

Characteristics of induced and tectonic seismicity in the Salton Sea area

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Final Project Report

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Investigations Undertaken

We developed a relocation catalog for all the events between 1981 and 2016 in the Salton Sea region, spanning the southeast end of the San Andreas Fault in California.

The relocation catalog was used to calculate seismicity rate change in the study area corresponding to four remote earthquakes, the 1992 Landers, 1999 Hector Mine, 2002 Denali and 2010 Baja California earthquakes.

We solved for focal solutions for all the relocated events and then calculated the average stress orientation for inside and outside of the Salton Sea Geothermal Field (SSGF). We also investigated the in situ V_p/V_s ratios in similar earthquake clusters within the SSGF.

Results

Earthquake Relocation Catalog

We first developed a relocation catalog for all the events between 1981 and 2016 in the study area by applying the 3-D ray-tracing through the 3-D velocity model by *Lin* (2013) and waveform cross-correlation relocation methods. In Figure 1, we show the map view of over 30,000 relocated events and the active injection/production wells.

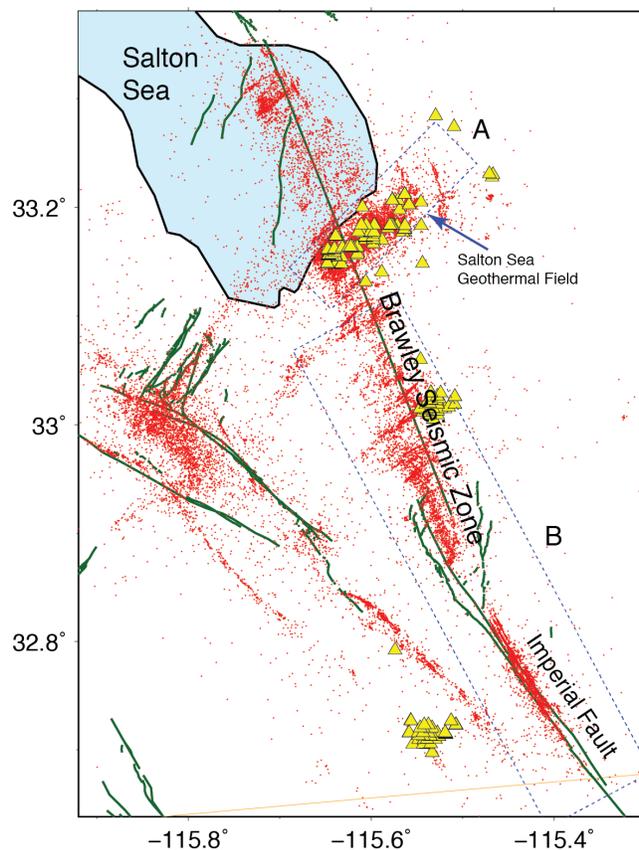


Figure 1. Map view of the relocated seismicity between 1981 and 2016 in the study area. The yellow triangles represent the active injection/production wells. The dotted lines enclose the two subareas for stress inversions shown in Figure 3.

Seismicity Rate

The relocation catalog was then used to calculate seismicity rate change in the study area corresponding to four remote earthquakes, including the 1992 Landers, 1999 Hector Mine, 2002 Denali and 2010 Baja

California earthquakes. We first computed the magnitude of completeness M_c of the full earthquake catalog (*Wiemer and Baer, 2000*) and then declustered the catalog (*Reasenber and Oppenheimer, 1985*). In order to compare the seismicity rates in our study area before and after each remote mainshock, we calculate β -statistics based on the declustered catalog, which compare the difference of the observed and expected seismicity in a certain time period, normalized by the standard deviation of the expected seismicity (*Matthews and Reasenber, 1988; Hill and Prejean, 2007*). The β -values in Figure 2 show that the Salton Sea Geothermal Field is not as responsive as the surrounding fault areas following each remote mainshock (*Lin, 2018b*).

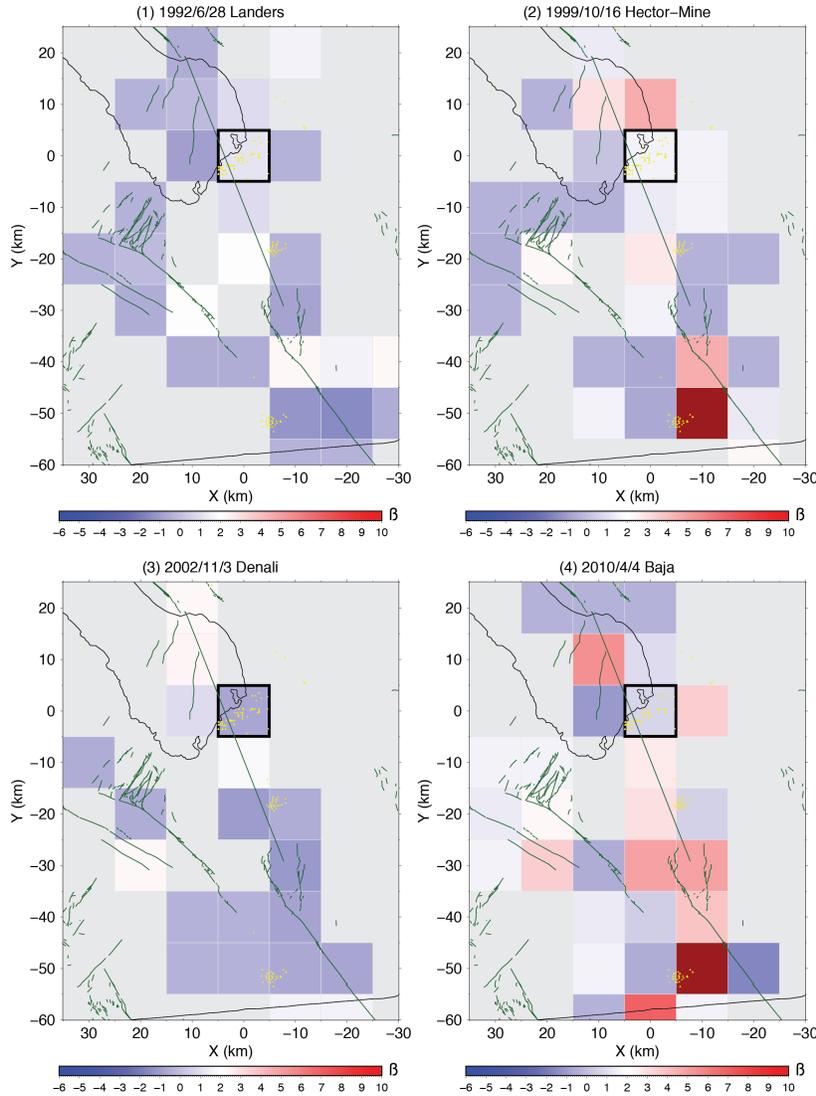


Figure 2. β -statistics based on the declustered catalog following each remote mainshock.

Focal Mechanism and Stress Inversions

We solved for focal solutions for all the relocated events by using the HASH program (*Hardebeck and Shearer, 2002, 2003*). The focal solutions were then used to calculate the average stress orientation based on the SATSI (*Hardebeck and Michael, 2006; Martinez-Garzon et al., 2013*) package. Figure 3 shows the average stress orientations for subareas A and B in Figure 1, indicating that inside and outside of the SSGF share similar stress distributions, although respond to remote earthquakes differently.

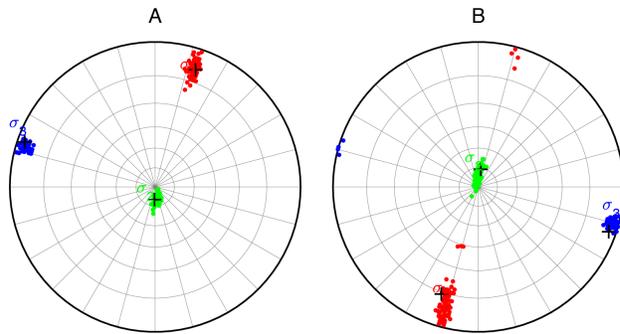


Figure 3. Average stress orientation, obtained by inverting earthquake focal mechanisms. The orientations of three principal stresses ($\sigma_1 > \sigma_2 > \sigma_3$) are shown with clouds representing bootstrap points within 95% confidence intervals. The center corresponds to the vertical direction.

In Situ V_p/V_s Ratios

We estimated the V_p/V_s ratios for similar earthquake clusters using waveform cross-correlation data. These ratios vary from 1.510 to 1.811 and show correlations with the heat flow and well production data, indicating that the near-source V_p/V_s ratios strongly depend on the subsurface natural properties, but are influenced by the amount of injection volume throughout the production period (Lin, 2018a).

Non-technical summary

We have developed a new location catalog for over 30,000 earthquakes during the last 36 years, based on a 3-D seismic velocity model and waveform cross-correlation data. Our systematic comparison between inside and outside of the SSGF enables a better understanding of induced and tectonic seismicity, which will help constrain future seismic hazard assessments in the area.

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