Slip Behavior of Faults through Several Earthquake Cycles
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Investigations Undertaken

This study is designed to document the offsets of recurrent earthquakes at a single location to see how slip varies through earthquake cycles. One of the best places to determine if a fault segment experiences similar amount of slip through time is a 100-meter section along the Carrizo segment of the San Andreas fault, just a few hundred meters southeast of Wallace Creek (Figure 1). There, small channels about a half-meter deep are cut by the simple, narrow, rectilinear trace of the San Andreas fault, three such small channels (labeled A, B, and C) have been incised several meters into the Pleistocene alluvial fan on the NE side of the fault. On the SW side of the fault, several small gullies are dextrally offset from these upstream channels.

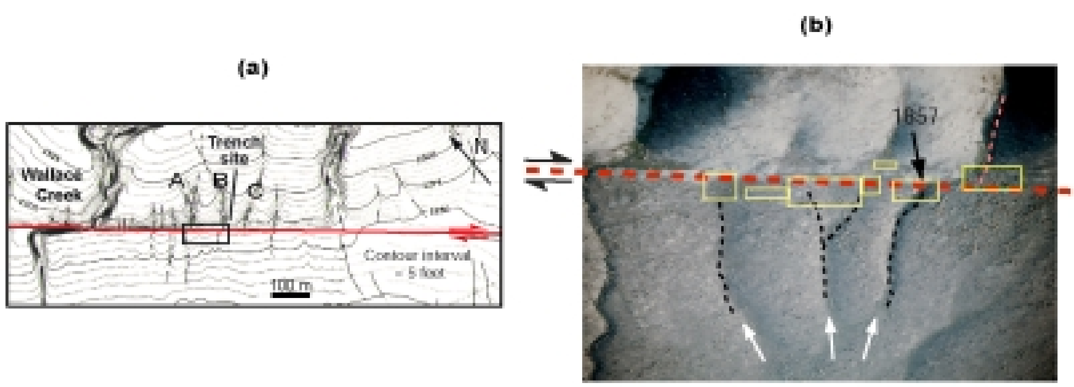

Fig.1 Location of our trench site. Fig.1a shows that our trench site is about 300 meters southeast of Wallace Creek, on the Carrizo section of the San Andreas fault. Fig.1b is the blow-up of the rectange region in fig.1a. Yellow rectangles are areas of our hand excavations, which straddle the channels. Four channels are still visible on surface, shown here as dashed lines and white arrows. 1857 event is indicated by the smallest offset of 8-9 meters.

During the past year, we finished the 3D excavation at this site across the gullies shown as boxes in Fig.1b. We started to digitize and organize our trench logs of over 100 exposures utilizing Arc/View GIS software, and to visualize the channels in 3D views. We also prepared carbon samples retrieved from the channels and sent for AMS analysis. We then refined our correlation of channel pairs based on new data and dates of carbon samples.

Results:

Exposures of the downstream channel segments tended to reveal singular channel scours and fills, as represented by the exposure depicted in Figure 2. In some cases, however, superimposed channels did appear in the downstream exposures. In typical downstream cuts, a solitary channel cuts into a bioturbated sequence of gravelly and sandy lenses. A pedogenic carbonate horizon in these older alluvial deposits suggests they are several thousand years old, since such concentrations of soil carbonate are found only in early Holocene or older deposits in this region.

As one would expect, the upstream exposures were far more complex. They consisted of a broad V-shaped scour in the late Pleistocene "bedrock," filled with a complex scour-and-fill sequence. Figure 3 is a typical upstream exposure. It shows 8 distinct channel scour-and-fill sequences. Several of these are topped by distinctive, laminated silt beds. These must represent ponding of the upstream channel following large ruptures that placed shutter ridges in front of the channel at the fault.

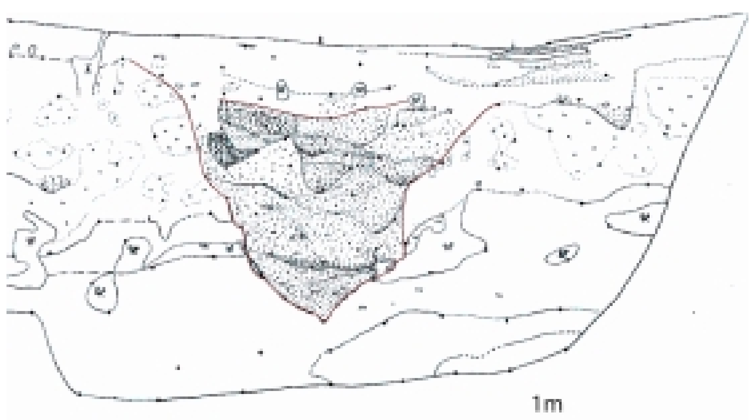

Figure 2. Exposures of channels downstream from the fault typically revealed that the geomorphically expressed channels belied an underlying deep channel scour into late Pleistocene colluvium, subsequently filled with alluvial sand and gravel and then subdued by colluvial infilling.

Figure 4 is a map of the thalwegs of all the channels at the site. Each point represents the exposure of a thalweg in an exposure. The thalwegs are color-coded to indicate the correlations that we thought were likely in early to mid-2001, prior to receiving radiocarbon dates on detrital charcoal samples within several of the channels.

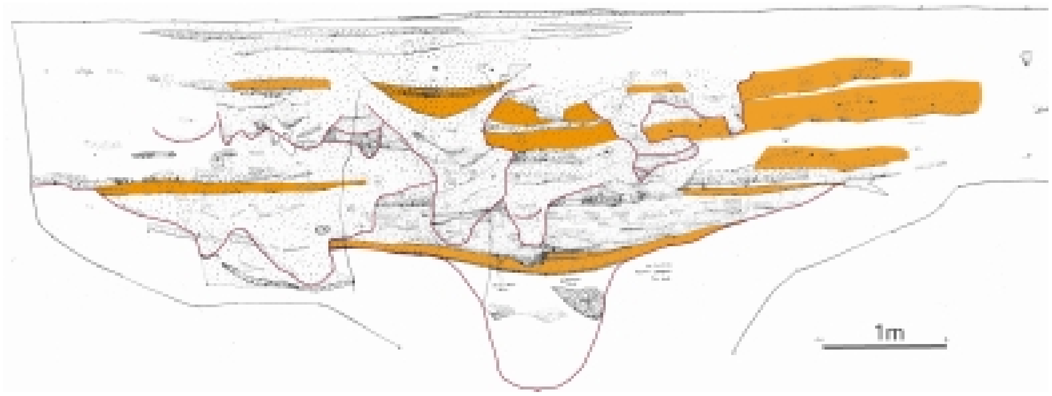

Figure 3. This example shows that exposures upstream from the fault revealed a set of nested channel cuts and fills. Alluvial and colluvial sediment are gray in this illustration. Suspended-load silts in tan represent the temporary ponding of the drainage behind sequential shutter ridges.

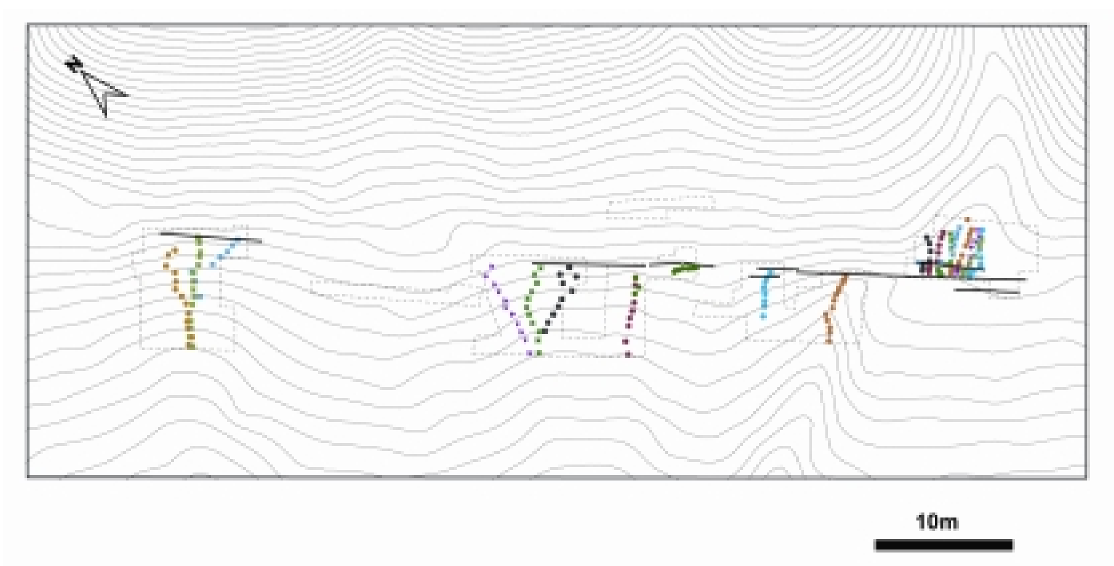

Figure 4. Map of the thalwegs of channels uncovered during our excavations. The color-coding indicates correlations we had made prior to receiving most of our radiocarbon dates in late 2001.

The stratigraphic correlations, geomorphic similarities and radiocarbon dates do allow us to pin down the latest two ruptures, and are consistent with matches that we suggest below for the previous two previous offsets, as well.

The lone downstream channel in Figure 5 is broad and deep, and its thalweg is very well defined. It is very similar in shape to that of the youngest channel on the upstream side (Figure 5). The alternation of colluvial and alluvial beds within the upstream and downstream channels are also grossly similar. Figure 5 shows that the base of the channel runs into the fault at a high angle. The stratigraphic evidence is clear that the offset represents either a single seismic event or multiple events no more than a few years apart. The most plausible conclusion is that this offset represents the 1857 event.

The offset of this youngest channel is 7.8 meters, with an uncertainty of only about 10 cm. This slip is about 15% smaller than the 9.5 ± 0.5 m previously inferred from geomorphology alone[14] and less than suggested by comparisons of modern and pre-1857 broad-aperture geodetic

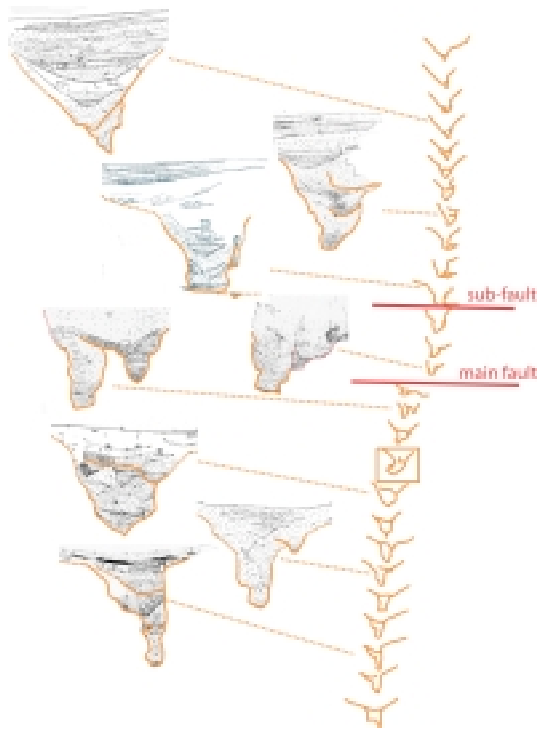

Figure 5. The shapes of all the youngest channel walls upstream from the fault, within the fault zone and downstream from the fault, aligned for comparison. A few representative cross-sections appear with much more detail to allow more detailed comparison. In this figure, the offsets have been removed and the channels stacked from upstream (above) to downstream (below). Note that although the channel geometry changes along the stream, the general shape is similar from one exposure to the next.

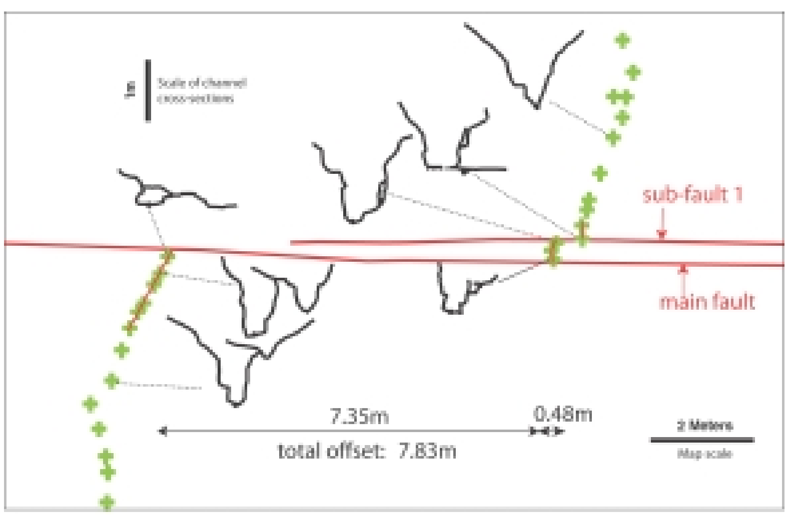

Figure 6. Map of 7.8-m dextral offset associated with the 1857 earthquake. Each cross represents the location of the thalweg surveyed in an exposure wall. The bend in the thalweg just downstream from the fault is not due to warping, as the next channel to the west, which is several hundred years older, is not warped similarly.

data that show 1857 offsets were 11±2 m.[23] But it is nearly identical to short-aperture measurements made in 3-D excavations a few km to the southeast at the Phelan Ranch site.[19]

We can also constrain the magnitude of dextral and vertical offset associated with the previous rupture. The date of this event is about A.D. 1500. Figure 7 shows the shape of the offset channel to be much narrower than the channel depicted in Figure 5. There is no geomorphic evidence of the downstream portion of this channel in Figure 4, because the creation of the next channel to the southeast, which was first offset in 1857, eroded the landform. The dextral offset of this channel is 15.6 m and, like the 1857 offset, has an uncertainty of about 10 cm.

Subtracting the youngest channel from the next-oldest yields the offset associated with the rupture prior to 1857. Within our resolution, it is the as same magnitude as the 1857 rupture, 7.8 m. This result is remarkable for its importance in understanding the physics of fault rupture. It suggests strongly that there is an underlying physical reason for nearly identical sequential ruptures.

Suffice it to say that we have strong, but somewhat less compelling evidence for the previous few ruptures. The next three channels downstream appear to correlate with channels upstream, and each appears to be offset about an additional 7 meters. The details of the geometry of the younger of these older offset channels leads us to suspect that it have formed in two or three increments. That is, we think that the 7 meters may represent more than one discrete rupture. We speculate that the ruptures occurred in rapid enough succession that new channels did not form in the short intervening periods.

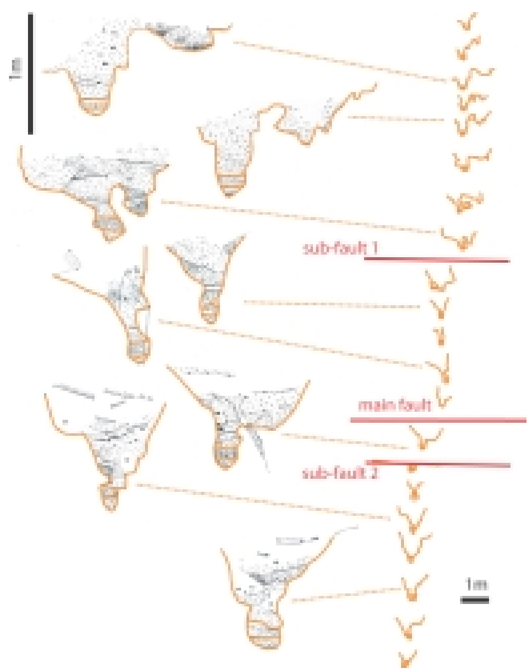

Figure 7. The shapes of all the second youngest channel walls upstream from the fault, within the fault zone and downstream from the fault, aligned for comparison. A few representative cross-sections appear with much more detail to allow more detailed comparison. In this figure, the offsets have been removed and the channels stacked from upstream (above) to downstream (below). Note that although the channel geometry changes along the stream, the general shape is similar from one exposure to the next and quite different from the shape of the younger channel shown in Figure 9.

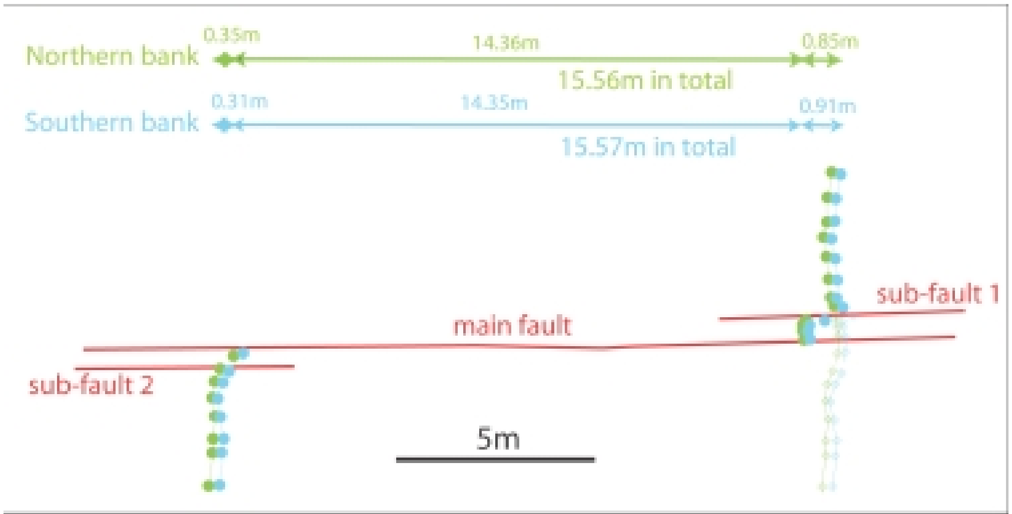

Figure 8. Map of dextral offset of second-oldest channel.

Non-technical Summary

This project is designed to understand how fault slip repeats through many earthquake cycles. Are the earthquakes characteristic or do they vary from event to event? The answers to these questions have both theoretical and practical significance. They will help us to better understand how strain is accumulated and released on faults, hence will improve our ability in earthquake hazard evaluation.

Our study shows that he offsets of the two most recent channels appear as nearly identical increments of 7 to 7.9 meters.

Reports Published

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Klinger, Y., J. Liu, K. Sieh, and C. Rubin, 2001,Slip behavior of the San Andreas Fault through several earthquakes. EUG meeting, April 11-14, France.