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HISTORIC AND PALEOSEISMIC BEHAVIOR OF THE SOUTH-CENTRAL SAN ANDREAS FAULT BETWEEN CHOLAME AND THE CARRIZO PLAIN

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Introduction

In this project, we strive to improve our understanding of the rupture potential of the San Andreas Fault (SAF) in the Parkfield-Cholame-northern Carrizo Plain area, and provide data for evaluating models of fault behavior and seismic hazard in Southern California. This is accomplished by 1) analysis of offset landforms and historic survey data along the northern portion of the 1857 rupture, 2) geologic and geomorphic mapping of the southern Cholame segment of the SAF, and 3) identification of suitable paleoseismic sites.

Logistical efforts

Access to private property along the Cholame segment of the San Andreas Fault

Property along the Cholame segment of the SAF is all privately owned. The landowners are mostly ranchers who are suspicious of the scientific investigations associated with earthquake geology. Documentation of endangered species and cultural artifacts, and illegal infiltration of their property by hunters and others has discouraged them from granting permission to access their property. Furthermore, they are concerned about future desires to preserve earthquake geology on their property by restriction of their legitimate ranching activities.

As we mapped the SAF zone in the region, we identified two sites (the Bitterwater Canyon Site and the Las Yeguas Site; see figures 1, 2, and 3). These sites turned out to be on the property of a recalcitrant landowner (Mr. P.). While we had permission to map on the property, he would not permit us to excavate (see appendix A for a documentation of the attempt). However, after more site evaluation, and a trip to the San Luis Obispo County Assessor's office, we know the property ownership and have found suitable sites (and propose to work at one--LY4--in our 1999 SCEC proposal) on property for which we have permission to work from Darrell Twisselman.

SCEC annual meeting and Fall AGU meeting

Arrowsmith, Stone, Rhodes, and Grant presented the results of this work at the SCEC annual meeting. We also presented our preliminary results at the fall meeting of the American Geophysical Union. The reference for that abstract is:

> Stone, E M, Arrowsmith, J R, Rhodes, D D, Grant, L B, Fault Zone Geometry and Historic Displacement Along the Cholame Segment of the San Andreas Fault, Southern California, EOS Transactions AGU, v. 79, p. F612.

Fault zone geologic and geomorphologic mapping

The Cholame segment of the San Andreas Fault (SAF) is the transitional zone between Parkfield segment to the north (containing both creeping and locked zones) and the locked Carrizo segment on its southern end (Figure 1). Unlike both the Parkfield and Carrizo segments, where the SAF is typically a single well-defined trace, fault strands are discontinuous within the Cholame segment and, in some places, there are multiple active traces (Figure 2). Because the northern end of the 1857 Fort Tejon earthquake ruptured through the Cholame segment, this area holds potentially valuable paleoseismic information. Careful mapping of this little-studied fault segment and the associated landforms has allowed us to interpret the geometry of the fault-zone strands and interactions among them. The complexity may indicate a difference in downdip fault surface continuity or interactions between basement rock and younger, less consolidated material near the surface.

Starting at SW 1/4, sec 22, T28S, R18E and continuing for a distance of 2 km southeast (Figure 2), the fault zone contains two parallel recently active strands. Along the next 2 km stretch farther to the southeast, the fault zone contains only one active but discontinuous strand, each trace of which strikes up to 10 degrees from the trend of the SAF, and is <1 km in length. The next 1 km to the southeast, the scarps are less sharp and the fault zone is characterized by alternating en echelon highs and lows approximately 40 m long, 20 m wide, and 2 m high adjacent to the fault. The fault zone becomes even more subdued for the next km where there is no surficial evidence for an active trace. Linear valleys and sag ponds characterize this area. In some locations, up to five valleys occupy the width of the fault.

The most prominent neotectonic landform in the central Cholame segment is an actively rising dome elongate parallel to the SAF (northwest end of the maps shown in figure 2). This structure is about 0.5 km wide and 2.5 km long; it is apparently produced by a 400-m left step between two fault strands. As the dome has risen, Bitterwater Creek appears to have slipped off its southwest limb where it has cut a canyon up to 50 m deep. On the southeast flank of the dome, Bitterwater Creek cuts through its edge, indicating that it has grown since the creek began incising.

Mapping along the central Cholame segment has yielded several possible sites for paleoseismic trenching and measurement of offset (Figures 1, 2, and 3). All sites are located on active alluvial fans emanating from the Temblor Range. Alluvial deposits at Bitterwater Canyon interfinger with fluvial sediments from Bitterwater Creek. At the

LY4 site, the right-stepping SAF cuts an alluvial fan that abuts a 100-m-long ridge. A 1-m-high scarp is evident along the most recently active trace. The Las Yeguas fan terminates in a poorly drained depression that may have accumulated peat. The southern Cholame site is at the proximal end of a fan and therefore should only contain its alluvial deposits. Paleoseismic and structural data collected on this segment will allow better characterization of the earthquake potential of the south central San Andreas Fault zone.

1857 coseismic and post 1857 postseismic and interseismic displacement of monuments near the San Andreas Fault

Introduction

Reliable surveys were conducted of two section corners in 1855 and 1979 which crossed the Cholame segment of the San Andreas Fault (T27S, R17E, sec 5 NW corner and north 1/4 of section 4; see Grant's progress report). The last earthquake along this segment occurred on January 9, 1857. Therefore, after correcting for the accuracy of the surveyors, the fault parallel component of displacement of the two corners can be attributed to a combination of coseismic, interseismic, and postseismic motion (7.8 to 8.1 m).

Coseismic displacement

Knowledge of the 1857 displacement distribution will permit us to test models for fault properties and to anticipate the magnitude and timing of the next large event along the structure. We have compiled all available 1857 offset data for the Cholame and Carrizo Plain area and have compared those data with models for the slip associated with variable stressdrop on variable depth and length fault surfaces (Figure 4). As more data are collected (such as the displacement of monuments discussed below) these models provide a means of interpretation. The depth of microseismicity increases from the Cholame segment to the Carrizo segment [e.g., Hill et al., 1990] so we tested the hypothesis that the apparent decrease in slip to the north is purely geometrically driven versus it being the result of a difference in stress drop which could reflect a difference in strength or loading history. Inferences of higher offsets along the Cholame segment imply that the stressdrop ratio between Cholame and Carrizo is close to 1 (Figure 4).

Interseismic displacement

To estimate the effects of interseismic motion, we determined the displacement field at the surface from a vertical screw dislocation buried at depth D in the lithosphere. Interseismic motion is modeled as slip from the base of the depth of coseismic faulting (also D) to $-\infty$; whereas, coseismic motion is modeled as slip confined to the upper portion of the fault from the surface to a depth of D. Thus, interseismic motion can be determined and corrected for using equations for this boundary value problem which describe the fault parallel displacement rate [$du_x(y)/dt$] and shear strain rate [$de_{xy}(y)/dt$] [Thatcher, 1990].

In order to determine the interseismic movement of the two corners surveyed, we measured the distance perpendicular to the fault (y). The distance was 0.636 km for the NW corner of section 5 and 1.248 km for the north 1/4 section 4. We must account for only 122 years of interseismic movement. Using the lower limit of microseismicity from Hill et al. [1990], we estimate the locking depth of the Cholame segment (D) to be 15 km. We determined the interseismic displacement to be 0.058 m for the NW corner of section

5 and 0.113 m for the north 1/4 section 4. The total interseismic displacement is therefore 0.2 m, and the 1857 coseismic displacement is 7.6-7.9 m.

Postseismic displacement

The calculations of interseismic displacement assume a constant interseismic strain rate since 1857. However, these results are minimum because of the observation of a higher postseismic strain transient which has been shown to exponentially decrease with time until reaching the interseismic rate after large earthquakes [Thatcher, 1983]. The increased postseismic rate is a result of stress relaxation after the earthquake and is attributed to slip along the fault below the locked fault surface or flowing aesthenosphere. This accelerated slip will always contribute to accelerated displacements even near the fault at the surface.

In order to correct for this increased amount of postseismic displacement, we can empirically determine the exponential decay of shear strain rate based on data from Thatcher (1983) which will have the form of $de_{xy}/dt = be^{-ct}$. If we integrate this equation over the elapsed time since the last earthquake (122 yrs), we get the accumulated total shear strain. We fit the data several different ways to determine the constants b and c. We used a best-fit curve, an approximation of the Thatcher best-fit curve, and enveloping minimum and maximum curves. Multiplying the total strain by the aperture of the two points perpendicular to the SAF (1.884 km) yielded a total displacement since the last earthquake ranging from 0.17 to 0.42 m.

Discussion

Note that the postseismic correction is greater than but consistent with the interseismic correction presented above. Grant and Donellan [1994] used a strain rate determined from the geodetically-defined velocity field in central California as presented by Lisowski et al. [1991] to determine a correction of 0.1 m for their Carrizo Plain study. The results we present here are consistent with that result. We expect a higher interseismic displacement correction for the Cholame segment because of its shallower locking depth. Furthermore, the geodetic data collected by Lisowski et al. [1991] were measured after the postseismic strain rate had decayed to the interseismic rate and thus would provide an underestimate of accumulated strain if that rate were applied for the entire time since 1857.

Conclusion

Our calculations of postseismic and interseismic displacement range from 0.2 - 0.4 m. Therefore the total 1857 coseismic displacement of the two corners is probably 7.4-7.9 m. Furthermore, similar magnitudes of stressdrop for the Cholame and Carrizo segments are implied for the 1857 earthquake.

References

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Appendix A. Documentation of landowner negotiations (written by Arrowsmith)

13 May, 1998: Stone and Arrowsmith reconnoitered the southern portion of the Cholame segment for a couple of days during spring break. I wrote a letter with assurances from the ASU Risk Management people to the landowner of the Bitterwater Canyon site and then followed up with a call, but the bad news is that he did not want to give us permission to trench there. He (Mr. P.) was quite supportive of our work in general last year so we were not expecting a flat out no.

3 July 1998: We sent Mr. Twisselman a letter about our plan for the Las Yeguas marsh site and he said that it is Mr. P.'s property. So I called Mr. Twisselman and talked with him and he was pretty nice and supportive, but he indicated that Mr. P. could be difficult. So then I called Mr. P. and told him the story and asked him if he would reconsider. He said that he just did not want to get into it. He said that he was concerned about getting lots of government agencies involved and that he had seen too many of his friends and neighbors get burned and so he was gun shy. I told him that we were a low maintenance operation and that we weren't interested in endangered species and so on. He said he understood, but then we would publish our findings and then he did not know where that would lead down the line.

December 18, 1998: I called Mr. P. on the morning of December 18, 1998. I had been trying for a few days even though I found calling him a bit intimidating. I was happy to reach him. He was reasonably cordial. I said that we had been continuing our mapping in the area and had concluded that the sites along the fault on his property were still the best. I said that we thought that these sites would give us a good opportunity to document the timing of the last events along the SAF in the area and that would help us to understand the earthquake hazard for much of Southern California. I also said that I recalled that he had some concerns about our proposal to work on his property the last time and that we had come up with a character reference in Leonard Bidart as someone with whom one of us (Lisa Grant) had worked in the past successfully. I pointed out that Leonard had been contacted and was willing to speak with Mr. P. and that Bidart did not have anything at stake in this situation and so should give a pretty unbiased opinion. To conclude my initial remarks, I also said that we could arrange to provide him a substantial lease fee.

At that point, he stopped me and said that he was just not interested in having a lot of people on the property. He said that the way that the government was going these days, he just did not feel comfortable with it. He was concerned about the interest that the government had in endangered species and cultural artifacts. I mentioned to him that we had no interest in those subjects and that he would be able to dictate the terms of our use of his property. He said that he just was not interested. He thought that the geological work that had been done in the Carrizo and up at Parkfield was sufficient. I told him that the sites we had selected were in a critical 60-70 mile gap and that the key problem was the relationship between events at Parkfield and at Carrizo. He still would not budge. I pushed on him some more. He had referred to the "Government" and "University Research" as things that he did not trust and thought were too involved in things they should not be. I said that we were people and not nameless institutions. He said he knew that but that he had seen too many situations like this start off quite cooperatively and end in disaster.

So I thanked him and said that we could continue to work out there and that we would always have an interest in those sites and that we hoped he might change his mind sometime.

Figures

Figure 1. Important sites along the Parkfield, Cholame, and Carrizo segments of the SAF. Note the 73 km between the existing paleoseismic sites in the Carrizo Plain and the Watertank site of *Sims* [1987]. The Bitterwater Canyon, LY4, Las Yeguas, and Southern Cholame sites, among others, have been investigated for their suitability for paleoseismic investigation (green). James E. Freeman surveyed township boundaries from township 24 south to 32 in 1855 and 1856 (shown in blue), and *Grant and Donnellan* [1994] recovered original monuments from that survey spanning the SAF in the Carrizo Plain near Wallace Creek. The intersections between the state highways in the area and the SAF are shown. The background is from the 1:750,000 scale state geologic map [Jennings, *et al.*, 1977].

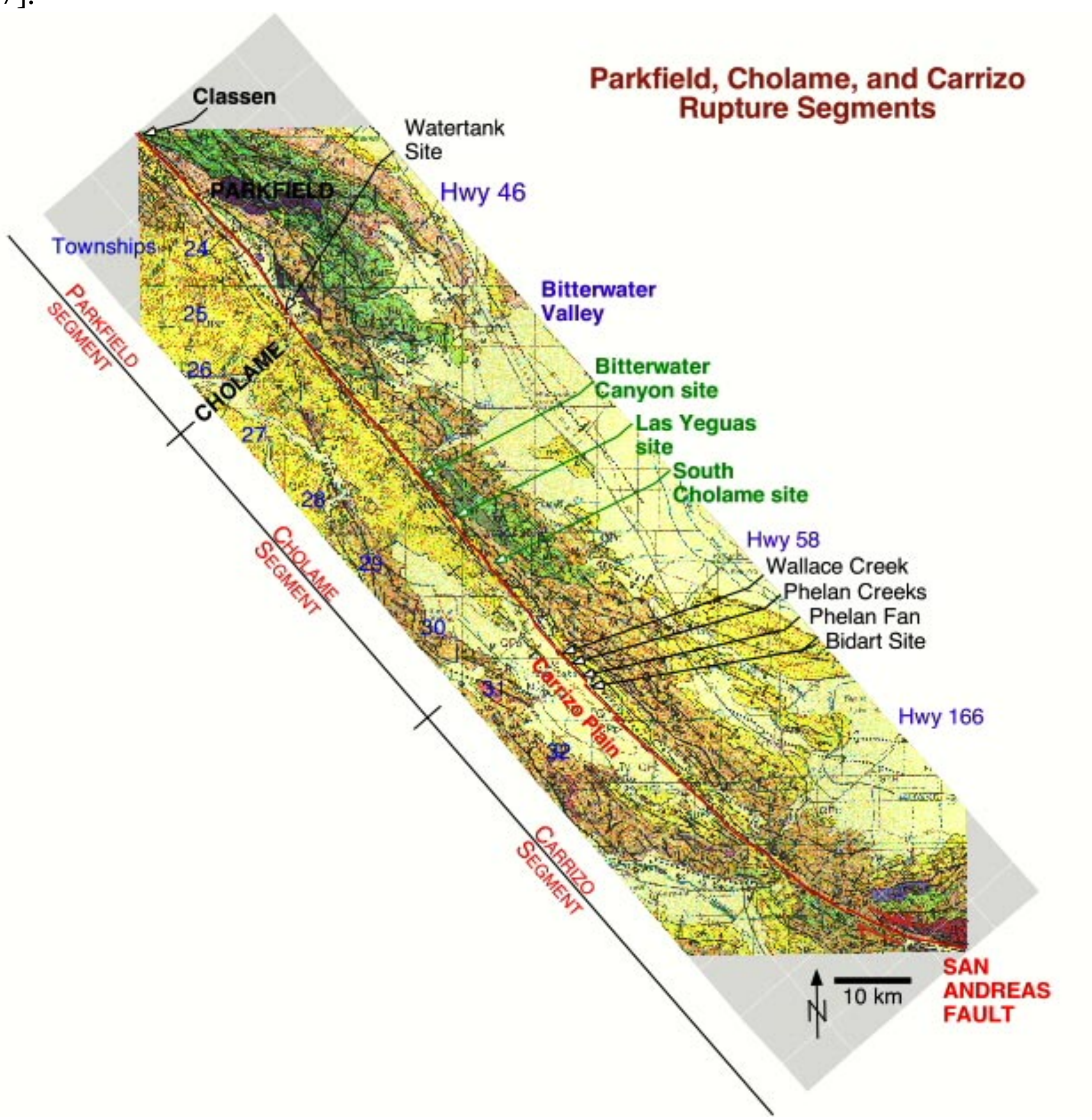
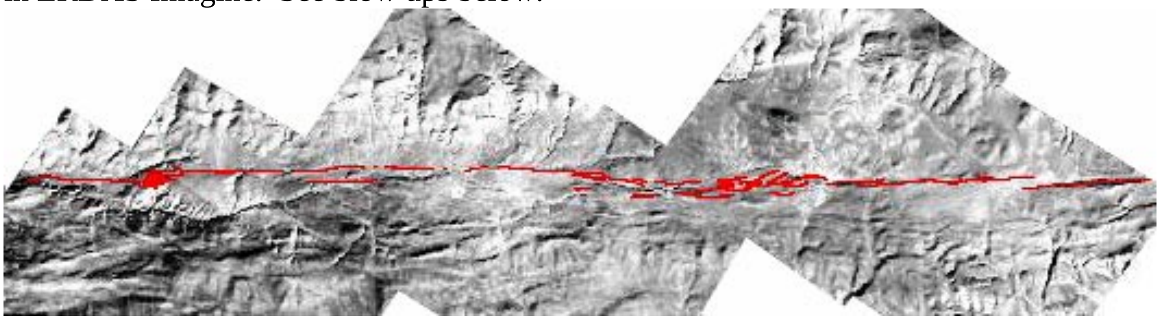
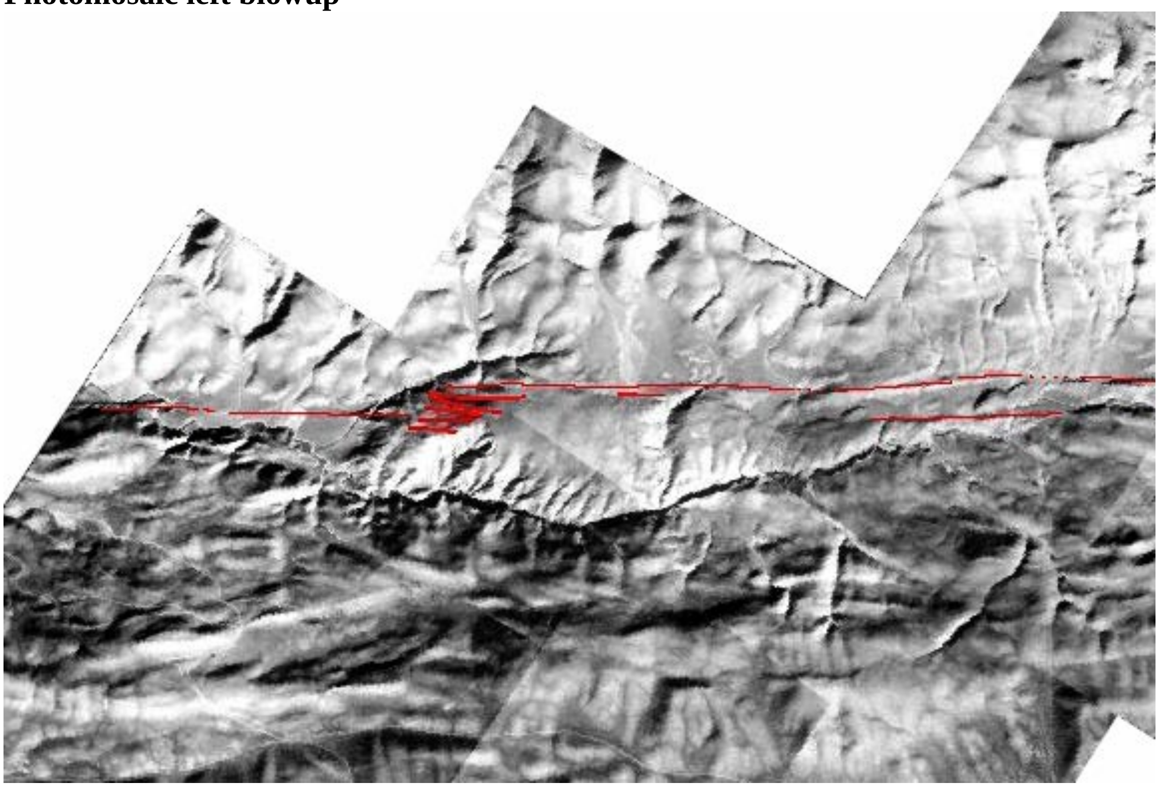


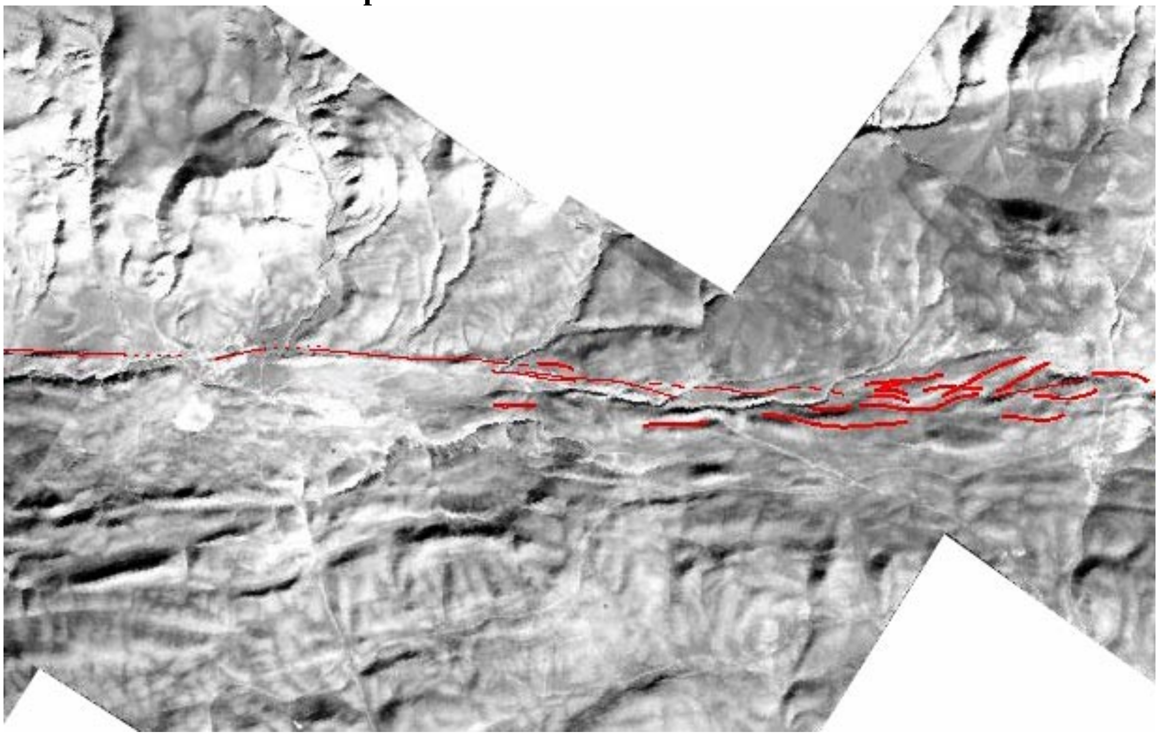
Figure 2. Photo mosaic and geologic map of southern Cholame segment of the San Andreas Fault. Linework from field mapping on the aerial photos was heads-up digitized in Imagine and cleaned in ARC/INFO. Coverages were compiled into the final map using Arcview and the USGS program A-la-Carte provided symbology. The photos for the aerial photo base were provided by the Fairchild Collection at Whittier College. They were rectified against the topographic maps in ERDAS Imagine. See blow ups below.



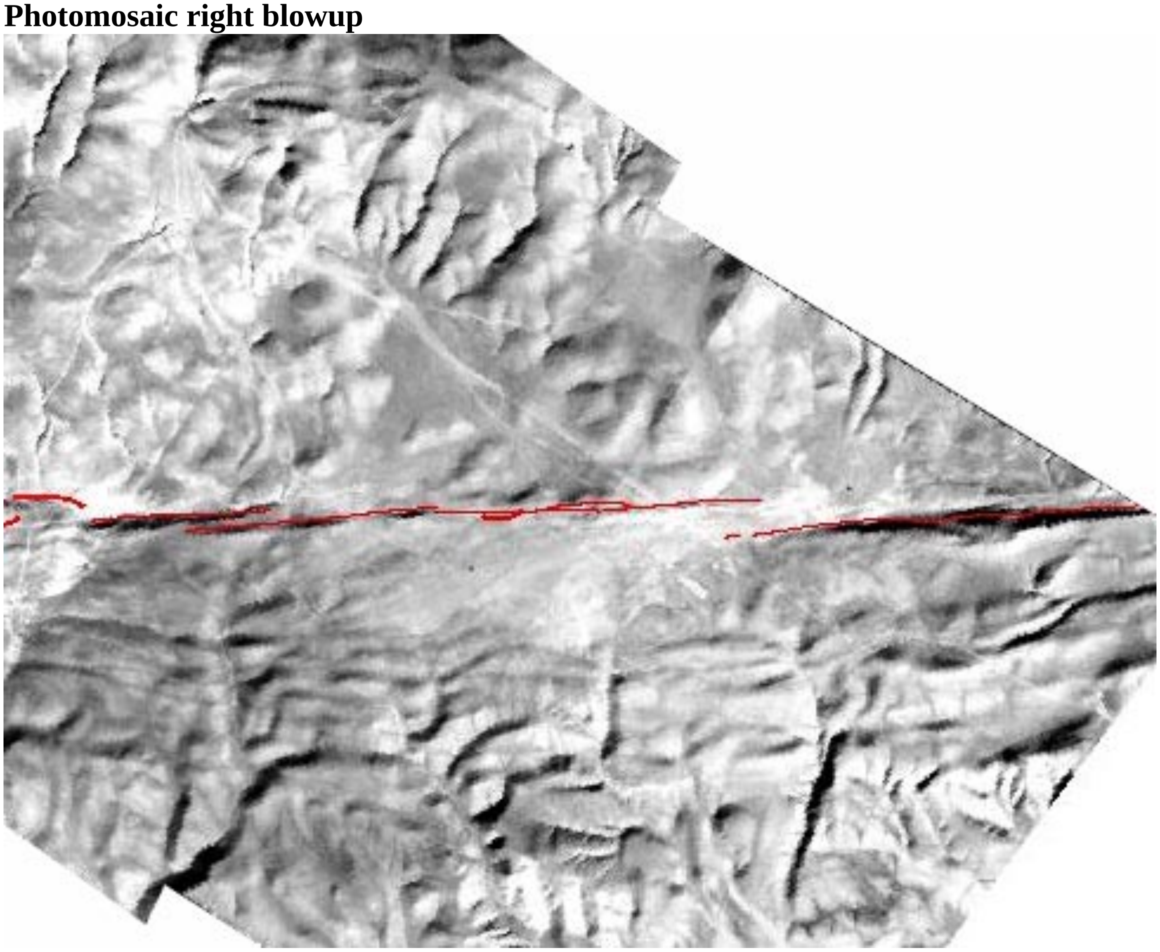
Photomosaic left blowup



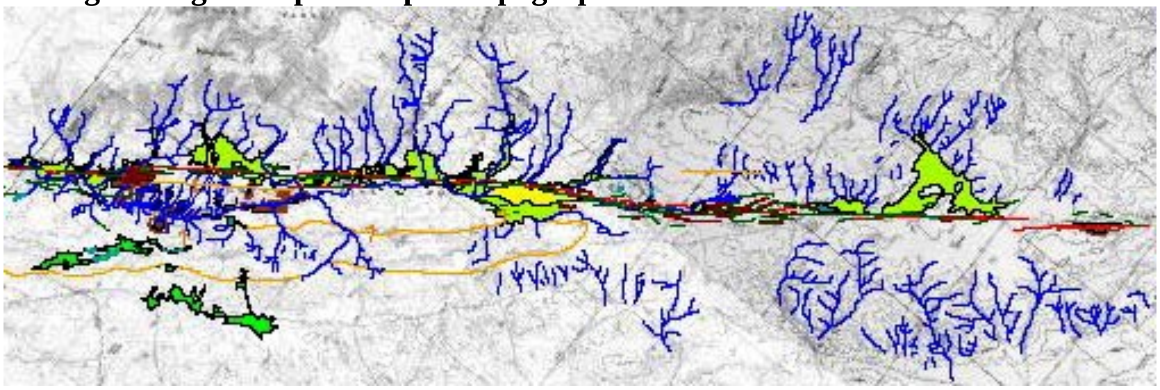
Photomosaic center blowup



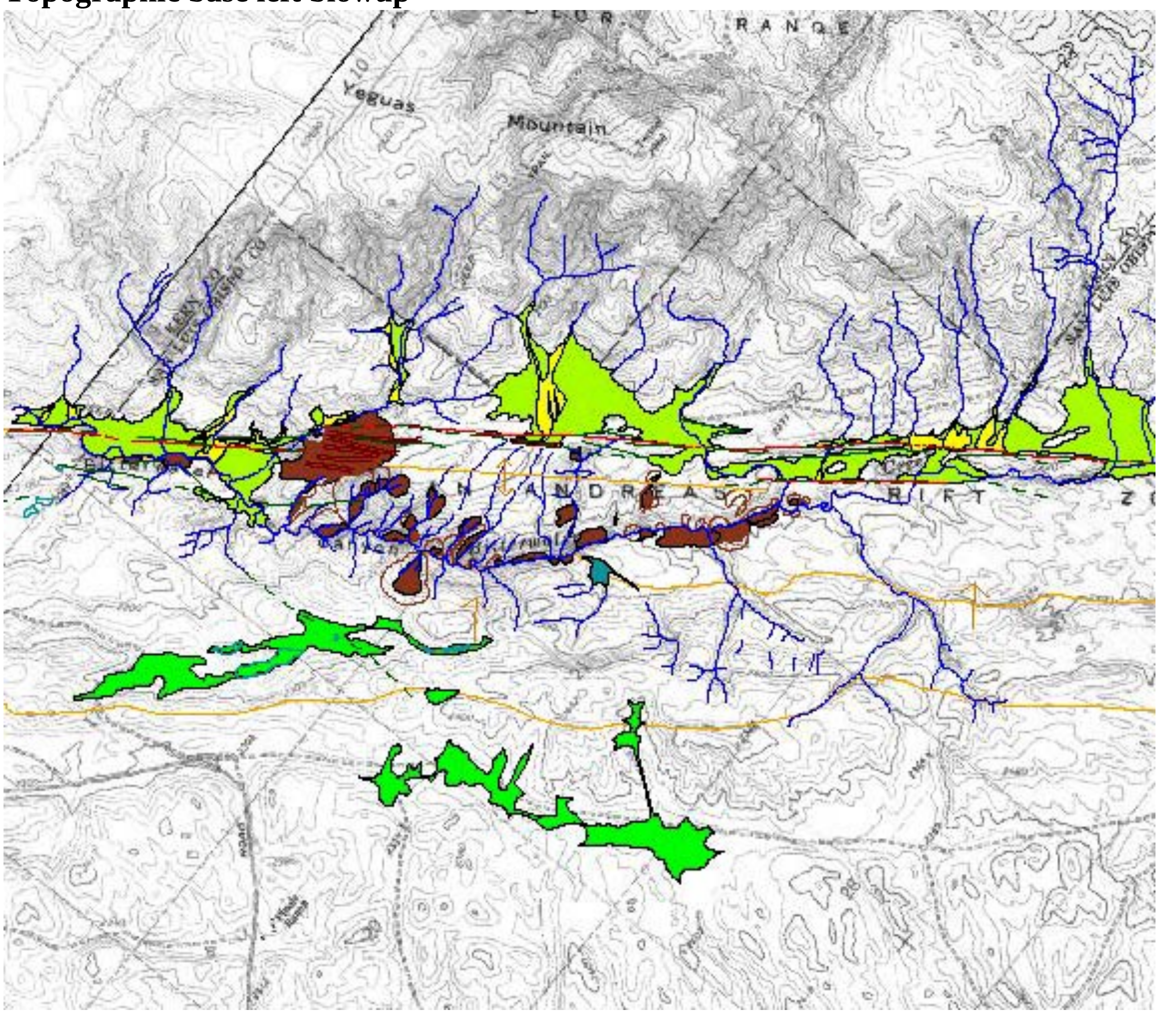
Photomosaic right blowup



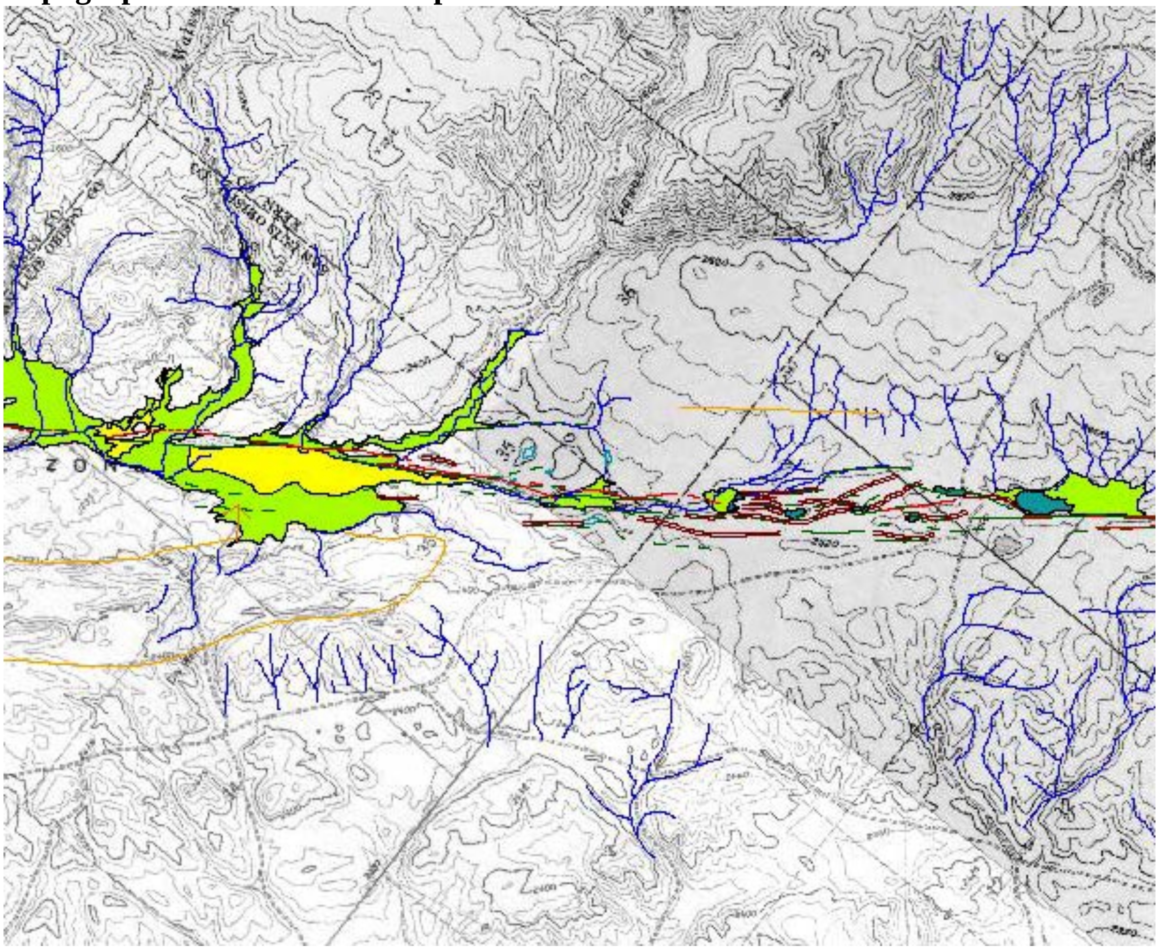
Geologic and geomorphic map on topographic base.



Topographic base left blowup



Topographic base center blowup



Topographic base right blowup

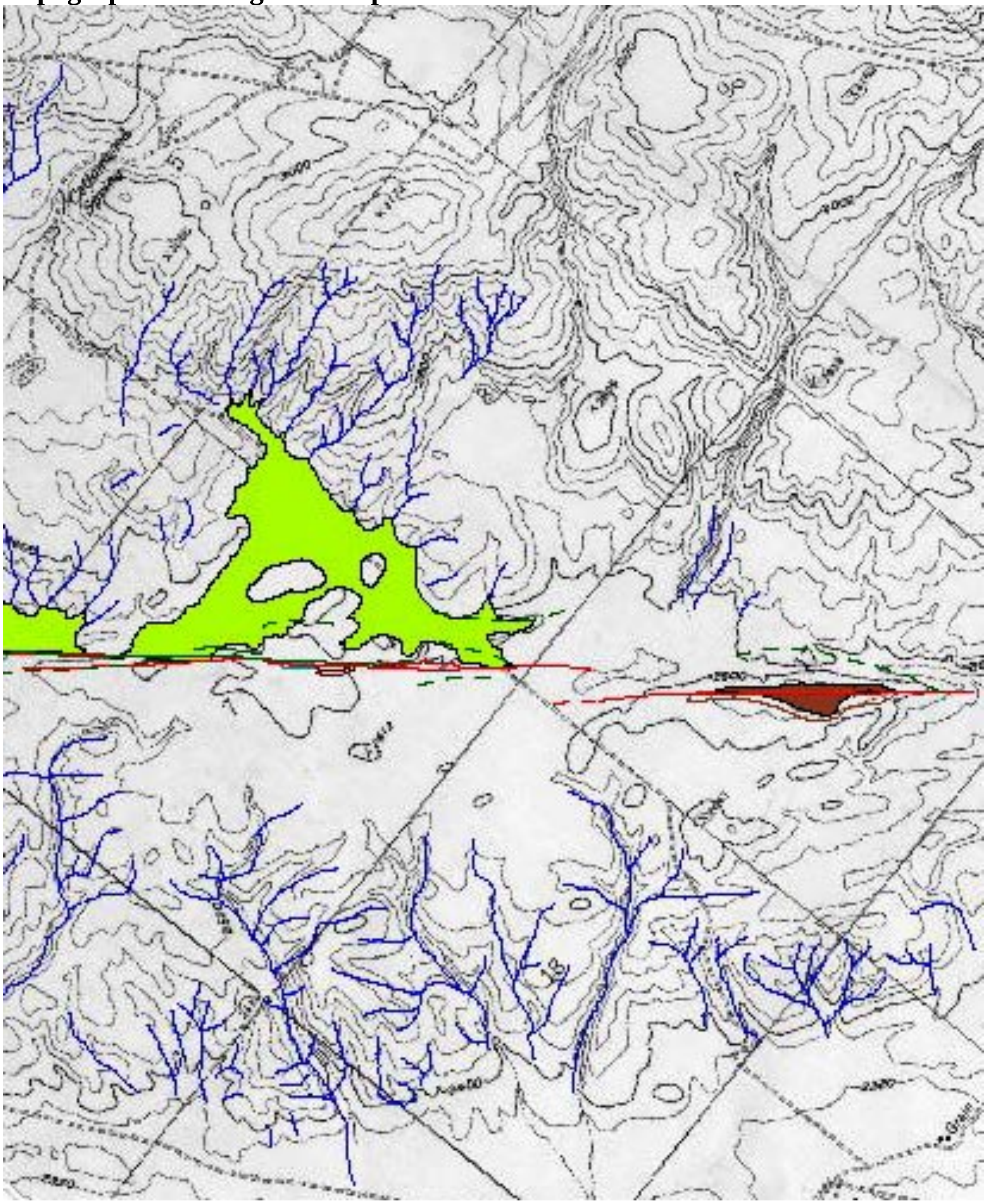
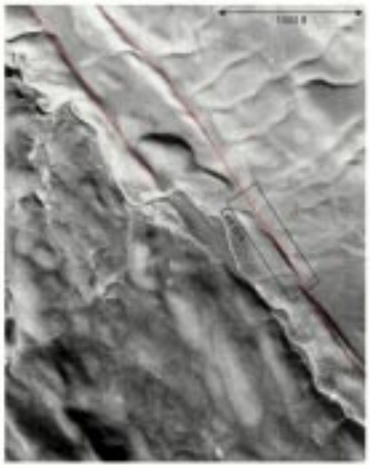
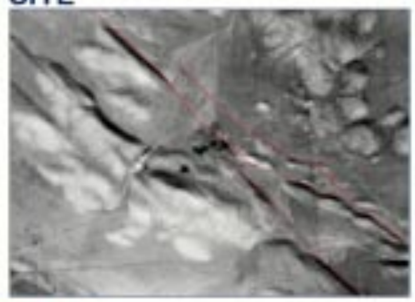


Figure 3. Potential paleoseismic Sites. We now have permission to work at LY4 and the south Cholame sites. See figures 1 and 2 for locations of these sites.

LY4



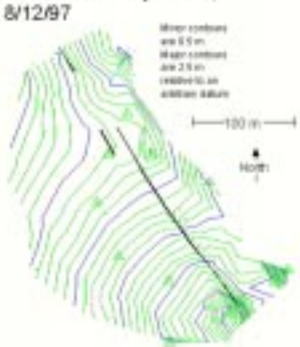
SOUTH CHOLAME SITE

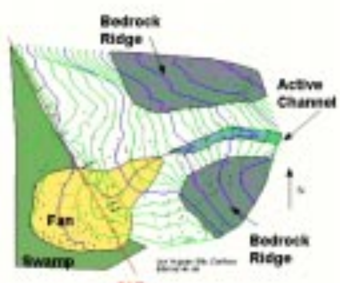


BITTERWATER CANYON SITE

LAS YEGUAS SITE

Bitterwater Canyon site, 8/12/97





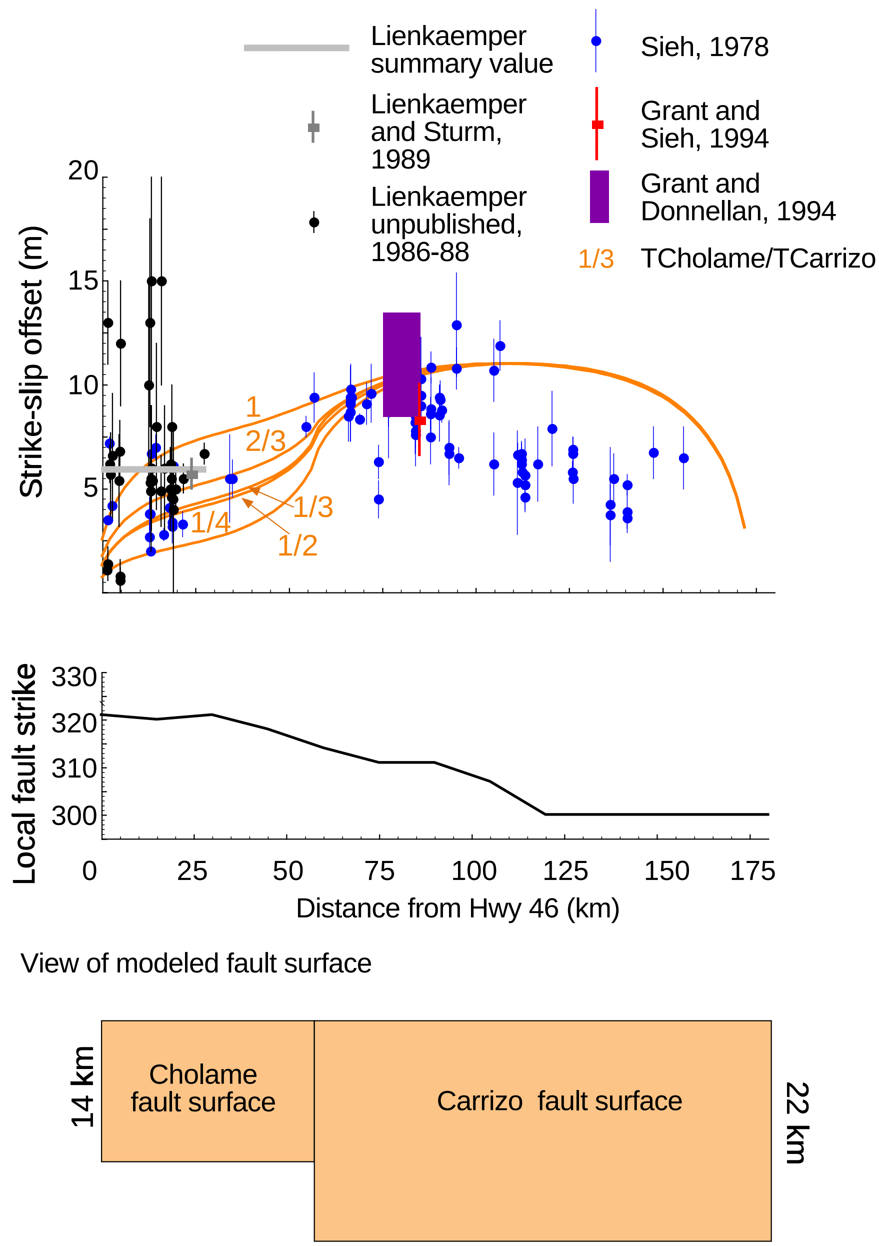


Figure 4. Offset data for the Cholame and the Carrizo segments compared to offsets modeled with variable stressdrops (T) on the two segments. The curve for TCholame/TCarrizo=1 shows the effect on the slip distribution of the deepening fault zone alone. As the strength of the Carrizo segment relative to that of Cholame increases, the segment boundary becomes more clearly defined by the change in offset. The model does not fit the data on the southeast end of the Carrizo segment because the San Andreas fault trace geometry changes as it enters the Big Bend and the loading geometry changes (unlike the constant strike of the of the modeled fault surface). Strike-slip offset would be expected to decrease in this area characterized by an increase in the compressive normal traction and a decrease in the shear traction along the fault surface. This frictionless model was run using DIS3D Erikson, 1987) and used a constant stressdrop for each fault segment. Modeling mesh size was 2km x 2km.