2011 SCEC Annual Report

Award #11061: Building a Holocene slip history for the Mojave section of the San Andreas Fault

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Summary:

Measuring histories of fault slip spanning multiple ruptures (e.g., 10-100) has the potential to advance understanding of fault and fault-system behavior, including temporal variations in the rate of strain release. A kinematic model of interacting fault systems in southern California (Dolan et al., 2007) and long paleoseismic records (Weldon et al., 2004) along the Mojave section of the San Andreas fault (MSAF) have revealed temporal variations in strain release. However, reported offset data along the MSAF are too sparse to measure the slip history.

For 2011 we proposed to evaluate the Holocene record of fault slip recorded by faulted landforms along the MSAF using both high resolution topographic data from existing airborne and new ground-based LiDAR measurements and new software tools that enable virtual-reality based visualization and analysis of such data (Bernardin et al., 2011; Kreylos, 2008; Kreylos et al., 2008; Kreylos et al., 2003). Our specific goal was to identify potential slip-rate sites along the MSAF and then generate surficial geologic maps and reconstructions for the most promising localities with the potential to infill gaps in the Holocene record of slip.

As demonstrated below, we found a number of new faulted landforms along the MSAF that show considerable promise for dating, providing the necessary foundation for future geochronologic measurements to construct the MSAF slip history. Specifically, we identified 58 faulted landforms with offsets ranging from 20 to 297 m along a 100-km-long section of the MSAF. At ten of these sites we used field and remote observations to map the surficial geology in detail, and have then reconstructed the sites to determine their suitability for future slip rate determinations. At 10 additional sites we have determined the offset magnitude and associated and maximum and minimum uncertainty bounds.

Technical report:

Our first step was to compile previously reported landform offsets, which revealed five gaps in the Holocene slip record at: 20-27m, 33-42m, 45-63m, 65-129m, and 131-360m of cumulative offset (Figure 1). Although this literature review resulted in over 25 offset markers ranging from 1m to 16,500 m we only used data within the Holocene record of offset markers as predicted from published average slip rates, which range from ~16 mm/yr (Becker et al., 2005; Bird, 2009; Loveless
and Meade, 2011; Meade and Hager, 2005) to ~30 mm/yr (Matmon et al., 2005; Weldon et al., 2004) and thus translate into offsets of between 16 m and 300 m. Within this interval, we found seven published data points, ranging from 18 m to 130 m. From NW to SE along the MSAF, the locations of these sites include: Frazier Mountain, Oak Flat, Ritter Ranch, Littlerock, Pallett Creek, and Wrightwood (Matmon et al., 2005; Rust, 2005; Rust, 1982a, b; Scharer et al., 2011; Schwartz and Weldon, 1986; Sieh, 1978; Weldon et al., 2008).

Using Crusta, a new virtual-reality visualization tool (Bernardin et al., 2011), we studied a 100 km-long section of the B4 airborne LiDAR dataset to discover unidentified Holocene landform offsets. This allowed us to identify 58 faulted landforms along the main strand of the MSAF (Figure 2) ranging from 20 to 297 m (Figure 2). A majority (35) of those offsets cluster in magnitudes of <100 m with 17 offsets ranging from 20-50 m and 18 offsets ranging from 50-100 m. We find several channel offsets that are particularly promising for further analysis at different localities along the fault and that fall within the data gaps noted above. At these locations, both the fault trace and offset are clear, and our preliminary analysis suggests the landforms are dateable. More details regarding our top 20 piercing points are summarized in Table 1.

We created surficial geologic maps (Figure 3) for our top ten offset markers (A6: Randall Ranch, A18: Robinson Canyon, A14: Richardson Canyon, A22: Oakdale Canyon, B7: Oak Grove Canyon, E2: Palmdale, G2: Pearblossom, H1: Shoemaker Canyon and H4 & H5: Mile High Ranch) although the map and reconstruction for markers H4 and H5 are under revision. With the exception of B7, we were able to conduct field-based mapping at all of these sites to further evaluate geologic and geomorphic relationships. Associated reconstructions for each offset site are presented in Figure 4.

To characterize uncertainties for each of these offset markers we used the slicer tool in Crusta, which allows the user to interactively reconstruct fault slip by defining a piecewise linear fault plane and incrementally moving one block relative to the other in any direction on the plane. For the recorded offset magnitude for each marker, we projected the best-fit orientation of the thalweg into the fault (Figure 5a). To determine the uncertainty bounds for each reconstruction we accounted for possible channel widening during displacement. To determine the maximum possible offset, we retro-deformed the landform until the last opportunity for channel connectivity (i.e., for a north-flowing channel, the western edge of the input channel is nearly aligned with the eastern edge of the output channel) (Figure 5b). In detail we used the approximate width of the present channel bottom to determine the opening width between the two edges of channels (i.e., we assumed the original channel width to approximately the same width as the present channel bottom). To determine the minimum offset we used a different reconstruction. Because the SAF is a right-lateral fault and all channels we examined flow north, we expect fault slip to induce erosion of the
channel walls as the stream is deformed, with stream attack focused on the eastern bank on the south of the fault and on the western bank to the north. Therefore, to determine the minimum bound we aligned the midpoint or thalweg of the southern channel with the western channel edge of the northern channel (Figure 5c). The slicer tool has been helpful in identification, evaluation and in particular, reconstruction of landform offsets (Figures 4a-4j). We conducted a terrestrial laser scanning (TLS) survey at one of those sites (G2). This TLS survey covered an area of 7100 m², included 23 scan locations, and resulted in approximately 17.5 million points. We also used TLS to image offset from the most-recent earthquakes at Littlerock, but have not completed processing of those data.

We are continuing work on several aspects of this project. These include: 1) A trip to Colorado in early March when student Tracy Compton will visit collaborator Dr. Ryan Gold to use his recently developed Monte Carlo method (Gold and Cowgill, 2011) to analyze the d-t data. This analysis will result in a new long-term average rate for the MSAF. However, due to lack of published data, we anticipate that there will not be sufficient information to resolove potential variations in slip rate over time. 2) Producing neotectonic maps and associated reconstructions for offset markers H4 and H5 at the Mile High Ranch site. 3) Annotating field photographs and constructing detailed site descriptions for each map to support the proposed reconstruction. 4) Further analysis of our methods used to evaluate offset uncertainties (i.e., using LiDiCaoz on numerous sites for comparison). 5) Additional work on the TLS data collected at site G2 (Pearblossom) to produce a more detailed digital elevation model (DEM) than the current available airborne data is able to produce. 6) Data processing of a TLS scan conducted at the Littlerock site in order to image offsets from recent earthquake events (i.e, 1-3 earthquake events).

Intellectual Merit
This study has identified a number of new potential slip-rate sites along the MSAF. Future geochronologic measurements at these sites should make it possible to construct a robust history of Holocene slip along MSAF, and thereby improve understanding of the apparently discrepant geodetic and geologic slip rates here. In addition, we have developed new insights into how to characterize the epistemic uncertainties associated with channel reconstructions.

Broader Impacts
The project forms the core of the MS thesis work for graduate student Tracy Compton, who is a female. The project also led to the development of a new software tool by collaborating computer scientists in the Keck CAVES group at UC Davis. We used this tool heavily to interactively reconstruct the sites. This tool allows the user to interactively reconstruct fault slip by defining a piecewise linear fault plane and incrementally moving one block relative to the other in any direction on the plane.
Bibliography:
Because 2011 was the first year on this project, we do not yet have any publications from this work. In addition to presentations at the 2011 SCEC annual meeting by student Tracy Compton and PI Eric Cowgill, Tracy Compton presented the work at the Fall AGU meeting:


Table 1: Top 20 offset markers identified in this study (top 10 in bold).

<table>
<thead>
<tr>
<th>MARKER NAME</th>
<th>SITE NAME</th>
<th>OFFSET (m)</th>
<th>+ (m)</th>
<th>- (m)</th>
<th>TYPE of SITE</th>
<th>GAP</th>
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<tbody>
<tr>
<td>A3</td>
<td>Quail Lake E</td>
<td>49</td>
<td>24</td>
<td>7</td>
<td>deflected</td>
<td>3</td>
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<tr>
<td>A4b</td>
<td>Quail Lake W</td>
<td>169</td>
<td>22</td>
<td>22</td>
<td>beheaded</td>
<td>5</td>
</tr>
<tr>
<td>A16</td>
<td>Quail Lake W</td>
<td>78</td>
<td>42</td>
<td>22</td>
<td>deflected &amp; beheaded</td>
<td>4</td>
</tr>
<tr>
<td>A6</td>
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<td>261</td>
<td>46</td>
<td>26</td>
<td>deflected &amp; beheaded</td>
<td>5</td>
</tr>
<tr>
<td>A18</td>
<td>Robinson Cnyn</td>
<td>39</td>
<td>9</td>
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<td>2</td>
</tr>
<tr>
<td>A14</td>
<td>Richardson Cnyn</td>
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<td>3</td>
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<td>1</td>
</tr>
<tr>
<td>A19</td>
<td>Patrick Plot</td>
<td>101</td>
<td>66</td>
<td>10</td>
<td>beheaded</td>
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<tr>
<td>A20</td>
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<tr>
<td>A22</td>
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<td>13</td>
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</tr>
<tr>
<td>B3</td>
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<tr>
<td>B4</td>
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<td>8</td>
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<tr>
<td>B5</td>
<td>Oak Flat W</td>
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<tr>
<td>B7</td>
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<td>32</td>
<td>beheaded</td>
<td>5</td>
</tr>
<tr>
<td>C3</td>
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<td>27</td>
<td>12</td>
<td>4</td>
<td>deflected</td>
<td>1</td>
</tr>
<tr>
<td>E2</td>
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<td>116</td>
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<td>12</td>
<td>shutter ridge</td>
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</tr>
<tr>
<td>G9</td>
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<td>131</td>
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<td>31</td>
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<tr>
<td>G2</td>
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<td>H1</td>
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<tr>
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<td>3</td>
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<tr>
<td>H5</td>
<td>Mile High Ranch</td>
<td>142</td>
<td>32</td>
<td>2</td>
<td>beheaded</td>
<td>5</td>
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</tbody>
</table>

1) Gaps are 1 = 20-27 m; 2 = 33-42 m; 3 = 45-63 m; 4 = 65-129 m; and 5 = 131-300 m.
Figures:

**Figure 1:** Map of the Mojave section of the San Andreas fault (MSAF) showing the locations of sites identified in the present study. Red squares indicate the 10 best offset landforms, green triangles indicate 10 other promising sites and blue circles are additional offset landforms we’ve identified. Yellow text indicates locations of prior work at CS: Cow Spring, GG: Garden Gulch, LR: Littlerock, PC: Pallett Creek.

**Compilation of offset markers, MSAF:**

**Figure 2:** Plot summarizing the offset landforms along the MSAF. Grey bars indicate portions of the Holocene slip history that are constrained by observations. Gaps in that record are shown in white. Top panel shows previously reported results, bottom panel indicates results from present study, with data points color-coded the same as in Figure 1. There are additional published data points below 20m and above 360m that are not included here because they outside the Holocene offset range considered here.
Figure 3: Surficial geologic maps for eight of the ten top offset landforms. Offset names are indicated in white text in upper left corner. See Table 1 for site names and Figure 1 for locations. Figure continues on next page.
Figure 3 (continued): See previous page for caption.
Figure 4: Images showing each site reconstructed to its original geometry. Maps correspond to those in Figure 3, but not at the same scale. See Table 1 for site names and offset magnitudes and uncertainties, and Figure 1 for locations. Figure continues on next page.
Figure 4 (continued): See previous page for caption.
Figure 5: Schematic diagrams illustrating how we determined the reported offsets and their maximum and minimum uncertainty bounds. See text for discussion.

References:


Rust, D.J., 1982a, Evidence for uniformity of large earthquakes in the "Big Bend" of the San Andreas Fault: Eos Transactions, American Geophysical Union, v. 63, p. 1030.

—, 1982b, Radiocarbon dates for the most recent large prehistoric earthquake and for late Holocene slip rates: San Andreas Fault in part of he Transverse Ranges north of Los Angeles: Geological Society of America Abstracts with Programs, v. 14, p. 229.


