# 2014 SCEC Final Report

# A High-Resolution Study of Microearthquakes on the San Andreas Fault at SAFOD

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## Project Summary

We have analyzed data from a dense, near-fault temporary borehole array deployed within the San Andreas Fault Observatory at Depth (SAFOD) main borehole by Paulsson Geophysical Services (PGS) between late April to early May 2005. We are using data from this unique, eighty-sensor borehole array to locate and estimate the magnitude of very small earthquakes on the SAFOD section of the SAF. Our objective is to illuminate fine-scale fault structures in unprecedented detail, and to look for evidence of interaction between the individual events. Preliminary analysis by PGS has located approximately 100 small magnitude earthquakes that appear to delineate three separate fault strands of the SAF. These 100 events are only a small subset of the approximately 1000 events that we have detected, and are currently working to locate and assign magnitude. We have achieved the following

* surface seismic data has been downloaded onto our new dedicated computer (Berkeley HRSN and the EarthScope-funded PASO experiments).
* Paulsson's VSP borehole data has been organized on the dedicated computer (3 TB raw data).
* Utility code has been written to read the Paulsson VSP data (continuous data in 16 second chunks in industry SEG2 format).
* The entire data volume has been plotted with preliminary seismic signal processing.
* Preliminary comparisons have been made between larger events detected using the surface array and those same events detected using the downhole array.
* The coding and initial application of a template-matching method for event detection was completed. Our assessment was that this should not be used.
* The coding and initial testing of a kertosis statistical method for event detection and time picking is in progress. This approach looks promising.

This project is a bit behind schedule because one of the P.I.s (Sumy) quit her post doctoral position at USC to take a full time job at IRIS. The work is being finished by a graduate student (Robert Walker) who will complete the catalog and complete the spatiotemporal analysis of triggered and/or clustered earthquakes.

**Technical Report**

From late April to early May 2005, Paulsson Geophysical Services (PGS) deployed 80 three-component seismic sensors within the SAFOD borehole to record active source shots and earthquakes (Figure 1). PGS placed the sensors within the inclined portion of the SAFOD borehole (red dotted line in Figure 1b marked receiver array) at a depth interval between 878-1703 m below sea level (~1500-2500 m deep). The sensors continuously recorded seismic data at 0.25 ms (4 MHz) and were spaced at 15.2 m (50 ft) along the length of the array, for a total length of ~1200 m.

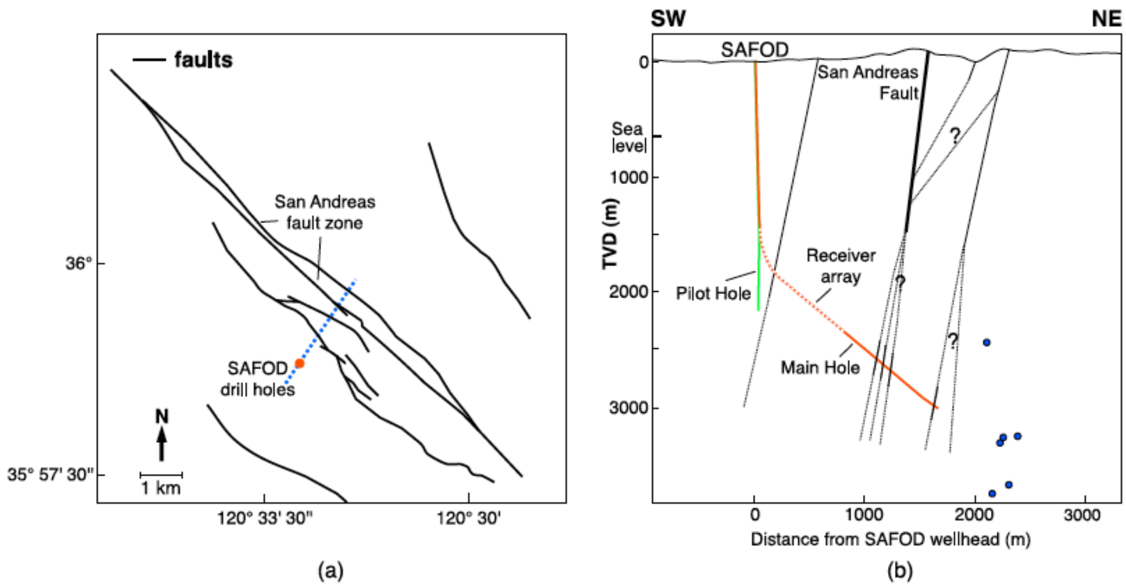


Figure 1: (a) Fault maps in the vicinity of the SAFOD drill holes, where the blue dotted line represents the direction of the cross-section. (b) Fault perpendicular cross-section around the SAFOD boreholes and location of six earthquakes (blue dots) analyzed in *Reshetnikov et al.* [2010]. The red line represents the main hole, where PGS deployed the receiver array (red dotted line). Figure from *Reshetnikov et al.* [2010].

Over the two-week duration, PGS collected continuous seismic data, and detected approximately 1000 earthquakes; the majority of these earthquakes have not been located and much of this dataset remains unexplored. Figure 2 shows the three-component waveforms of an earthquake recorded on 5 May 2005, and illustrates the capabilities of this network.

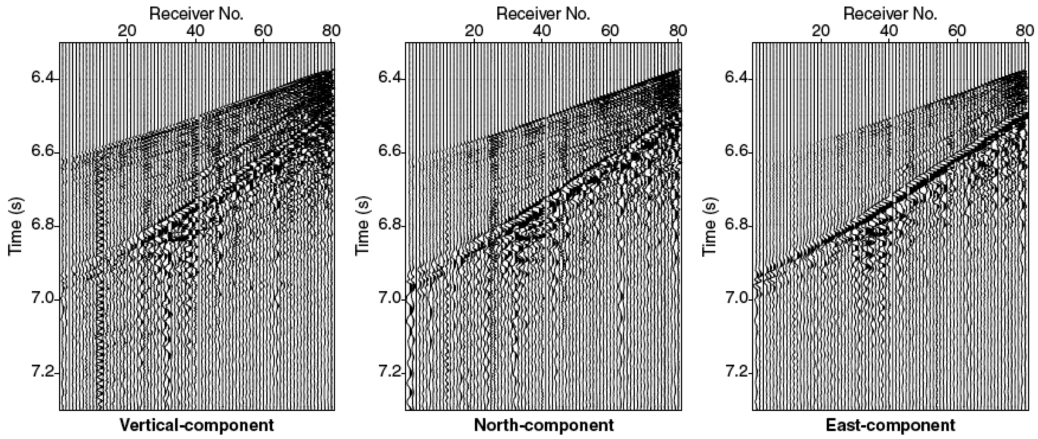


Figure 2: Vertical, north, and east-component waveforms from the largest event detected on 5 May 2005. Receiver #1 corresponds to the shallowest receiver, while receiver #80 corresponds to the deepest. Figure from *Rentsch et al.* [2010].

The resolution of this network and its immediate proximity to the SAF allow detection of very small earthquakes that escape standard earthquake catalogs. For instance, only 47 of the 1000 events appear in the USGS catalog (Figure 3a), and mostly occur on the SAF itself (white dotted line). In contrast, the initial 100 events located by PGS outline three main fault strands (Figure 3b), which is consistent with inferred fault geometry at SAFOD [*Bradbury et al.,* 2007; *Zoback et al.*, 2010; Figure 1]. Note that these initial locations are highly clustered, as is typical at all scales on the Parkfield segment of the SAF.

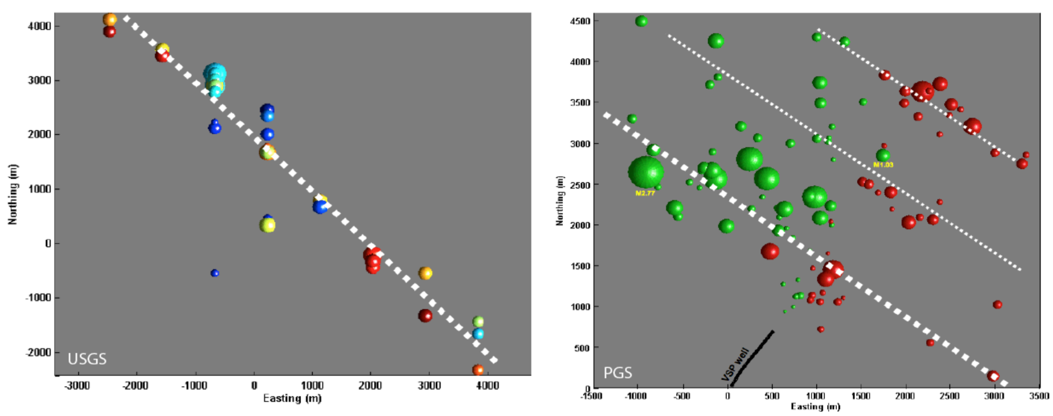


Figure 3: (a) 47 events reported in the USGS catalog near the SAFOD drill site. Most events occur along the SAF (thick dotted white line). Earthquakes are color-coded by time, where blue is earlier and red is later. (b) Preliminary locations of 100 earthquakes analyzed by PGS. Note the location of the array (vertical seismic profile (VSP)), denoted with a black line with respect to the SAF. The earthquakes are scaled by magnitude, where the largest detected in both catalogs is M2.77. Green colored earthquakes have a down (dilational) first-motion, while red colored earthquakes have an up (compressional) first-motion, consistent with Pacific plate motion.

The overarching goal of this project is to examine the spatial and temporal distribution of seismicity to better characterize the fracture network and fault patterns along the SAF, especially as it relates to earthquake scaling laws and earthquake-earthquake interactions. Thus far, we have systematically investigated the seismic data collected by the eighty-sensor array deployed within the SAFOD borehole, and begun to test detection algorithms. The work will be completed as the Ph.D. project of graduate student Robert Walker.

## Intellectual Merit and Broader Impact

Our resultant catalog will be used to address several SCEC scientific objectives: (4a) detailed geologic, seismic, geodetic, and hydrologic investigations of fault complexities at Special Fault Study Areas and other important regions, (6d) measurement of earthquakes with unprecedented station density using emerging sensor technologies, and (2b) improve descriptions of the spatiotemporal behavior of triggered and/or clustered earthquakes. This catalog will be archived as a SCEC product.

This project has supported the education of USC postdoctoral research student Danielle Sumy who has moved on in her career as a professional seismologist. It also supported graduate student Robert Walker who will continue this project toward his Ph.D.