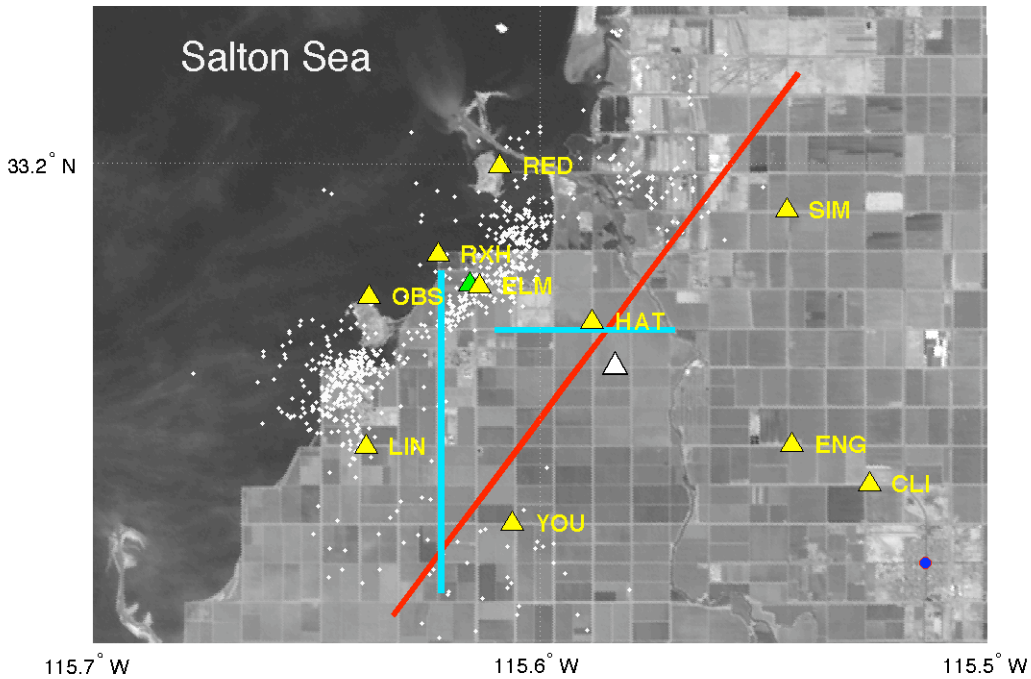

Figure 1: Relocated seismicity from Jeff McGuire, along with the location of new stations used in locations (triangles), seismic lines (blue) and approximate surface projection of fault that was involved in the 2005 Obsidian Buttes swarm (red).

Data Processing: Approach

To date, the seismic data acquired during the field deployment has been analyzed by students at Cornell as well as by the team at the USGS. As a sidenote – this project was funded as a joint effort between NEHRP and NSF. The NSF portion continues funding over the next year, which is how we are funding work by the Cornell students. The USGS team produced a preliminary velocity map for the North-South line (Figure 2), which was high enough quality that we were encouraged to explore other ways of processing the data as well. Two students from Cornell traveled to Menlo Park for tutorials on the use of their software as well as to share approaches for filtering and interpreting or removing the effects of surface waves, which in some cases dominate the signal.

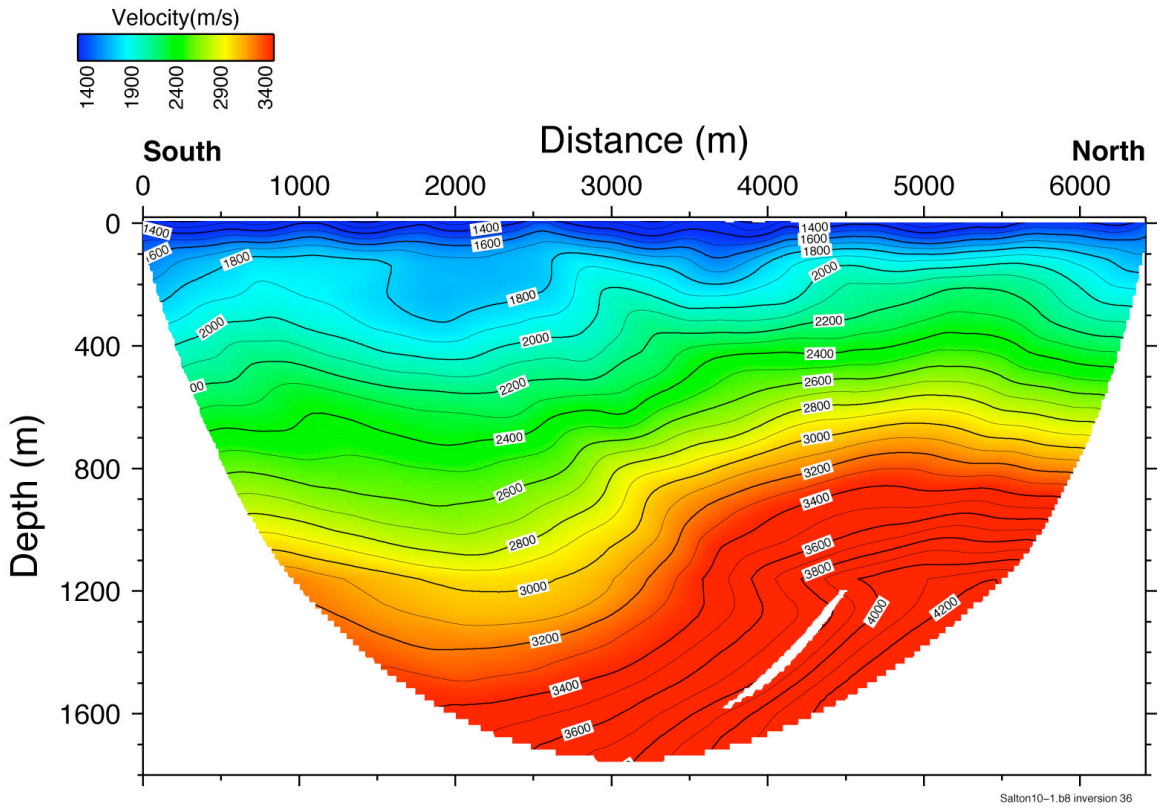

Figure 2: Velocity profile across North-South line from R. D. Catchings. Note exaggeration of vertical scale.

The Cornell student team (Anastasija Cabalova and Diego Quiros) divided post-collection processing of the active source data from the Obsidian Creep experiment into data preparation, velocity analysis, and common-depth point (CDP) stacking.

The data preparation consisted of geometry installation, trace editing and surface wave suppression. The geometry installation was applied to the data prior to all other processing steps; individual trace editing was used to remove dead or particularly noisy stations due to bad coupling or large volumes of ambient noise nearby the station location. Timing corrections were applied to several time-shifted shots and subsequently an elevation static correction was applied to all the data with respect to sea level. Surface wave removal was carried through surgical muting and automatic gain control (AGC) was used to bring out deep week reflections.

The velocity analysis was done through a constant velocity stack (CVS) applied to the common-depth point super gather. This technique utilizes constant velocity panels, allowing the velocity model to be picked from the reflectors showing the greatest coherence. A velocity model was picked for each CDP, which was subsequently improved by giving a larger weight to CDP's with largest fold length (i.e. CDP's located near the center of the array) and lower weight to CDP's located near the ends of the array.

With the obtained velocity model a normal-move out (NMO) correction with 30% stretch muting was applied to all traces with the same CDP number (i.e. conversion of each trace in a CDP gather to a zero-offset trace). Once the NMO correction was finalized a common-depth point stack was done followed by post-stack deconvolution to increase temporal resolution by compressing the seismic wavelet.

Results for this approach for the E-W and N-S lines are shown in Figure 3. Some of the initial processing indicated a change in velocity across the profiles in approximately the location of the inferred fault, but further exploration led us to decide that such a variation is not well-resolved by this data set. We also see no strong indication from the reflection data of features that are offset by the fault. This is, perhaps, not terribly surprising since the region is expected to be dominated by sub-horizontal layers with fairly homogeneous properties.

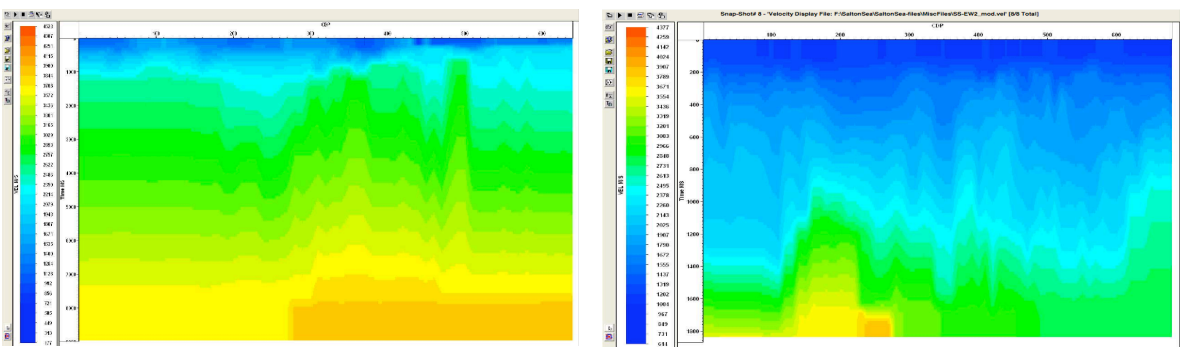

Figure 3: North-South (left) and East-West (right) lines processed by the Cornell student team. Color scales and depth (time) ranges differ between the two panels, in part due to the differing line lengths and types of shots. The general horizontal layering is the only feature that the students feel is well-resolved at the time, and is what they are now working on modeling (see Future Work).

Future Work

In order to wrap up the work proposed for this project, we will continue our efforts on the following fronts (using the remainder of the funding provided by NSF for this project):

1. Explore the use of surface wave tomography and analysis of the potential for ambient noise tomography. There is a relatively short amount of time on each trace before the waves from our active sources begin, but the Cornell group expects to spend some time exploring this initial set of data and the impact of the large noise sources at the geothermal power plants. They have experience with this approach from their work on Montserrat volcano with Professor Larry Brown. Similarly, they are now looking at an approach where they use the surface waves rather than masking them out completely, as has been done previously.

2. Re-analysis of InSAR data: Even without the above work, we now have velocity fields that are far superior to what we used previously in our inversions of the InSAR imagery spanning the 2005 Obsidian Buttes swarm. The student involved in this phase of the project (Quiros) spent the summer processing the velocity profiles, but also learning about InSAR and slip inversions. He is now benchmarking the finite element code Pylith against the use of a simple elastic half space to ensure that he understands the necessary mesh density and inversions approaches for the project. The next phase of his work will be to use a layered elastic model that is consistent with the seismic velocity profiles, and potentially to explore some variations on this model that include lateral variations in order to assess how important some of these unmodeled variations may be to the inversion.

Bibliography

There are not any publications resulting from this work so far, but we are preparing a manuscript that we expect to submit this fall.