Three-dimensional excavation of the San Andreas Fault at the Burro Flats Paleoseismic site near Banning, California.

Clay Stevens, *Department of Geological Sciences, California State University, Northridge, California 91330-8266*

ABSTRACT

Evidence from trenches opened in 1999 at Burro Flats suggested that the San Andreas fault at San Gorgonio Pass has remained dormant since about A.D. 1450. However, the 1999 trenches exposed a limited area of a complex, 150-m-wide stepover basin and may have missed evidence of more recent event(s). This summer an expanded trench network was excavated to search for evidence of more recent events. The new trenches show clear evidence of post-A.D. 1450 faulting and folding. The focus of my SCEC internship has been to construct contour maps of marker horizons and isopach maps of the intervening strata deposited in the last 550 years. Three marker horizons have been mapped over an area of about 1000 square meters. Marker horizon 84, near the base of the 550 year-old section, is faulted and folded into a syncline-anticline-syncline triad with a maximum structural relief of about 1.5 m that diminishes gradually to <0.25 m from south to north. Horizon 85, in the middle of the section, is not faulted and shows a maximum structural relief of about 0.6 m that also diminishes to the north. Horizon 88, near the top of the section, shows structural relief of 0.3 m or less. The modern ground surface is undeformed, dipping uniformly toward the southwest perpendicular to the fault. Sediment above horizon 85 is interpreted to have buried the folds and minor faulting that formed during the most recent event. Horizon 84 drapes a paleo-surface created by the penultimate event. The greater structural relief of horizon 84 is therefore attributed to deformation from both the most recent and penultimate events. Age data constrain the most recent event to between A.D. 1500 and 1800 and the penultimate event to between A.D. 1400 and 1550.

INTRODUCTION

The Burro Flats paleoseismic site is located midway between segments of the San Andreas fault with distinctly different paleoseismic records. To the northwest, the Cajon Pass region(Fig. 1) was the terminus of the 1857 Fort Tejon earthquake (Sieh, 1984). The most recent event here was the 1812 San Juan Capistrano earthquake (Seitz and others, 1997). It was not determined how far the 1812 event propagated south on the SAF. Average recurrence intervals at Wrighwood and Pallett Creek are about 125 to 140 years (Sieh and others, 1989; Fumal and others, 1993). In contrast, Indio to the southeast (Fig. 1) has an average recurrence of about 250 years and the most recent event recorded is about A.D. 1680 (Sieh, 1986). This apparent difference in fault behavior suggests that some sort of segment boundary occurs in the vicinity of Burro Flats. Furthermore, the current period of dormancy for both the Cajon Pass and the Indio segments of the fault suggest that the next large SAF earthquake seems to be overdue here.

Burro Flats is located within a structurally complex zone on the SAF in the San Gorgonio Pass (Fig. 1). At Burro Flats the SAF consists of a series of right lateral stop-overs and pull-apart basins (Fig. 2). The trench site is located within one of these basins. Evidence for earthquakes in the trenches is a series of short en echelon stepping faults segments and folds over and a broad 150-m-wide zone of folding (Fig. 3). A three-dimensional network of trenches was therefore required in order to constrain the paleoseismic record at Burro Flats.

The goal of my SCEC internship was to construct a three-dimensional fence diagram, surfaces of important layers, and to construct isopachs of the intervening strata. Raw data was gathered in the field by surveying and logging the trenches that were excavated across the SAF. This data was analyzed using computer drafting and GIS.

METHODS

Field

Work in the field started with expanding the topographic base map to include the area that was going to be trenched this summer. This was done using a total station and a stadia rod with a reflective prism. A total station works by aiming a small telescope mounted on a tripod towards the reflective prism and then shooting a laser out of the front of the telescope. This laser beam is then reflected back and the total station calculates the coordinates (easting, northing, and elevation) of the point occupied by the prism (and the stadia rod). The total station's onboard computer calculates the coordinates of the survey point by using the horizontal azimuth, vertical inclination angle, and the two way travel time of the laser. This area, a thicket of willow trees and poison oak, was not surveyed last summer. Lines of site were cut through the thicket to survey the topography. Once surveyed, a bulldozer cleared the trees to make way for the track hoe that was used to excavate this summer's trenches (Fig. 3).

A track hoe with a 1.2 m (4 ft.) wide bucket excavated the trenches. Trench six, located directly to the south and parallel to last years trench three is about 2 m deep, 20 m long, and 1.2 m wide. Trench five, to the south and parallel to trenches three and six, is 3.5 m deep and benched in order to prevent caving. Trench seven was excavated along a northwest-trend to a depth of about 2 m and connected trenches three, five, and six.

Some walls partially collapsed immediately after the trenches were dug because of the shallow water table in the marsh and the unconsolidated nature of the sediment. This was most problematic in trench five, where the water table was shallowest, at the northern edge of the wettest part of the marsh. Channels were dug in the bottom of the trenches to get the water to flow westward into a beheaded stream valley to the southwest. Then we scraped the trench walls with hoes and shovels to remove the effects of excavation. At this point rough interpretations of the stratigraphy and structure were made. Next, we placed painted nails into the walls along prominent layers and structures (Fig. 4). A dense coverage of nails was used around structurally complex regions. Discussion and revision of interpretations continued.

We then set up the total station at the end of one of the trenches in a place where most nail heads were visible and then surveyed each one of the nails. Two people were needed to complete this task: one person to hold the prism on each nail head and mark which ones were surveyed, and one person to operate the total station. Survey data for each trench wall was stored in a separate data file in the total station (separating upper and lower walls if the trench was benched). Once surveyed, the data files were converted to comma-delimited-text files in the total station and stored on the on-board PCMCIA-flash-RAM card. A map view of each trench wall was plotted in ArcView™. Cross-sections were made of each trench wall by plotting the elevation vs. the easting. Data for some trenches had to be first rotated into an east-west trend. Cross-section views of each trench wall were plotted and printed at a scale of 1:20. The points were transferred gridded mylar sheets. The nails in the trench wall matched to point pattern on the map sheet and the stratigraphy was logged.

Lab

Prominent peat layers 84, 85, and 88 were digitized from the scanned field logs. A three-dimensional fence diagram was then created to show the layers through all of the trenches. Contours of the layers were made from the digitized data. Isopachs of the intervening sediment was made from the contours. A generalized list of the entire procedure is given below.

1. Scanned and tiled field logs.
2. Computer drafted prominent layers .
3. Rectified exported image.
4. Created lines in GIS over rectified image.
5. Projected lines onto digital surface of trench wall (Fig. 5).
6. Extracted easting, northing, and elevation from points along line.
7. Plotted all lines in three dimensions for fence diagram (Fig. 6).
8. Created surfaces of horizons using extracted coordinates.
9. Subtracted lower surface elevations from upper surface elevations to create

isopach maps.

DISCUSSION

From the data that was collected in 1999, the most recent event at the site was loosely constrained to horizon 84 or younger. After all of the trenches were logged in 2000, the variation in deformation in layers above 84 still was not easy to discern from the trench logs directly. For this reason contour maps and isopachs were made on horizons 84, 85, and 88 (Fig. 7) to better constrain this most recent event. The contour and isopach maps reflect changes in the paleo-ground surface with time . Determining whether or not two layers are deformed by the same amount or not when looking at separate trench logs for each wall can be very difficult. That is when this type of analysis can prove to be very helpful.

After analysis of the isopach between 84 and 85 it was apparent that there was evidence for an earthquake after the deposition of 84 (Fig. 7). This event horizon occurs just beneath 85. There is no evidence for younger events. All younger strata above 85 are either draping the deformed surface or filling in the basins between the anticlines. The sediment that is filling in the basins above 85 is not back-tilted or deformed. Whether the sediment was actually deformed or just draping a deformed surface was based on the type of process that deposited the sediment. Wind-blown, fine-grained sediment was evenly deposited over a deformed surface. Peats and soils also will drape pre-existing topography. Though the topography of these post-event strata is irregular, tectonic forces have not deformed them. In contrast, debris flows do not drape existing topography evenly, they tend to fill in the basins between the highs (anticlines), or cover the entire surface such that the topography of these deposits will be flat and inclined slightly downhill. If the top surface of a debris flow was back-tilted upslope or concave then the debris flow was interpreted as having been deformed by a seismic event.

Trench 5 shows a syncline-anticline-syncline growth fold - the older underlying strata are clearly more deformed than younger overlying strata (Fig. 8). A fault in trench five on the north edge of the anticline terminates at the base of layer 85 (Fig. 8). This fault is one of the short en echelon faults within the trans-tensional basin and can only be seen in trench five.

The amount of structural relief is not consistent throughout all of the trenches - an indication that structural features at this site change quickly along trend. The trenches are located on the west-terminus of one of the right lateral stepovers (Fig. 3). Within and to the south of the trenches a series of en echelon faults transfer slip to the next northern primary trace of the SAF. The structures in the trenches become less pronounced to the north, probably due to slip transfer to the northern stepover-bounding segment. Deformation in the southern trenches is more apparent than in the northern trenches.

Final interpretations this summer are that layer 85 records deformation of the most recent event and that layer 84 records deformation of the recent and penultimate events (D. Yule, personal communication). Radiocarbon dates constrain the most recent event to A.D. 1500 to 1800 and the penultimate event to A.D. 1400 to 1550 (D. Yule, personal communication).

CONCLUSION

The paleoseismic data gathered during the summer of 1999 and 2000 overlap with the event record at Indio. These data suggest that the Burro Flats and Indio sites may rupture together . The Burro Flats record does not appear to match the paleoseismic record established near Cajon Pass. Therefore, a segment boundary probably lies to the northwest between Burro Flats and Cajon Pass.

ACKNOWLEDGMENTS

Thanks to Caryn Howland, and Joseph Koo for their assistance. Christopher Madden and Ashley Streig, both of you were a lot of help, and neither of you got paid! And finally thanks to Dr. Doug Yule for approaching me with this great opportunity.

REFERENCES

T.E. Fumal, S.K. Pezzopane, R.J. Weldon, II, D.P. Schwartz, Science, 259, 199-203 (1993). K. Sieh, J. Geophys. Res., 95, 7641-7660 (1984).

K. Sieh, EOS, 67, 1200 (1986).

K. Sieh, M. Stuvier, D. Brillinger, J. Geophys. Res., 94, 603-623 (1989).

G.G. Seitz, R.J. Weldon, II, G.P. Biasi, J. Geodyn., 24, 129-138 (1997).

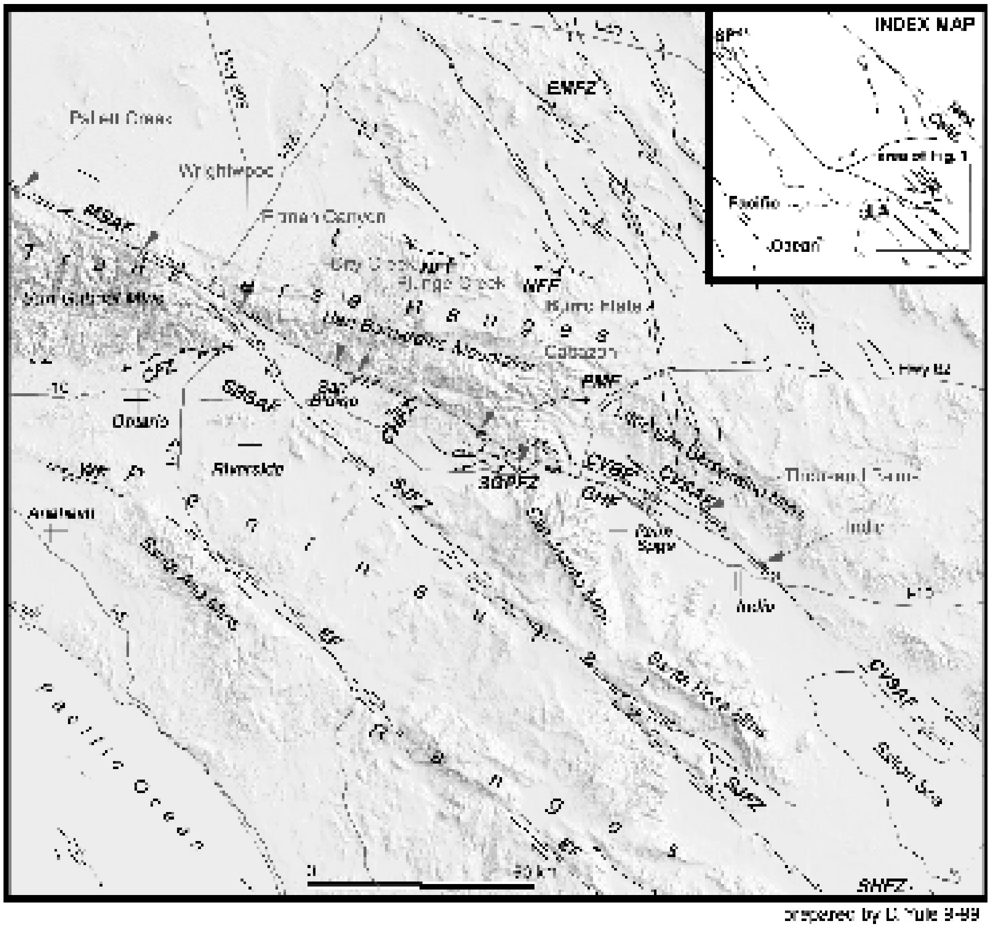

Figure 1. Shaded relief map of the eastern Transverse and northern Peninsular Ranges, southern California. Red arrows show the locations of paleoseismic sites along the San Andreas fault system in this region. Only Holocene faults are shown (modified from the CDMG Fault Activity Map, 1994). Fault shown include CFZ - Cucamonga fault zone; CHFZ - Crafton Hills fault zone; CVBF - Coachella Valley segment, Banning fault; CVSAF - Coachella Valley segment, San Andreas fault; EF - Elsinore fault; EMFZ - Eastern Mojave fault zone; GHF - Garnet Hill fault; MSAF - Mojave segment, San Andreas fault; NFF - North frontal fault; PMF -Pinto Mountain fault; SBSAF - San Bernardino strand, San Andreas fault, SGPFZ - San Gorgonio Pass fault zone; SHFZ - Superstition Hills fault zone; SJFZ - San Jacinto fault zone; and WF - Whittier fault.

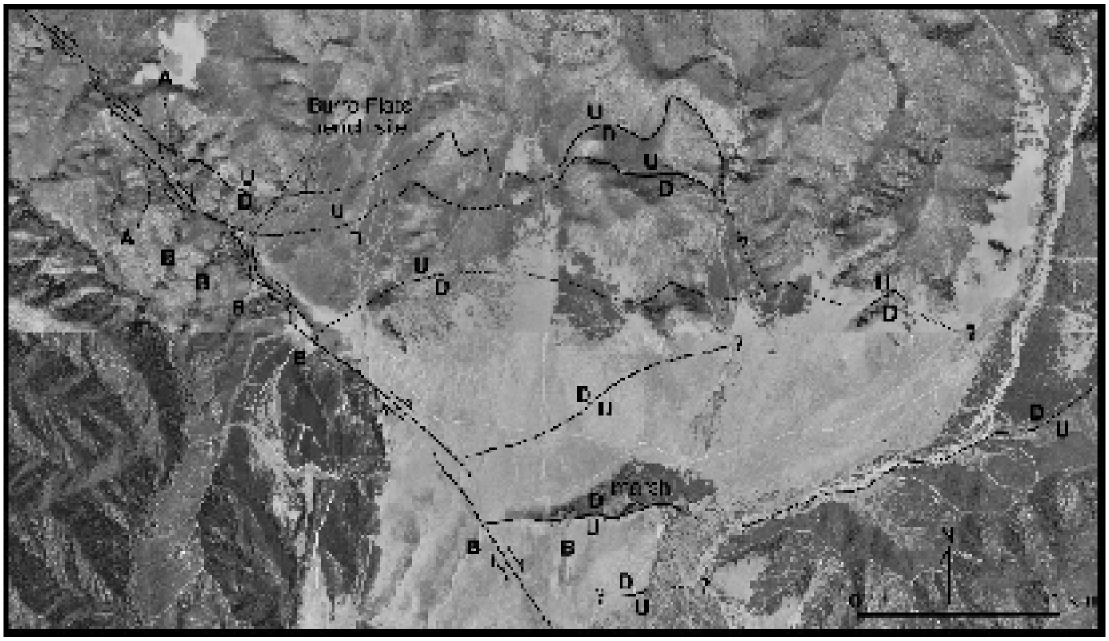

Figure 2. Orthophoto quad showing local faulting and right lateral stepovers along the SAF. SAF starts at lower center of photo and continues to the upper left. D - down thrown block, U - up thrown block.

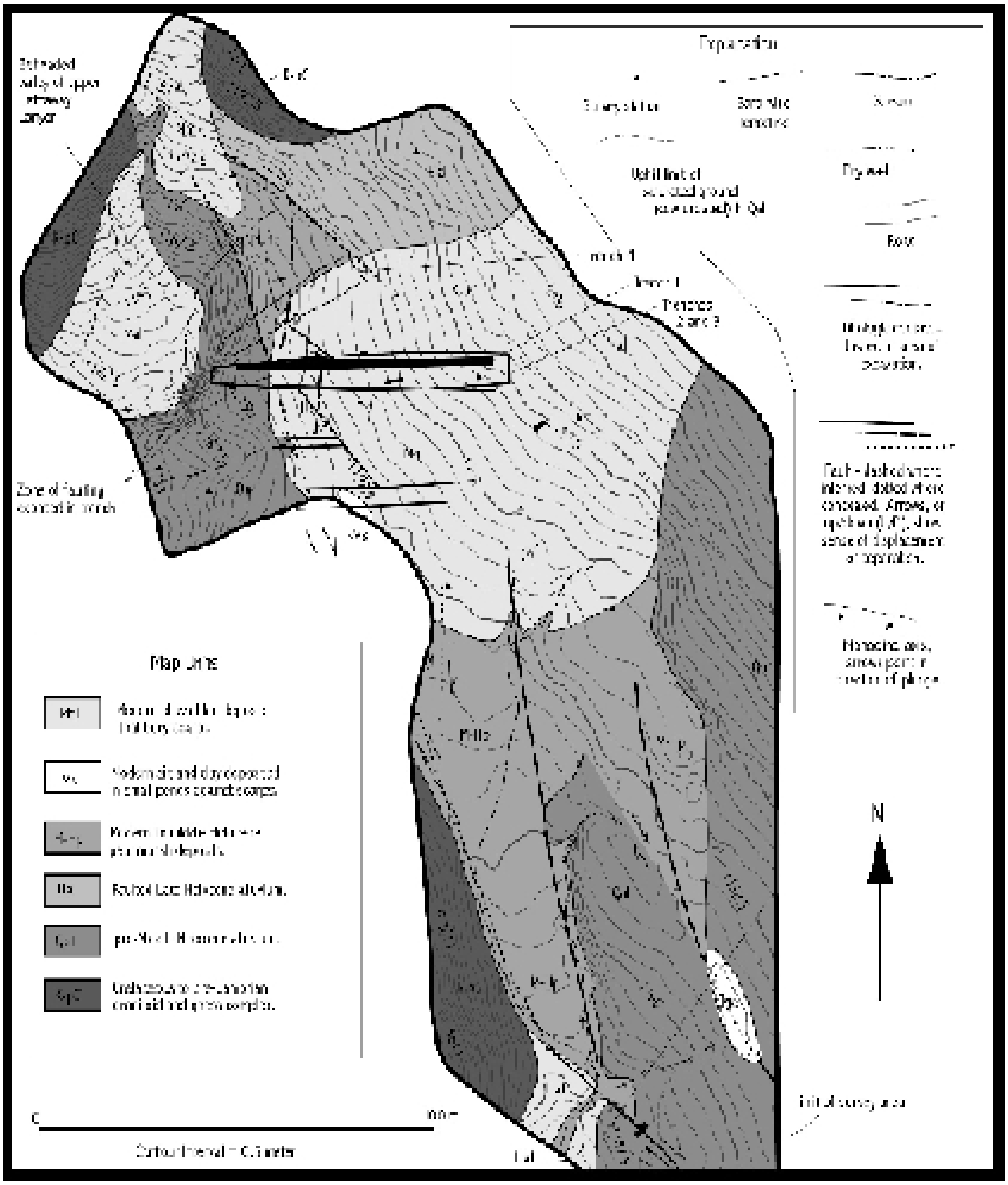

Figure 3. Site map showing geologic units and location of trenches within a transtensional basin. Main branch of SAF coming in at lower middle of picture. Series of en echelon faults that peel off main fault and transfer slip to the next segment of the SAF located to the northeast.

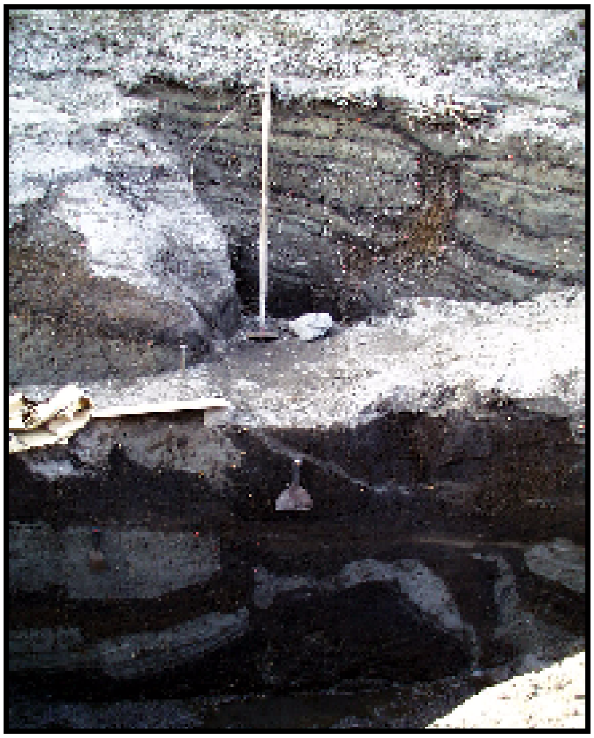

Figure 4. Photograph of upper and lower north walls of trench 5. Fault can be seen to left of both taping knifes on lower wall. Colored nails visible along horizons in wall were surveyed, graphed on a vertical plane in a computer and then printed out to a specified scale to be used as an aid to field logging

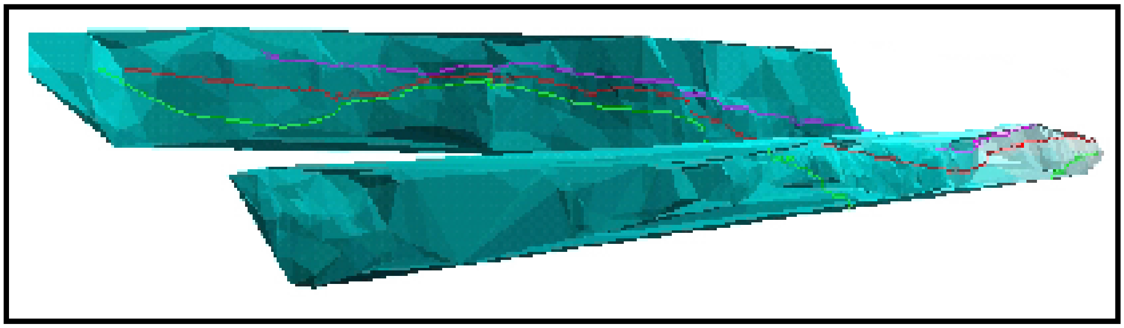

Figure 5. Perspective view looking NE at TIN surfaces of the north wall of trench 5. Upper and lower walls were made separately due to surfacing problems created by benches. After the selected horizons were digitized, they were projected onto surfaces like this for all trench walls. Horizons 84 in green, 85 in grey, and 88 in blue are shown superimposed on the surface of the trench wall. Note that 85 appears most deformed.

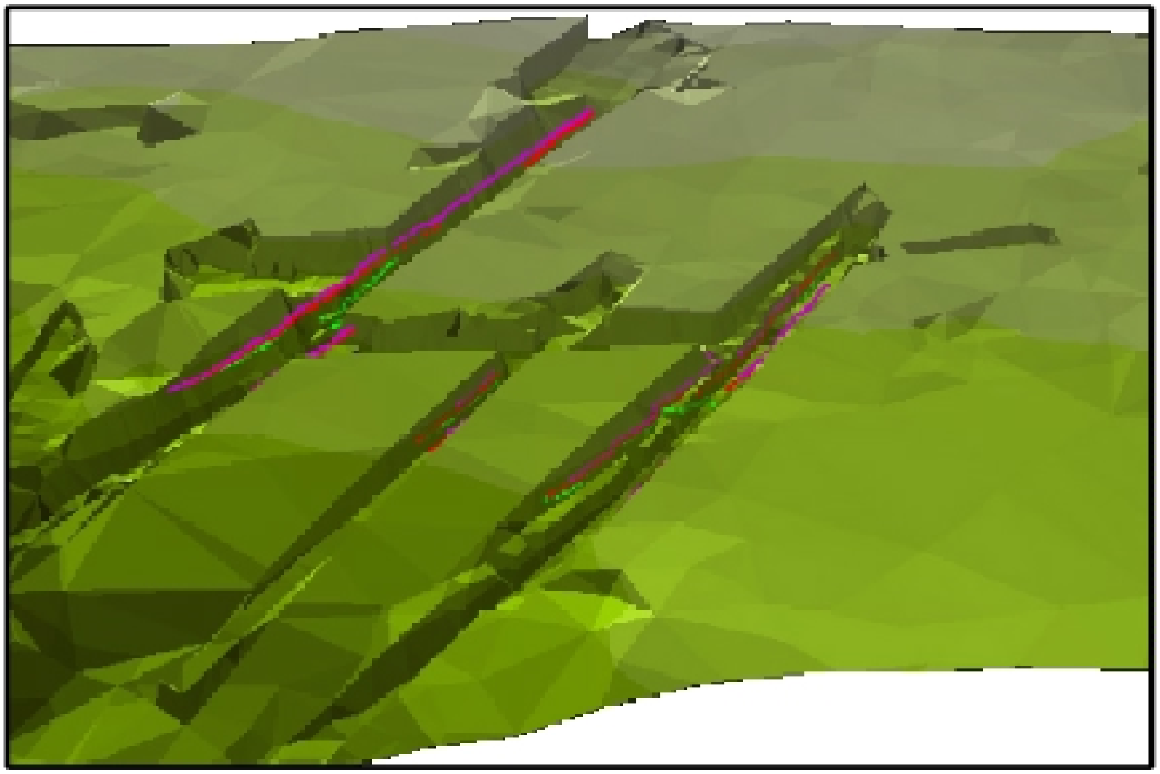

Figure 6. Perspective view looking NE at trench site. Digitized points along selected horizons displayed in color, 88 in purple, 85 in red, 84 in green. TIN surfaces are created by connecting all field surveyed points to their nearest neighbors with straight lines and then connecting the straight lines with flat planes. The resulting surface is an interconnected network of 3-D triangle facets.

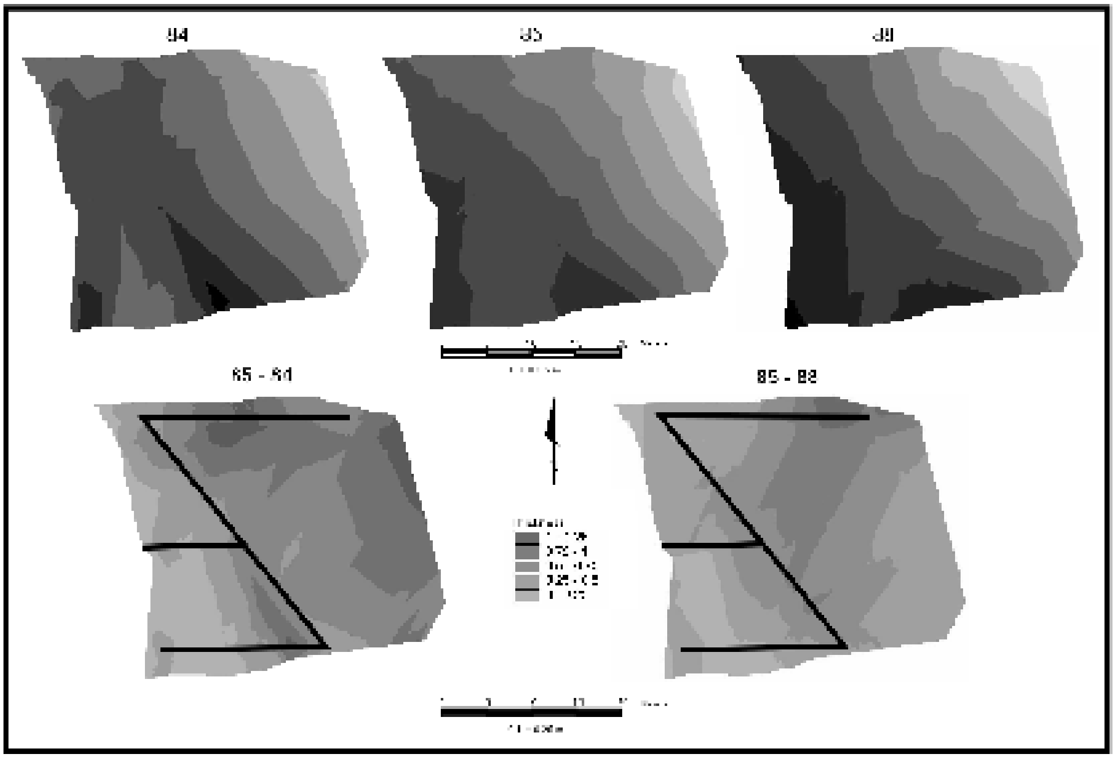

Figure 7. Contours show that horizon 84 has the greatest structural relief (across a parallel syncline-anticline-syncline), horizon 85 has intermediate structural relief, and horizon 88 has no appreciable relief. The deformation that took place at this location can therefore be attributed to the past two rupture events. The south boundary of the surfaces is the located near the south wall of trench 5, and the north boundary is located near the north wall of trench 3. Lines on the isopachs give the approximate center-lines of the trenches.

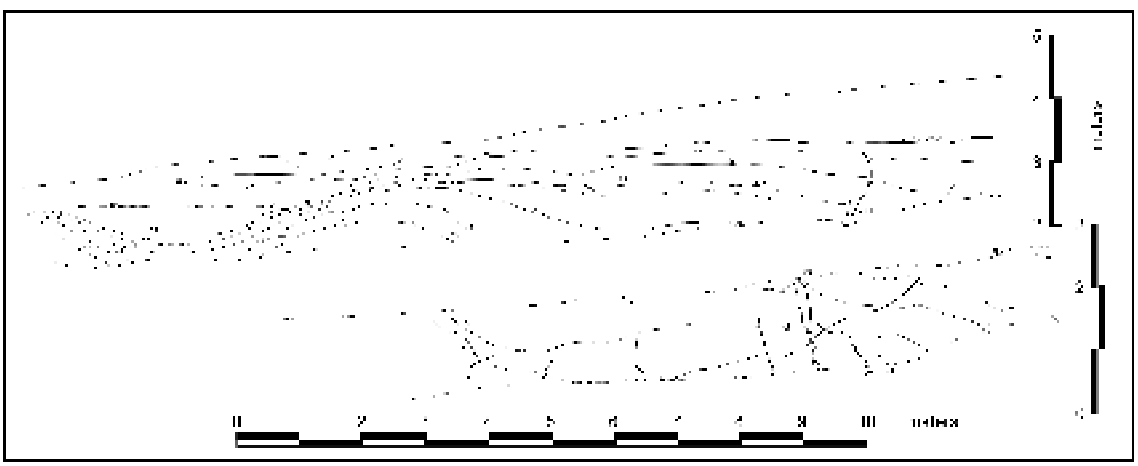

Figure 8. Line drawings of the upper and lower south wall of trench 5. Upper wall has been offset vertically from the lower wall by 1 m due to overlapping problems created by bench surface. These line drawings were drafted in the computer directly over the scanned in field logs. They were then spatially rectified in GIS and used for the digitization of the selected horizons.