Tectonic geomorphology and earthquake geology of the 1857 reach of the San Andreas Fault: a new look from Airborne Laser Swath Mapping

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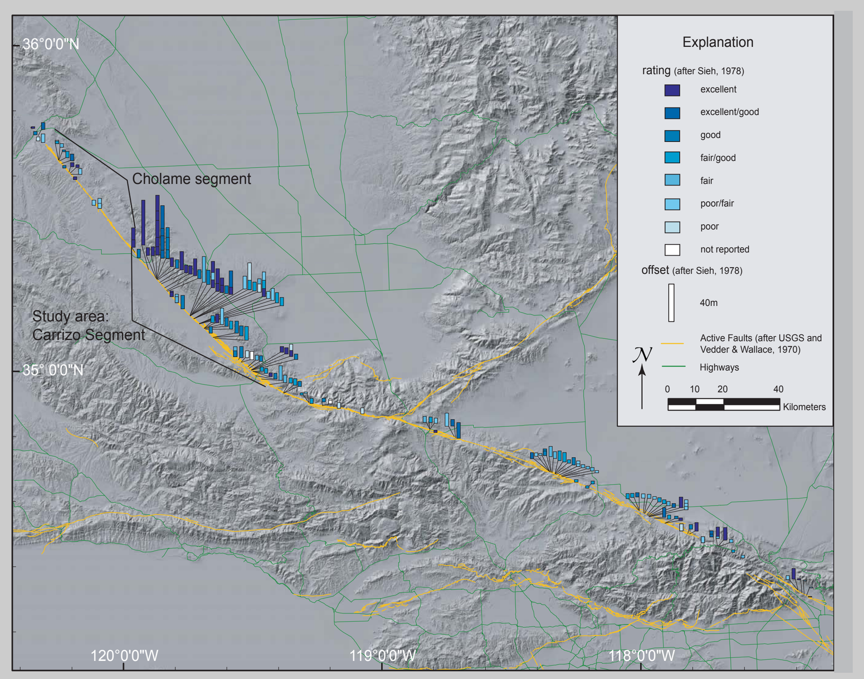
Problem: slip along the San Andreas Fault in 1857 earthquake and earlier

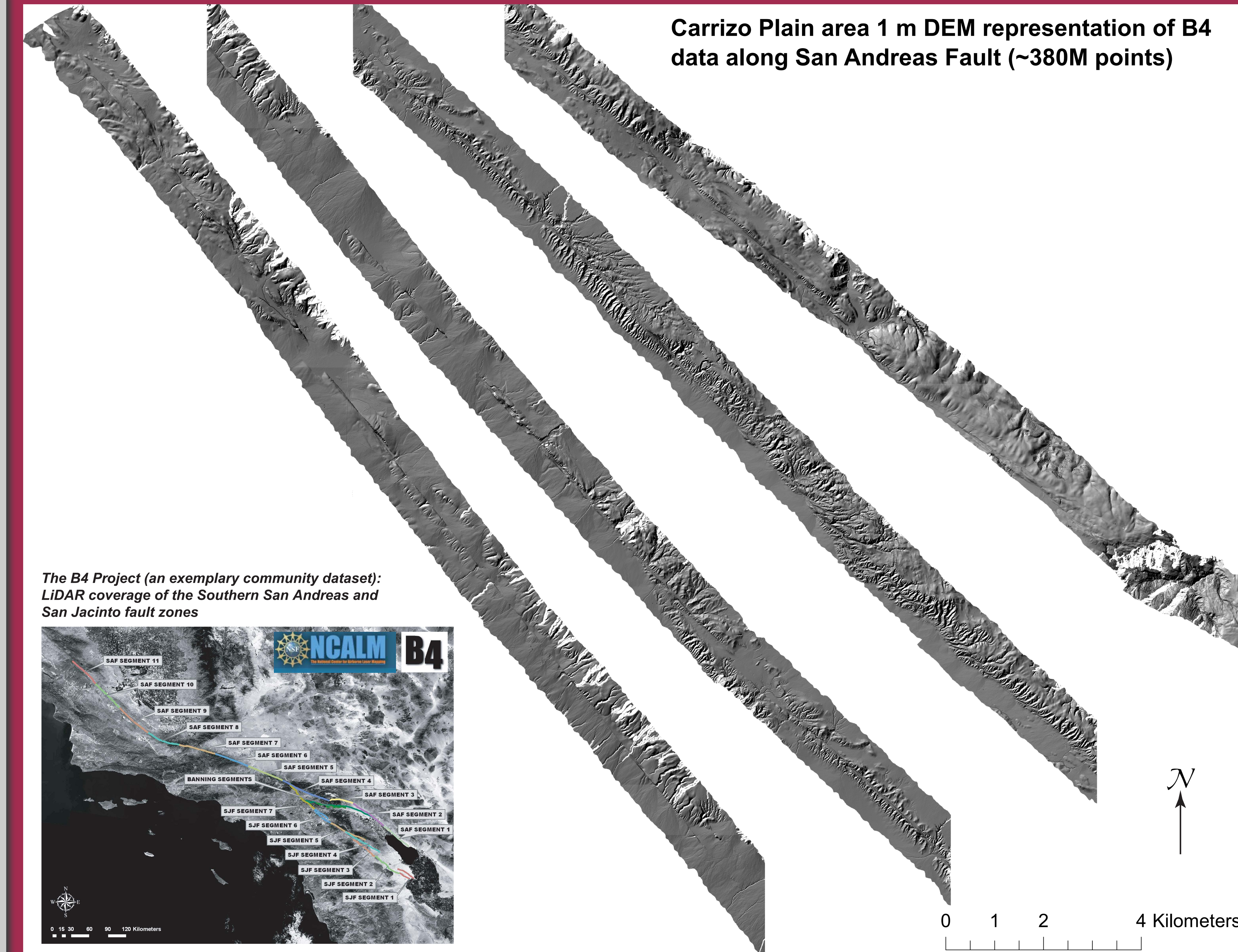
Offset stream channel along SAF in Carrizo Plain depicted in 4 cm resolution georectified aerial photo from remote control balloon system draped over 25 cm from B4 survey and GEOn Lidar workfow

Important information about paleoearthquakes is recorded in the meter-scale tectonic geomorphology of fault zones. Such information is available from both the records of offset and from paleoseismic sites which are better understood with enhanced knowledge of geomorphic context. The B4 airborne laser swath mapping dataset of the topography along the San Andreas Fault (SAF) zone has enabled a spectacular new look at the 10s-of-meter scale tectonic geomorphology and is a powerful complement to field survey.



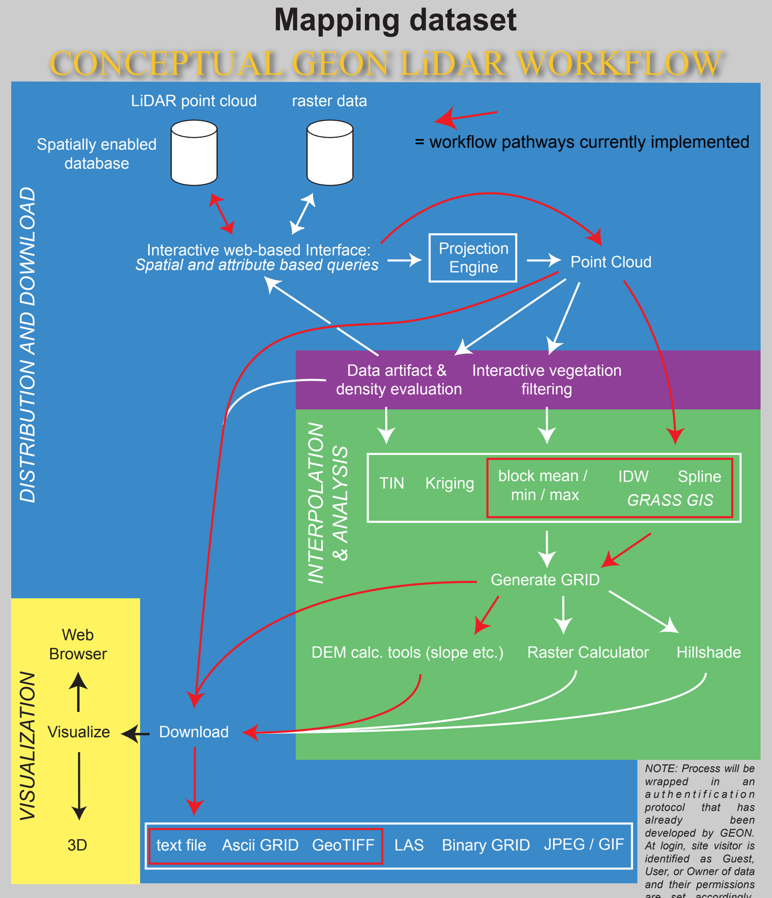
Offsets along the San Andreas Fault in Southern California (Sieh, 1978). The smallest offsets in this group are attributed to the 1857 earthquake. Offsets along the northwestern portion of the Cholame segment were also studied by Lienkaemper. The south central SAF preserves numerous offset landforms that will be uniformly charaterized in detail with high resolution ALSM. The entire SAF shown in this map has been imaged with ALSM. Active faults in yellow from USGS and Vedder and Wallace, 1970.

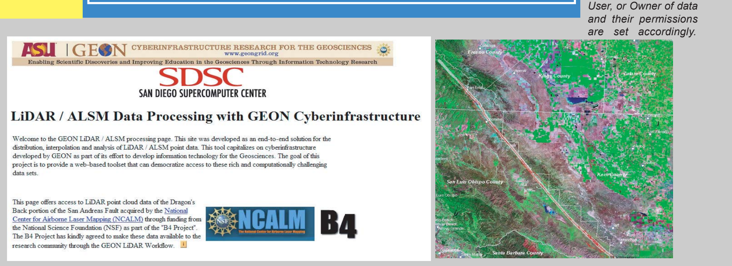
Carrizo Plain area 1 m DEM representation of B4 data along San Andreas Fault (~380M points)



The B4 Project (an exemplary community dataset): LiDAR coverage of the Southern San Andreas and San Jacinto fault zones

Tools: GEON LiDAR Workflow & B4 Airborne Laser Swath Mapping dataset



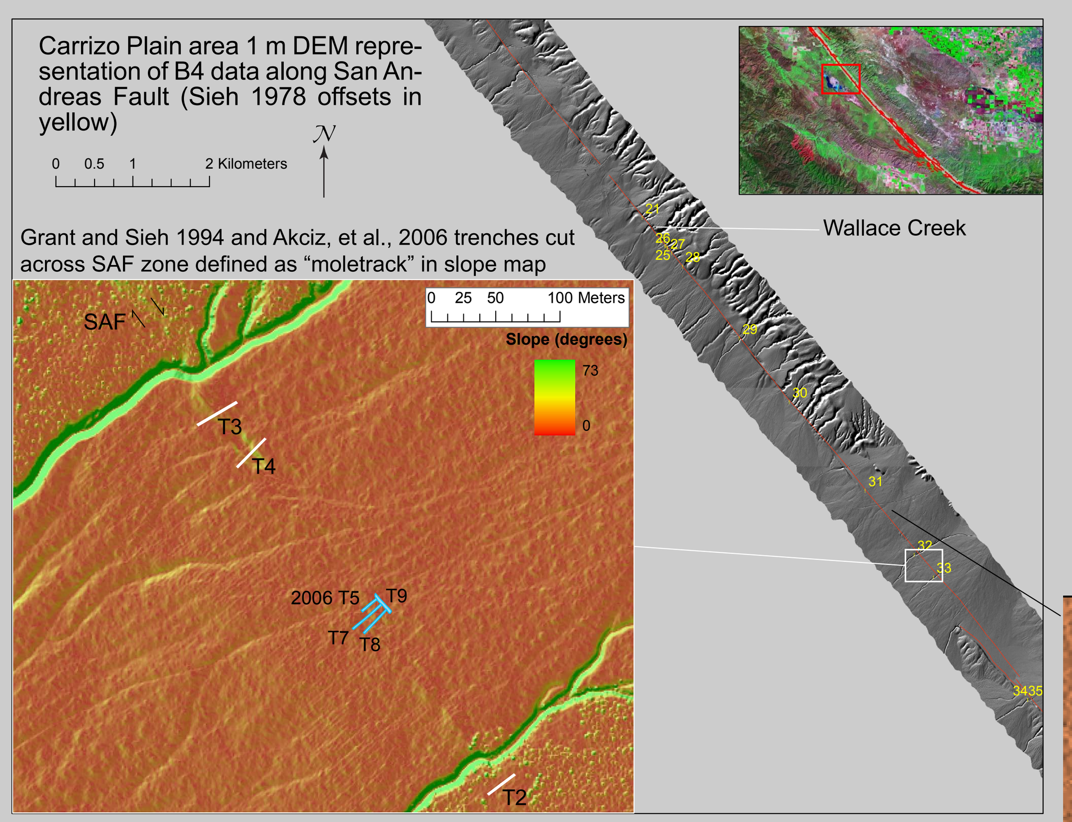


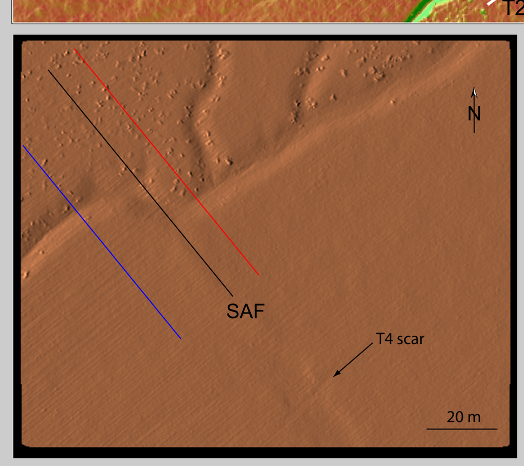
The GEON LiDAR Workflow (GLW-- Crosby, et al., 2006; and Jaeger-Frank, et al., 2006) enables users to select, manipulate, process, and download Airborne Laser Swath Mapping (ALSM) point clouds and to produce various Digital Elevation Model (DEM) products using the tools of cyberinfrastructure though our collaboration with GEON (http://www.geongrid.org/science/lidar.html). We have incorporated the more than 38 billion points of the B4 survey into the GLW.

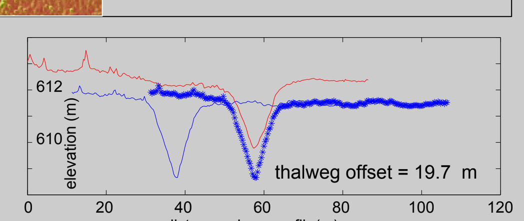
Application to Bidart site offsets in the Central Carrizo Plain: 7 m 1857 offsets

Carrizo Plain area 1 m DEM representation of B4 data along San Andreas Fault (Sieh 1978 offsets in yellow)

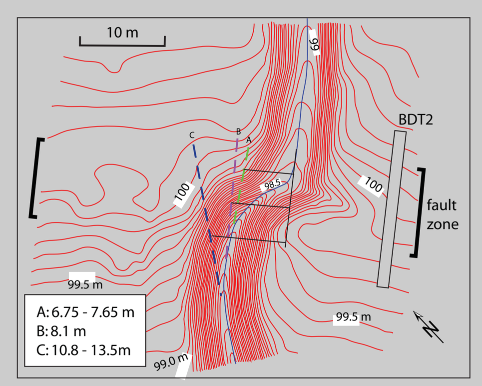
Grant and Sieh 1994 and Akciz, et al., 2006 trenches cut across SAF zone defined as "moletrack" in slope map



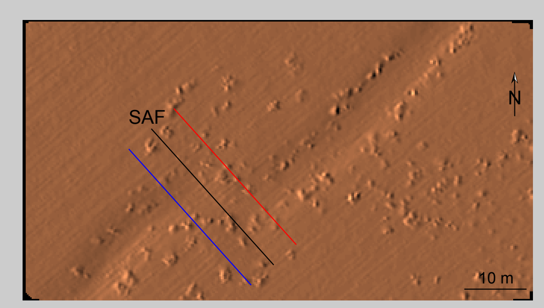


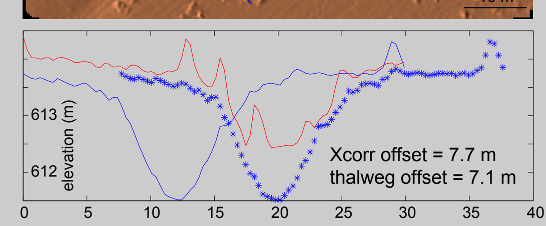


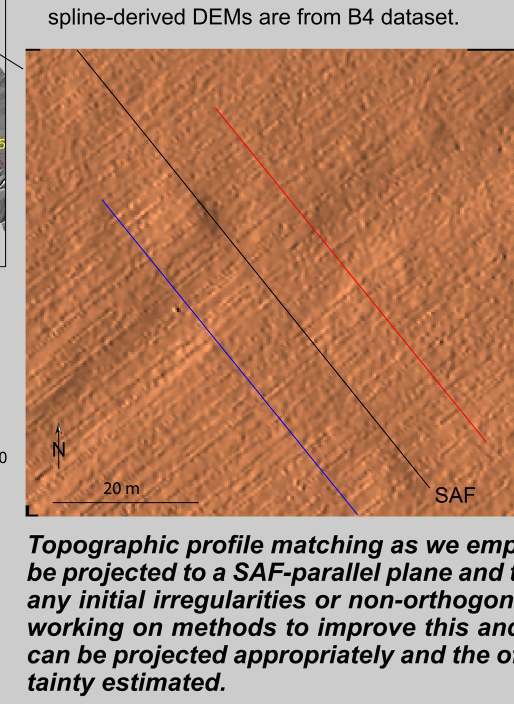
Offset at NW end of the Bidart site (NW of T3 and T4; Sieh #32) was measured as 18.3±0.9 m by Sieh. We measure 19.7 m of the channel thalweg parallel to the local SAF (black line) on the B4 DEM. 25 cm resolution spline-derived DEMs are from B4 dataset.



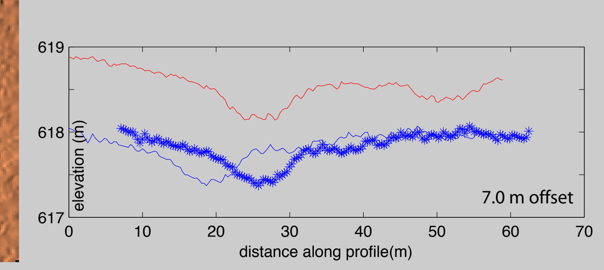
Offset at SE end of Bidart site (NW of T2) was measured as 9.6±1.4 m by Sieh and 7-8 m by Grant and Sieh, 1994. Alternative interpretations are as much as 13.5 m. T2 offset in B4 data has thalweg offset of 7.1 m and a cross correlation offset of 7.7 m. 25 cm resolution spline-derived DEMs are from B4 dataset.





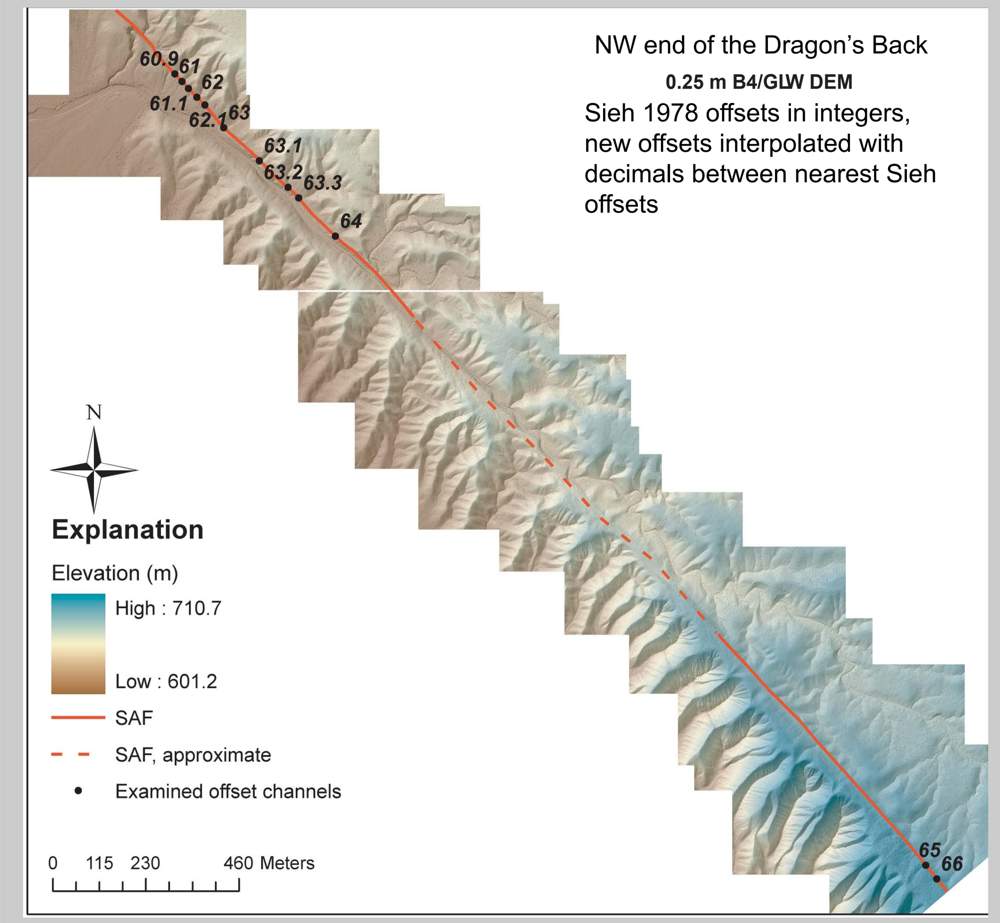


New offset channel discovered with cursory review of 0.5 m B4 DEM. This 0.5 m deep and ~10 m channel is offset 7 m. 25 cm resolution spline-derived DEMs are from B4 dataset.

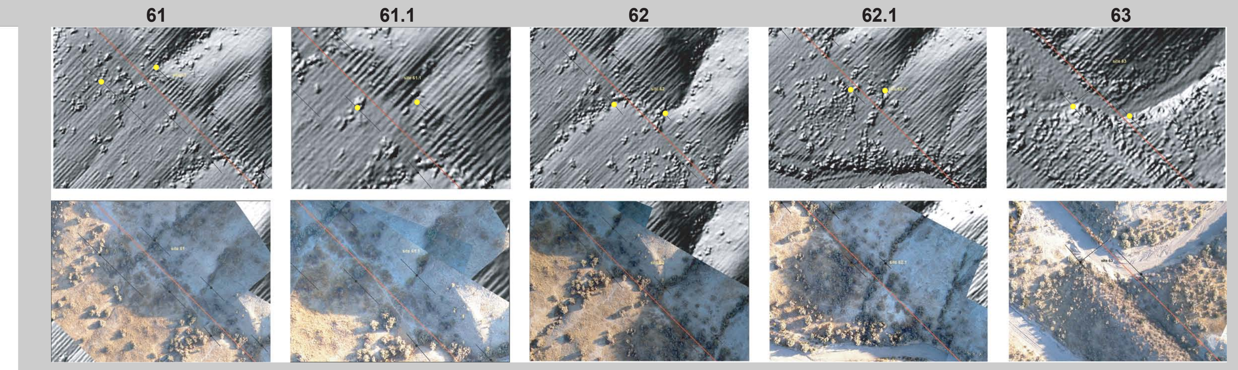


Topographic profile matching as we employ here assumes that the channel elements can be projected to a SAF-parallel plane and there offsets thus measured. It does not allow for any initial irregularities or non-orthogonality to the SAF in the channel elements. We are working on methods to improve this and fit surfaces to each side's geomorphology that can be projected appropriately and the offset more carefully reconstructed and the uncertainty estimated.

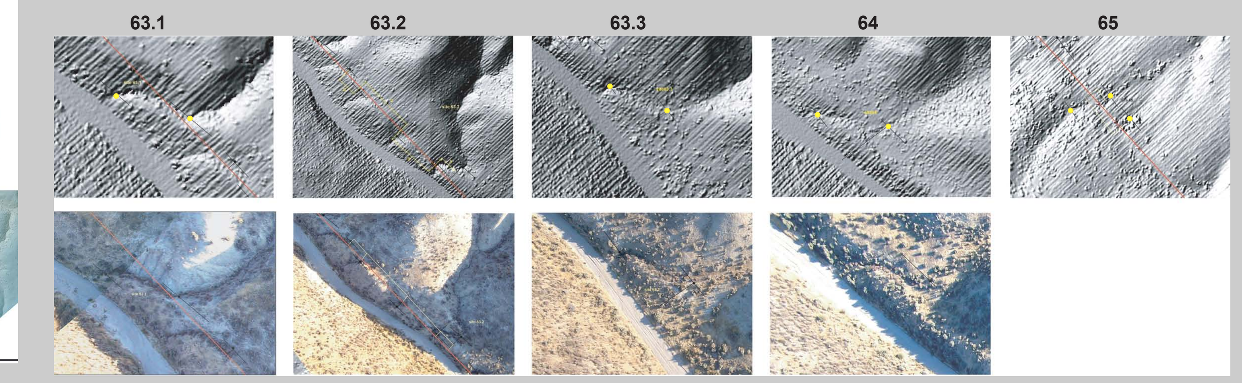
Study area: central Carrizo Plain--25 cm B4 DEM combined with high resolution balloon platform imagery



The data are unprecedented in their power to quantitatively depict the tectonic landforms along the SAF. We closely examined several reaches of the fault in the Carrizo Plain. We compared our estimates of 1857 and earlier offset from the field and from the B4-derived DEMs to the estimates from Sieh, 1978. Combinations of field and virtual examination provided our most confident estimates. In addition, a quantitative offset estimation using SAF spanning and parallel profiles was possible in places with higher quality obvious offsets. Broad (>several m) and shallow channels (<1 m) were difficult to confidently match with this semi-automated approach.

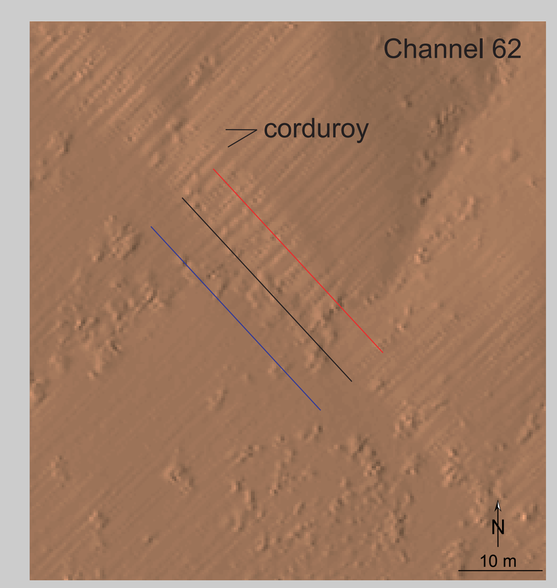


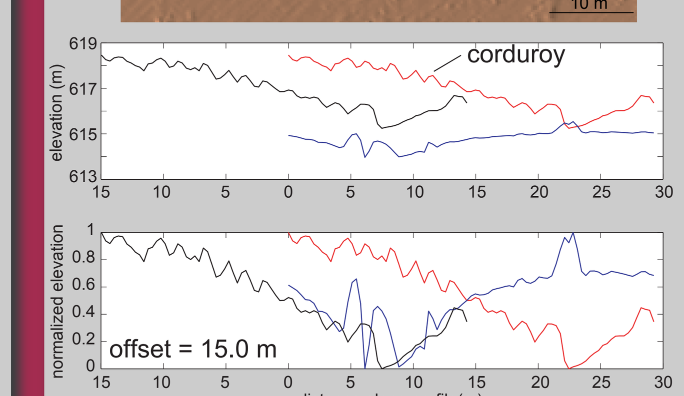
61	61.1	62	62.1	63
Sieh, 1978: excellent- Beheaded gully and very short scarp face gully Sieh Offset: 9.4 ±0.6 m 2006 field observation: 7.8±1.0m Lidar determination: 10.8±1 m	Not found within the Sieh 1978 report Lidar determination: 11.4 ±1.0 m	Sieh, 1978: poor/fair - Offset gully - Deformation in addition to main fault slip is ambiguous because of gully geometry; minimum value, some warp. Sieh Offset: 17.4±0.6 m 2006 field observation 15.5±1 m Lidar determination 16.8±1 m	Not found within the 1978 Sieh report Lidar determination: 8.7±1 m	Sieh, 1978: good - Offset SE wall of large stream - Wall NE of fault trace may have sloughed some material since last movement Sieh Offset: 9.3±0.9 m 2006 field observation: 9.5±0.5 m Lidar determination: 12.8 m±1.0 m



63.1	63.2	63.3	64	65
Not found within the 1978 Sieh report 2006 field observation: 21.1±2 m Lidar determination: 15.9±1.0 m	Not found with in the 1978 Sieh report 2006 field observation: 10.6±1.0 m Lidar determination A= 8.9 m ±1.0m B= 25.5 m ±1.0m C=30.7 m±1.0m D=22.7 m±1.0 m T=87.7 zzzhm	Not found within the 1978 Sieh report 2006 field observation: 20.8±1.0 m Lidar determination: 21.8±1.0	Sieh, 1978: good/fair - Offset gully -Channel separated along fault - Shutter ridge in front of channel may be eroded by post 1857 run-of. Therefore this may be a minimum value. Possibility of deflection suggest that it is a max value. Sieh Offset: 8.8±0.6 m 2006 field observation 23.4±1.0 m Lidar determination 23.9±1.0 m	Sieh, 1978: fair - Very small gully drain across fault trace at 1.2m-wide bench. Bench and alluvial deposits at bench result in imprecise offset value. Sieh offset: 7.0±1.3 m 2006 field observation: 19m ±.0.5 m Lidar determination: A=6.0±1 B=20.7±1.5 m

Advanced methods for computing offset: profile cross correlation and hydrologically correct DEMs



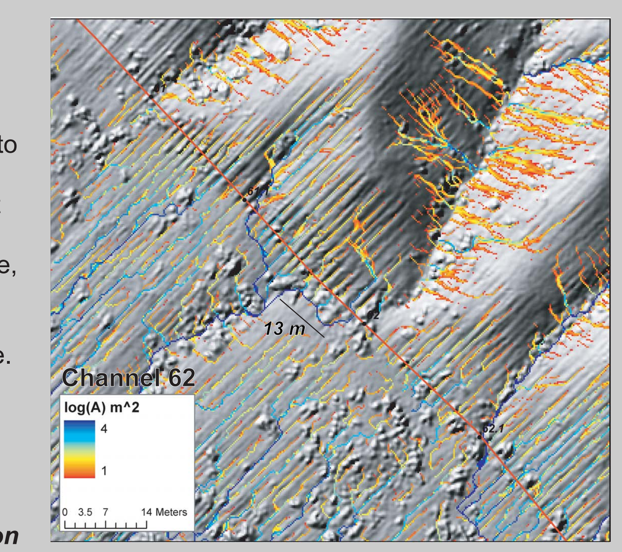


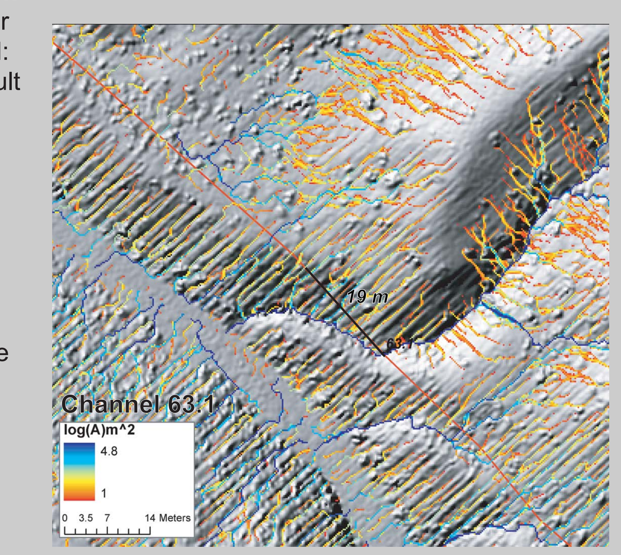
One basic idea of determining offsets is to assume that the channel was similar in profile on each side of the fault, so offset determination comes from simply matching parallel profiles. In this example, I took a 25 cm DEM from the GLW at channel 62 (see above) and extracted a profile 5 m on each side of the SAF trace. The profiles correlate best with an offset of 15 m which is similar to the 15-17 m offsets determined above.

The ***problem*** is that this approach removes the ***geomorphological intuition*** that is typically employed as the observer ponders the subtle history of the channel: Was the channel perpendicular to the fault trace prior to offset? Has it been offset more than once? (Should have been in this case.) Where is the evidence for channel development between the first and second offset?

Note also the ALSM scanner parallel grooving ("corduroy") from superposition of mislocated swaths. It has an amplitude and wavelength of 20-50 cm.

Profile matching via cross correlation follows method of Borsa, et al., 2001.





Another way to have the DEMs help the tectonic geomorphologist is to produce hydrologically correct DEMs (fill pits) and then compute drainage network parameters, such as contributing area (A). Such information should help to guide the observer in semi-automatically delineating the channel network, and thus the offsets.

In this case, I show examples from channels 62 and 63.1 on 25 cm DEMs from the GLW

Channel 62 comments:
1) Note that the network delineation is disrupted by the vegetation in the channel--indicating the need for vegetation filtering.
2) I measured an offset of about 13 m, which is about 2 m less than the other approaches.

Channel 63 comments:
1) The channel is well defined in the hillshade and in the contributing area computation.
2) I measured an offset of 19 m which is in the middle of the 15-21 m measurements from the other methods.

Conclusions

Semi-automated approaches to measurement of earthquake offsets along strike-slip faults such as the SAF using high resolution ALSM data is a promising tool for assessing fault activity, but understanding the local geomorphic history still requires careful and potentially subjective consideration. These data (and high resolution imagery) enable virtual geomorphology and enhance a true field effort. In the area of the Bidart paleoseismic site, we measured 7 m offsets and attribute them to the 1857 earthquake.

Future work

- Extend to entire 1857 earthquake reach of SAF and provide improved estimate of 1857 slip variation and moment release.
- Use vegetation-minimizing local minimum elevation binning algorithm for gridding (see Kim, et al. poster-- G53C-0921).
- Continue semi-automatic cross correlation effort and introduce uncertainty estimation. Apply longer portions of faults to estimate reach-averaged offset.
- Further idealization of landscape (half cylinders/ellipsoids to channels, etc.)
- Continue to assess utility of hydrologically correct DEMs and drainage network parameters to improve channel detection.
- Apply understanding of landscape development to simulate geomorphic modification of offset channels.

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