Final Technical Report for USGS/NEHRP #G09AP00012 (UO #238610)

Project Title: Slip Rates for the San Andreas fault between the Big Bend and the San Bernardino Valley, So. California.

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Project Period: December 1, 2008 – November 30, 2009

SUMMARY

We investigated 5 sites along the San Andreas fault from Frazier Mountain to Devore (Figure 1). While none of the sites has yielded the "silver bullet" that will tell us the exact slip rate on the fault, the sites provide constraints on the upper and lower limits on the slip rate to 21 to 38 mm/yr and suggest a best estimate for the Mojave portion of the San Andreas fault of ~32 mm/yr; these ongoing investigations should further constrain the slip rate along this stretch of the fault.

Report:

The first site, Frazier Mountain, has not yet yielded a slip rate. We had hoped that the incision of a ~70 m offset stream could be dated to provide a slip rate. The stream appears to be incised into a surface that we initially inferred was deposited by the stream that feeds the pull apart depression, and possibly was equivalent to a coarse boulder gravel that formed the base of the fine grained section revealed in the pull apart depression. We excavated five trenches on the surface north of the depression to examine its character and collect samples for dating (Figure 2). While we did not find any dateable material it was clear that the surface north of the pull apart is much older than we had anticipated and is a complex deeply weathered surface that is much older than the offset streams incised into it. In addition, deeper excavations within the pull apart revealed that the coarse gravel that formed the base of our earlier excavations was not the bottom of the fine grained section, but was simply a very thick and coarse layer within it, so cannot match the surface to the north of the depression, as we had originally thought.

There is still some hope that we will develop a slip rate at the site as we continue our paleoseismic investigations. The first possibility involves developing a structural model that relates the growth of a small depression across a step to the lateral slip generating the sag (Figure 3). Graduate student Ashley Streig is digitizing our trench logs to make structure contour maps on dated layers to determine the space generated by slip across the small step. While is unlikely to yield an extremely precise slip rate it may give us a useful range. The second possibility involves a small fan east of the area we have extensively trenched within the larger depression that will be the target of next year's field work (Figure 3). It is likely that channels or thickness changes associated with this small fan can be traced across the fault and dated where they interfinger with the fine grained sediments of the close depression.

The second site is between Horse Camp and Cow Springs creeks near the town of Three Points. We pursued 2 offsets, an older 3-500 m offset of alluvial fans associated with Horse Camp Creek and 2 unnamed stream between Horse Camp and Cow Springs creeks (Figure4&5) and a beheaded stream offset ~35 m at Cow Springs (Figure 6&7). Unfortunately, the site is owned by the Tejon Ranch which has not been very accommodating and we were not able to make any excavations. Because the offset of the ~35 m beheaded stream is so clear all we need to do is excavate it and date it. While we continue to pursue getting permission to complete this excavation we have focused on reconstructing a large eroded ~12,000 year system of fans. The deposits associated with two fans, one deposited by Horse Camp creek and the other by two unnamed streams immediately to the SE, are well exposed in natural and road cuts (Figure 5). We collected samples from the exposure (Figure 5) along the road that contained 7 charcoal layers in

a 20 m section. We dated 4 layers, including the highest and the lowest, and found that the fan accumulated very rapidly between about 13 ka and 11 ka. This is the same age as geomorphically similar fill terraces found in the Transverse Ranges, associated with the Pleistocene Holocene transition in climate (Weldon, 1986). Because the fans are largely eroded away it is difficult to determine a precise offset (Figure 4) but our reconstruction suggests an offset of ~370 + 250 - 100 m, yielding a slip rate of ~31 mm/yr. We hope that additional mapping of the distribution of these units and excavations to better expose them will allow us to narrow this range, but it is likely that there is simply so little left of these fans that they cannot be precisely reconstructed.

Near the mouth of Cow Springs Creek (Figures 6&7), Rust (2005) proposed that three ~7 m offsets, representing the past 3 earthquakes, are recorded as beheaded gullies originally sourced by the main Cow Springs Creek. As discussed in the figure captions, we are skeptical that these 3 small gullies represent downstream continuations of the main wash, but it is impossible to be certain one way or the other without trenching them. There is a very clear ~35 m offset of a sharply beheaded drainage immediately east of the proposed Rust offsets. We have been seeking permission for the Tejon Ranch for 5 years to trench this site with no success. Hopefully, as the Tejon Ranch develops a policy for research on the new Tejon Nature Preserve we will be able to convince them to allow us to excavate the Rust "offsets" and the ~35 m offset.

The third site we worked on was Ritter Ranch (Figure 8). We are collaborating with a group of consulting geologists and archeologists to determine the slip rate from a small landslide that is offset ~64 m. The offset is remarkably well defined because the developer of the site completely exposed it while preparing the site for development. While removing the landslide, Native American fire pits were exposed, that had been buried by the slide. While we cannot vie too much detail about the site until the group completes their analysis and obtains permission to publish, we have been assisting them in analyzing the C-14 dates, interpreting the geomorphology and developing a statistical model that will put limits on the slip rate. At the moment the data from the site provides an absolute minimum slip rate of 21 mm/yr. **[text continues on p. 6]**

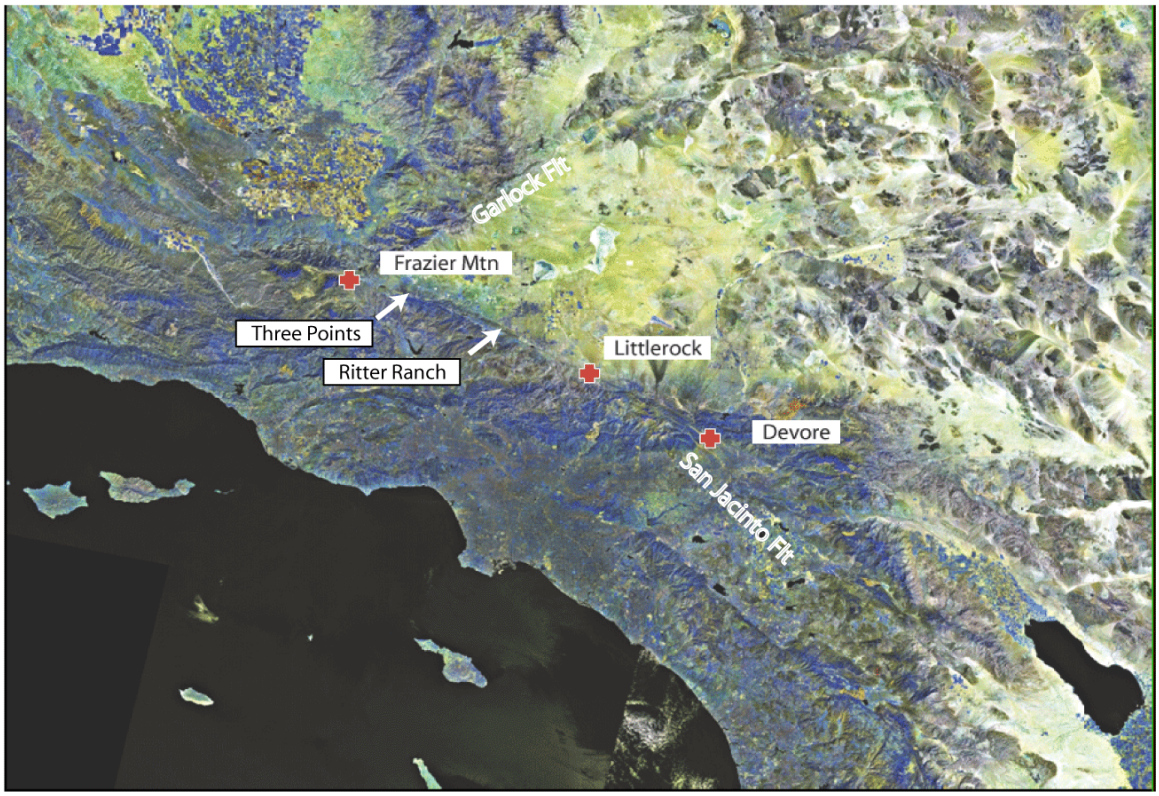


Figure 1 – Slip rate sites; Three Points and Ritter Ranch were added to original sites.

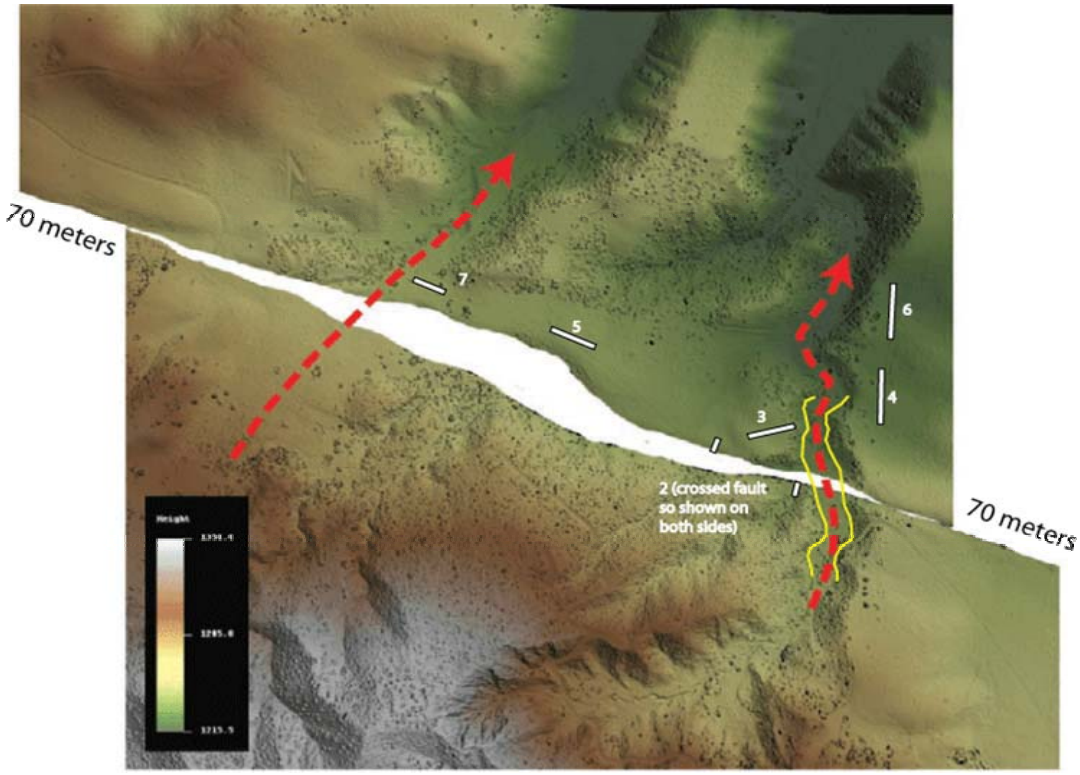
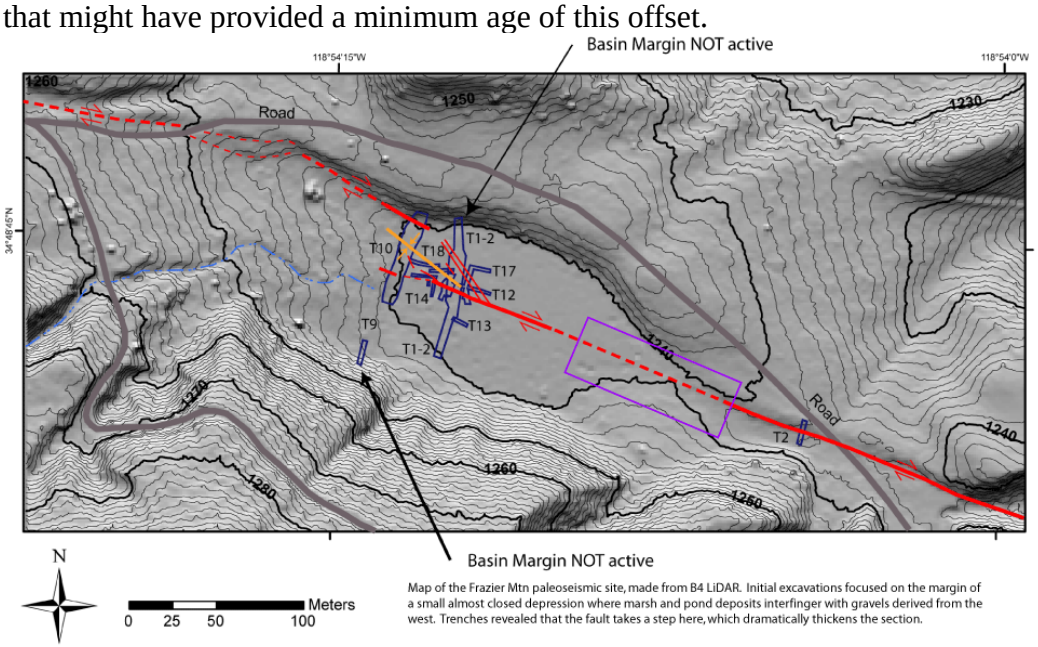


Figure 2 – Originally proposed offset model for the Frazier Mtn site. We hoped that there was a widespread gravel layer that covered the area before the development of the pull apart and that that ~70 m offsets would be cut into it. We dug 7 trenches to test this idea (two trenches, 4&6 were also located to see if older traces of the fault are still active). We were not allowed to make excavations within the well defined eastern gully, that might have provided a minimum age of this offset.



Map of the Frazier Mtn paleoseismic site, made from B4 LiDAR. Initial excavations focused on the margin of a small almost closed depression where marsh and pond deposits interfinger with gravels derived from the west. Trenches revealed that the fault takes a step here, which dramatically thickens the section.

Figure 3 – Current understanding of the structures within the pull apart. We hope that 3d excavations in the stepover or offset of a small fan (purple box) will yield a slip rate.

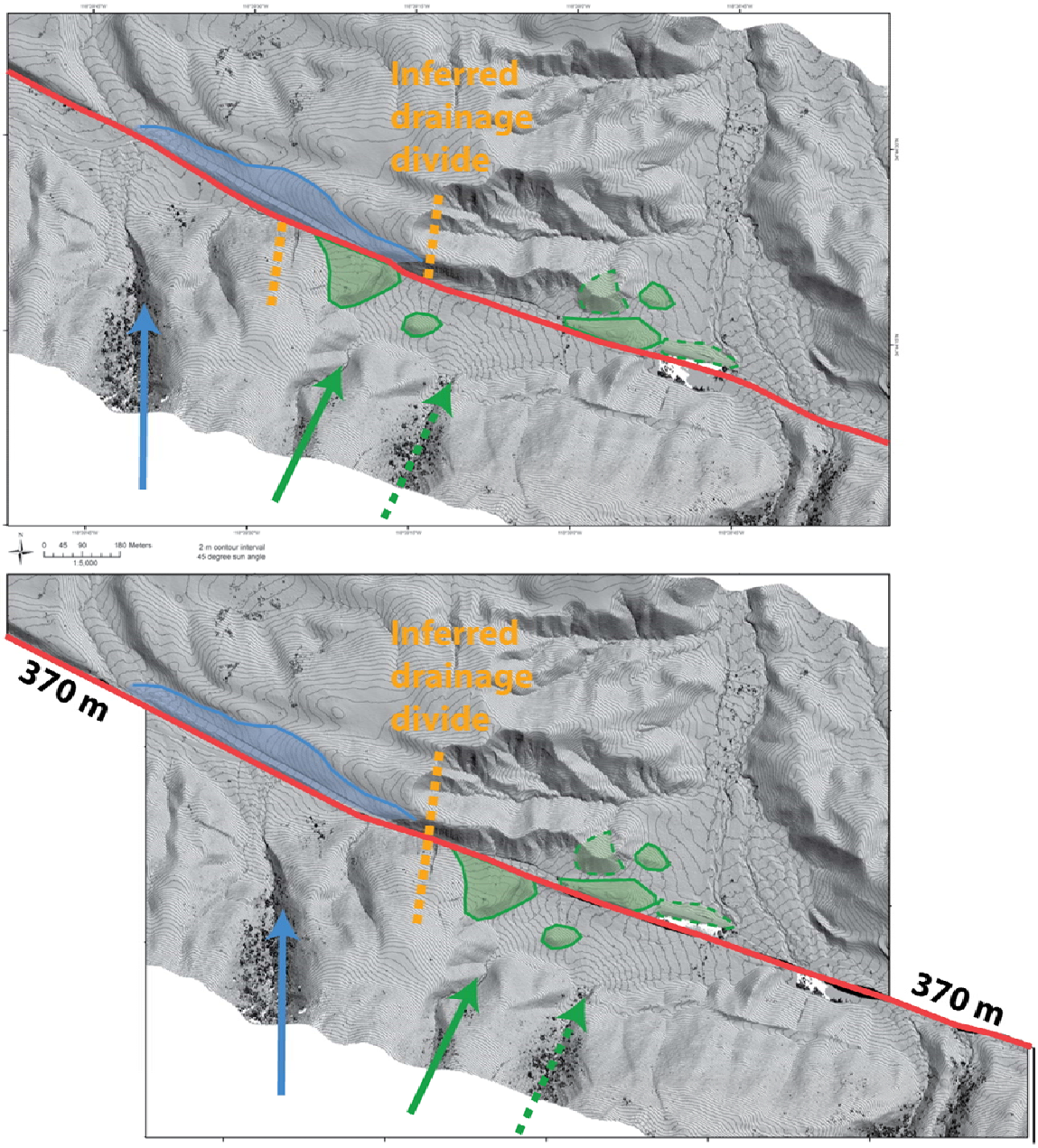


Figure 4 –Between Horse Camp and Cow Springs there are remnant of two fans. In the Horse Camp drainage only a small slice of the old fan is preserved where it is buttressed against a fault parallel ridge on the north side of the San Andreas fault (blue). This fan is made of coarse bouldery alluvium similar to what is currently being deposited by Horse Camp Creek. To the east remnants of a fan (or fan system; it may have been deposited by two streams indicated by green arrows) can be found on both sides of the fault (green) although the upper fan surface is only preserved on the south side of the fault (see Figure 5). Because the fans are incompletely preserved, it is impossible to precisely reconstruct them but it is clear that they did not overlap, as they currently do, requiring a minimum offset of about 270 m. Based on the slope of the preserved surface remnants it appears that the two fans were deposited in separate drainages (ie the blue fan drained NW and the green NE), with a drainage divide in between (orange dashed line) offset ~370 m.

Figure 5a - Oblique view looking east at where Horse Camp Creek crosses the San Andreas fault (the view is approximately 500 m along the fault). After the road crosses the creek (going east) it rises up a long smooth slope, which is the remnant of a fan deposited by Horse Camp Creek (sediments identical to those currently being transported by Horse Camp Creek are well exposed in the fault scarp below the road). This fan buttressed against a fault parallel bedrock ridge (to the left of the blue line). Because the apex of the fan is near where the road leaves the top of the photo, the offset is ~370 m, depending upon how one aligns the fan remnant on the northeast side of the fault (left) with Horse Camp Creek on the SE side (right).

Figure 5b - Oblique view looking west, east of where Horse Camp Creek crosses the San Andreas fault (the view is approximately 700 m along the fault and Horse Camp Creek is at the very top of the photo). NE (right) of the fault the road rises up the remnant of a fan from Horse Camp Creek that was buttressed against the obvious fault parallel ridge. SW (left) of the fault there is a fan remnant deposited by two streams that enter the image from the SW (left). The upper surface of this fan slopes NW (see Figure 4) and thus is the NW edge of the original fan that was probably centered at about the switchback in the road near the bottom of the photo. The road exposes more than 10 m of sediment containing 7 layers with charcoals that we collected and dated.

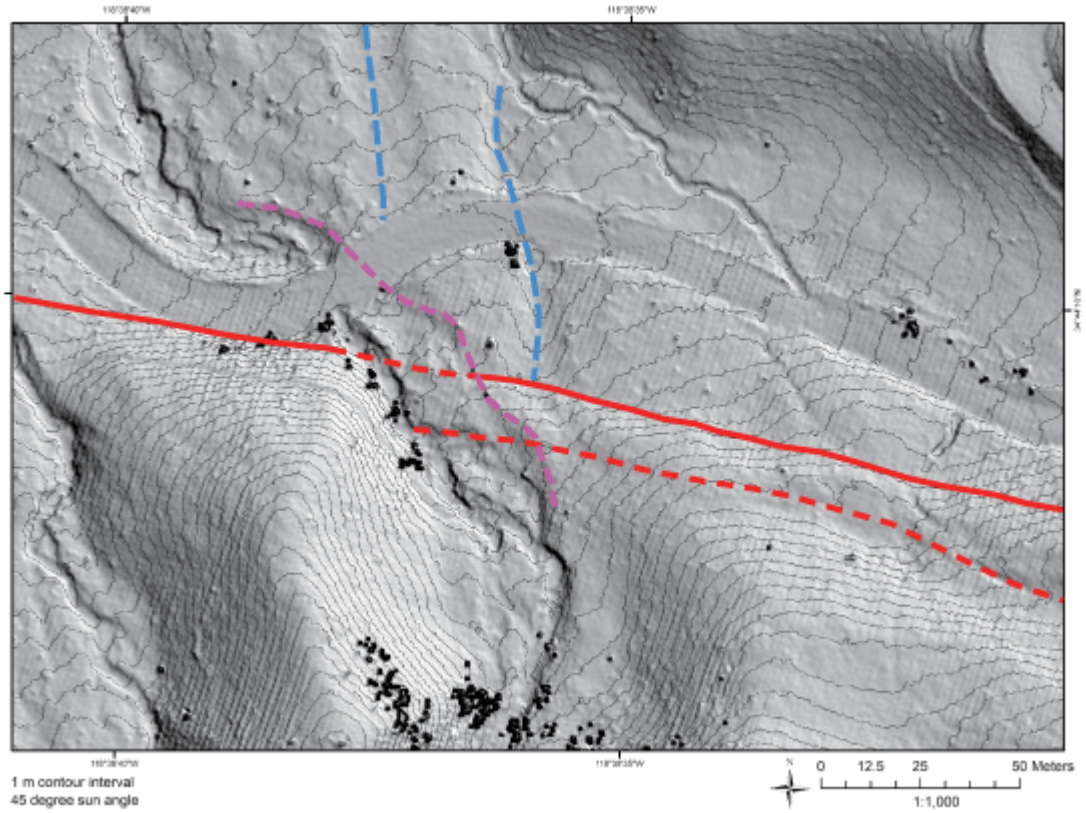


Figure 6 – Microgeomorphic offsets at Cow Springs Creek – There are several issues that potentially complicate the simple picture presented by Rust (2005). First, east of Cow Springs Creek there appears to be a sub-parallel trace of the SAF, which makes an obvious side hill bench. It does not appear to extend west of the creek but there is a trail along its projection so it is impossible to be certain. More significantly, the gullies that Rust proposes to be offset from the main creek are extremely small compared to the creek; while it is possible that the creek narrowed for awhile, older abandoned portions of the creek (shown in blue) are much deeper and broader, like the modern creek. The westernmost abandoned creek appears to project right back to the where the modern creek crosses the fault, suggesting little or no offset. It is clearly cross cut by younger fluvial features (limited by the purple dashed line) that appear to be overflow channels and levees associated with the modern creek. If this is the case, the Rust (2005) offsets would be part of this set of features and cannot represent multiple offset traces of the creek.

The easternmost of the abandoned Cow Springs Creek drainages (blue) is clearly beheaded at the fault appears to be offset ~35 meters. We are attempted to gain access to this land so we can trench this offset and potentially get a ~35 m slip rate, which should span the period of time represented by the Frazier Mtn and Pallett Creek paleoseismic records, NW and SE respectively, and will tell us at least what the average slip per event is over the past 5-7 events.

[continued from p. 2] The fourth site we worked on is near Littlerock (Figure 1). At his site we re-exposed trenches first excavated in 1986 to conform the match of the “yellow gravel” across the fault and to collected samples for C-14 dating. Figure 9 shows all of the trenches and seismic lines that constrain the depth and extent of the yellow gravel and the two pits from which we collected the new C-14 samples, and Figure 10 shows our reconstruction of the yellow gravel. We infer that the aggradation of yellow gravel set the offset, because 6 m of sedimentation filled and preserved the channel geometry when aggradation began. **[text continues on p. 9]**

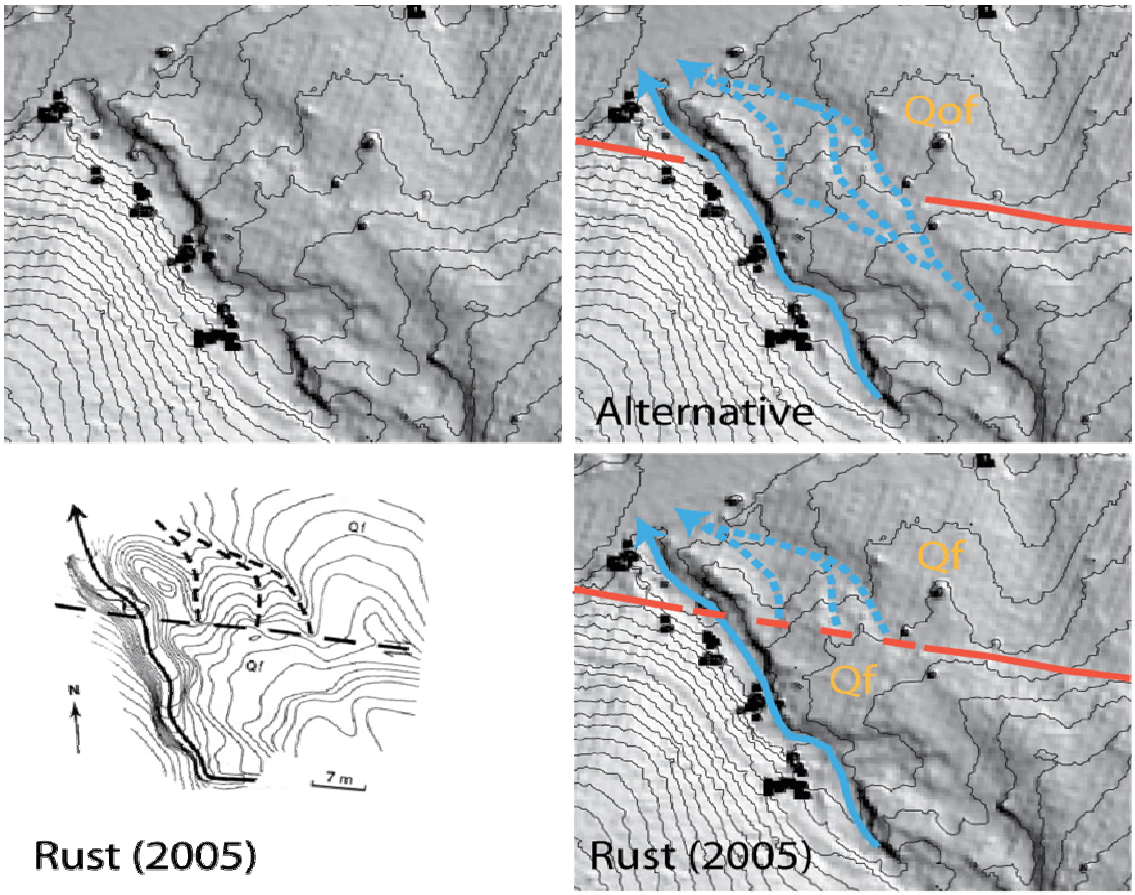
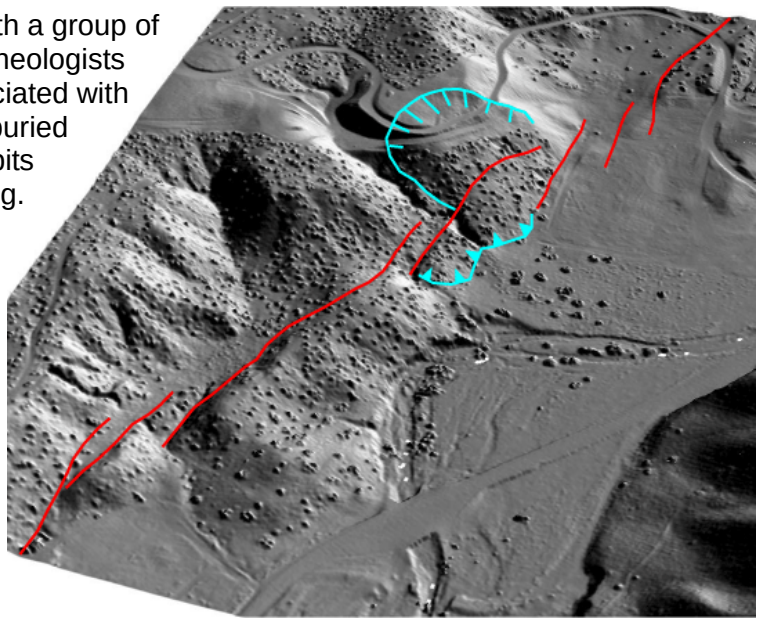


Figure 7 – B4 LiDAR image of the Cow Springs area; scene is about 50 m wide and contour interval is 1 m. It appears to us that the small channels Rust (2005) proposed are offset extend across the fault; also, the Rust model infers that Qf is offset by the fault more than the younger streams; however, the fan north of the fault (Qof in our interpretation) is geomorphically much older than the modern appearing Qf south of the fault.

Figure 8 – We are working with a group of consulting geologists and archeologists To determine a slip rate associated with a 64+/-3 m offset. The slide buried Several native American fire pits that we have assisted in dating. The current suite of dates provides a MINIMUM slip rate of 21 mm/yr and we are working on a statistical model to help determine the range of possible slip rates that are consistent with the range of ages of fire pits both under and around the landslide.



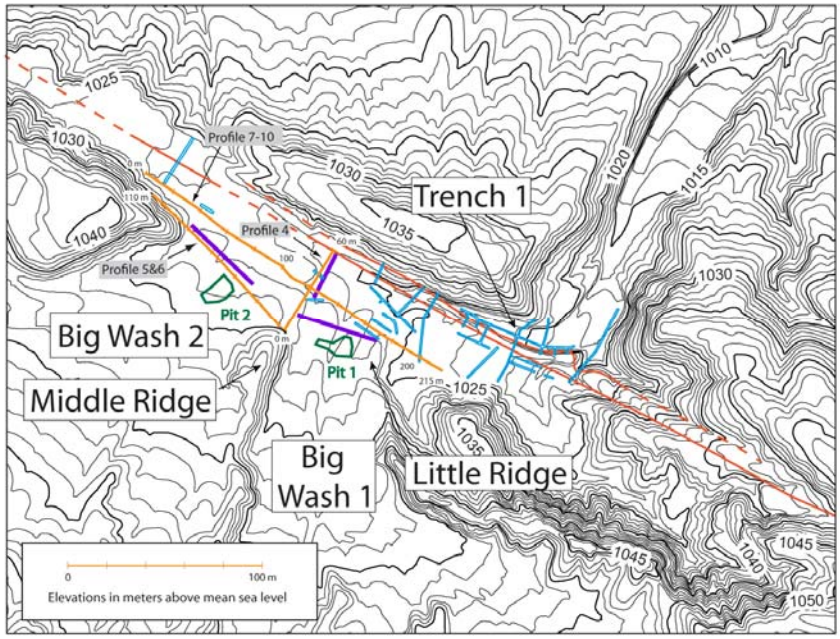


Figure 9 – Map of the Littlerock site; blue trenches, green pits and others seismic lines.

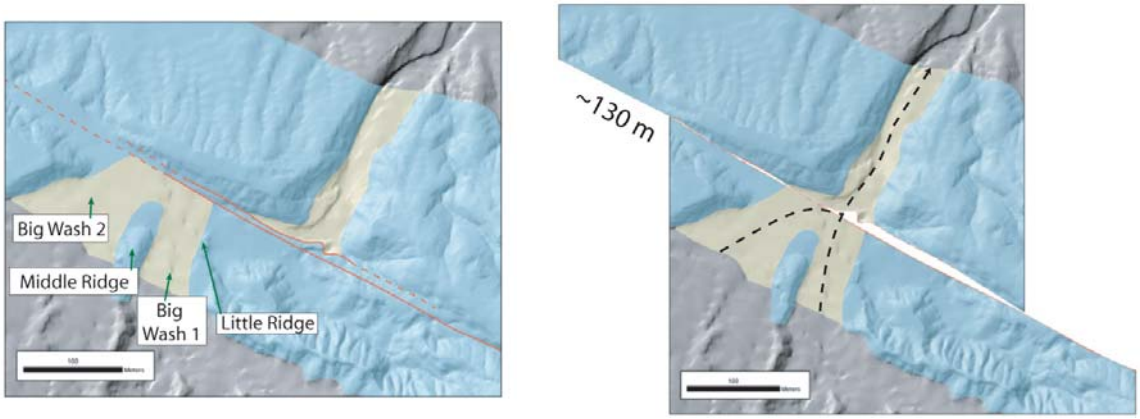


Figure 10 - A) Distribution of the "Yellow Gravel" using all trenches, exposures, seismic lines and pits. B) Reconstruction of the Yellow Gravel when it was deposited; it is clear that Big Wash 1 was aligned with the downstream continuation of the channel, as the margins of Big Wash 2 turn as they approach the fault. C) C-14 samples collected from Trench 1 and the 2 pits form a straigraphically consistent set that suggests that the channel began depositing ~4000 BP. This probably provides a slip rate of ~32 mm/yr.

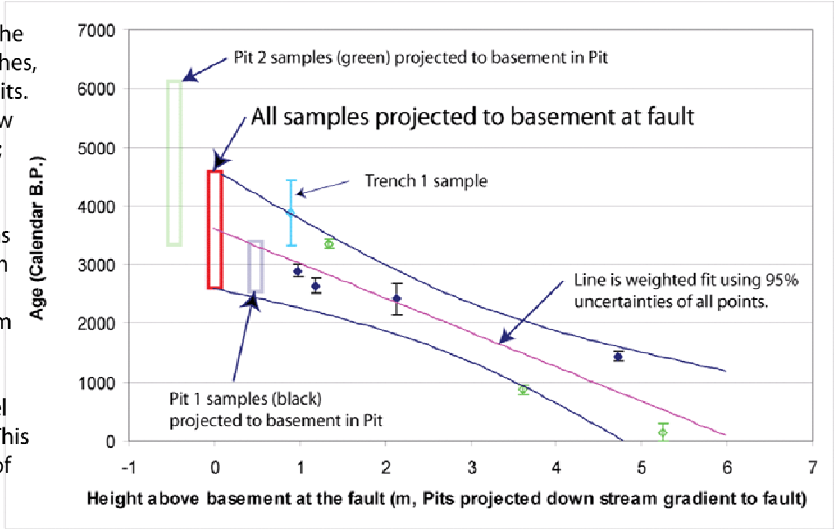
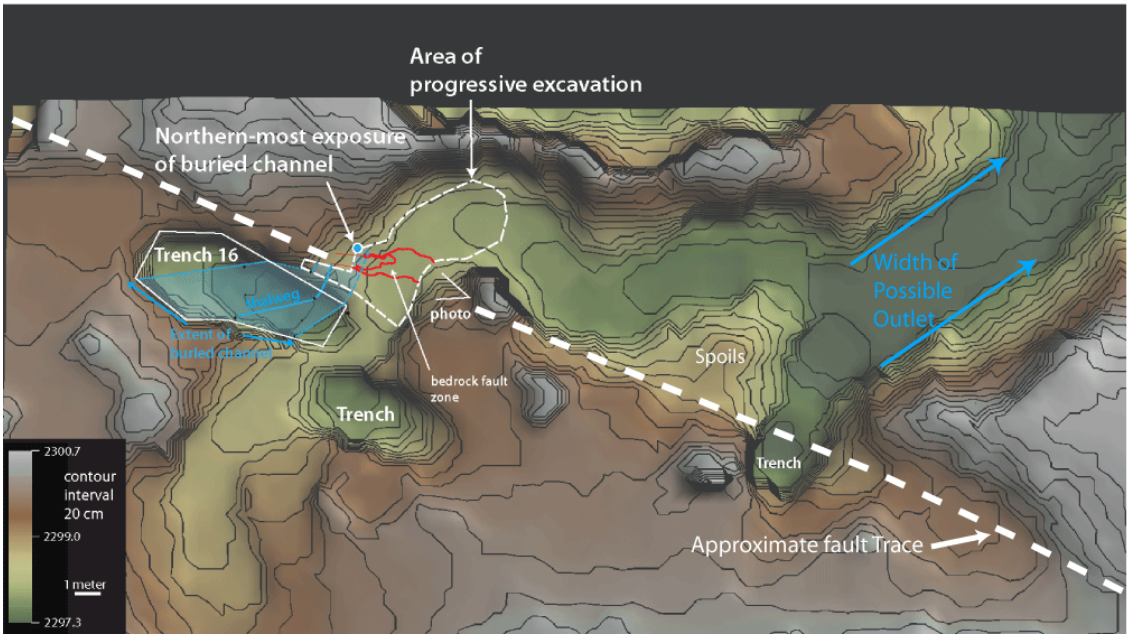


Figure 11 – The small gully just east of Trench 1 on Figure 9, is deflected across the fault. We excavated Trench 16 to expose a small channel that we then hand excavated to where it was truncated by the fault. We cleaned off the floor off the gully and could not find it north of the fault because a sliver of Juniper Hills bedrock is being uplifted in the fault zone. Based on the geometry of the channel, the channel is most likely offset ~11 m, but could be offset as much as ~27 m.

Photograph of bedrock base of modern channel and buried channel. View south; yard stick for scale. Buried channel predates pond sediments, is truncated by Juniper Hills bedrock, and is overlain by Juniper Hills colluvium. Note smooth bedrock channel forms underlie both the buried and the modern channel (separated by dashed black line).



[continued from p. 6] The ~130 m offset of the channel filled by the Yellow Gravel thus yield s a slip rate of 32 mm/yr. One could argue that this is a maximum rate because the channel may have been deflected or offset some before the gravel filled it, but if the switch from downcutting to aggradation represented by the Yellow Gravel set the geometry of the channel it is an actual rate.

We also dated and investigated a much younger offset channel, just east of trench 1 on Figure 9 (Figure 11). A bedrock sliver within the fault zone blocked this small drainage, creating a closed depression that held a pond that was originally recognized in our early (1986) excavations. A small ~1600 AD channel associated with these pond deposits was traced to the fault where it was truncated and offset. Because the channel is not preserved north of the fault (due to the uplifting bedrock sliver) we cannot tell exactly how much it is offset. However projecting it across the fault suggests that it is most likely offset ~11.5 m (to the meander north of the pile of trench spoils in Figure 11). However, it could be offset somewhat less and still turn the corner or as much as 27.5 m and still go out the gap downstream (Figure 11) for s slip rate of 23-82 mm/yr, with a best estimate of 32 mm/yr (using 11.5 m). The age of the channel suggests that it is offset by the past 3 earthquakes dated at the nearby Pallett Creek paleoseismic site.

The final site we worked at is Perdew Canyon near Devore, on the NE border of the San Bernardino Valley (Figure 1). A thick alluvial deposit is clearly offset ~1.3 kms (Figure 11) and e dated boulders with Be-10 and are still interpreting the results.

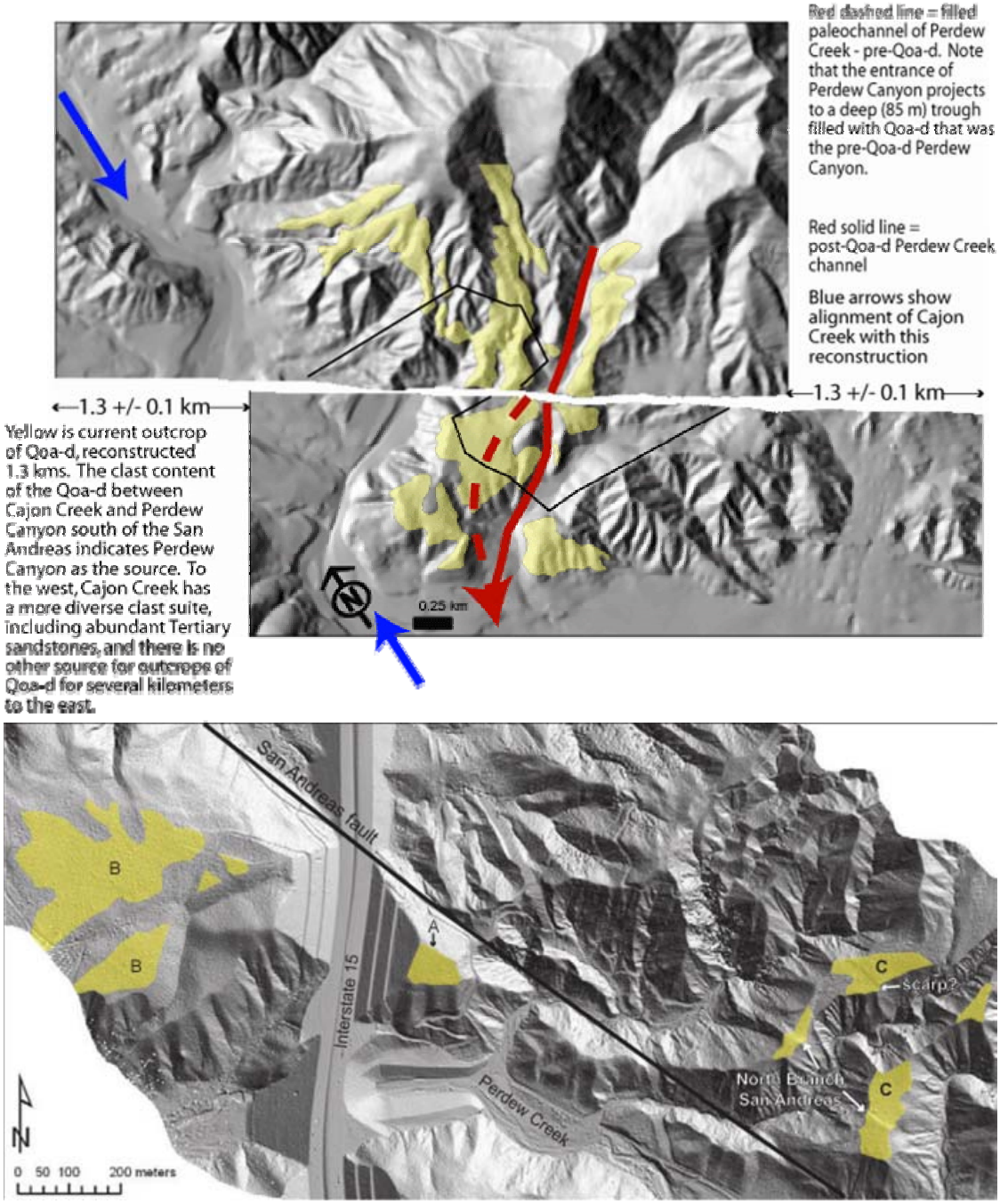


Figure 12. Reconstruction of the paleochannel of Perdew Creek which restores ~1.3 km of slip across the San Andreas fault. The offset black box on the upper image corresponds to the area of the lower image, which shows a LIDAR image of our sampling localities (A), (B) and (C). The yellow regions corresponding to (A), (B) and (C) are mapped remnants of the Qoa-d. Field work and cosmo dates on boulders suggest that areas (A) and (B) have been degraded and that the best surface remnants are (C), although boulders from (C) gave ages that are too young to represent the age of the Qoa-d deposit. Perhaps even the (C) surfaces are degraded, more recently exposing the boulders we dated, or sediment continued to accumulate on these surfaces after the main deposit was formed and only stopped once deep incision isolated them from the hillsopes

Publications: We have published 2 SCEC (2008, 2009) and 1 AGU abstract (2009) from this work, and are working on papers for the Littlerock and Devore sites.