A 30-Event Paleoseismic Record on the San Andreas fault at Wrightwood, California

Award Number: 02HQGR0005
Principal Investigator: Ray Weldon II
Department of Geological Sciences
University of Oregon
Eugene, OR 97403
Phone: 541-346-4584
Fax: 541-346-4692
Email: ray@newberry.uoregon.edu

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1. Introduction

We proposed to extend the event series at Wrightwood, California, beyond the published 14 event record which ends at ~1500 years BP (Figure 1; Weldon et al.; Fumal et al.; and Biasi et al., 2002), to 30 events. Many statistical models, including Poisson, normal, lognormal, Weibull, and clustered, have been proposed for characterizing long-term earthquake recurrence behavior. Each of these models results in a different calculated probability for future earthquakes and has different implications for how faults work. Although the existing 14 event series at Wrightwood provides a high-resolution temporal record of earthquakes, we showed in our proposal that the record must be lengthened to at least 30 events to provide compelling evidence for any specific recurrence model

Our investigations have been very successful, but have been modified from the original proposal due to results from trench investigations completed last summer. In 2001, we excavated a network of four trenches in the southeast corner of the site, as planned in our original NEHRP proposal. These trenches show fantastic evidence for ~10 events between ~3000 and 4100 years BP (Figure 1). Given the average 105-year recurrence interval of large earthquakes on this portion of the San Andreas fault (Fumal et al., 2002), a 30-event series would extend into stratigraphy approximately 3100 years old. The older ages of the events in the four 2001 trenches had two implications on our project: 1) the record is extendable to ~40 events, 30% longer than originally hypothesized, and 2) future excavations should focus on the ~1500 to ~3000 year BP stratigraphy (Figure 2). Gaps in the record present special problems to interpreting the recurrence behavior, so we submitted an additional proposal for 2004 to fill this gap. This Annual Report summarizes results from our first year of funding (FY2002) and describes fieldwork completed in the summer of 2003.

2. Wrightwood Paleoseismic Site

The Wrightwood paleoseismic site is located northwest of the town of Wrightwood, California, at an elevation of approximately 1800 meters in the San Gabriel Mountains. The site is a small flake structure (Weldon et al., 2002) approximately 225 meters wide by 600 meters long, located

in Swarthout Valley along the main trace of the San Andreas fault. The deposits at Wrightwood make the site ideal for this research. Throughout the section, we observe two basic types of layers (Figure 2):

Debris flow units. The textures of these layers range from one-half meter subangular cobbles to medium pebble gravel to fine sand and silt. In many cases, the layers are continuous across the site, with only centimeter scale variation in thickness. These layers comprise approximately 70% of the stratigraphy and are inferred to be debris flows. Historic debris flows in the region usually have occurred during rapid snow thaw events, and did not temporally correlate with earthquakes (Sharp and Nobles, 1953).

Peat-like layers. These layers are dark and contain significant proportion of organic material, including roots and subaerial plant material, and in many cases contain a very fine-grained charcoal component.

Based on the stratigraphy at Wrightwood and unpublished reconstructions of the plant material and pollens, we believe that the depositional environment of the Wrightwood site was usually a waterlogged bog that produced large volumes of plant material. Evident in the top 50 cm of the modern ground surface, bioturbation (large root casts and burrows) is rarely observed in the older units at the site. This observation, coupled with the predominance of peat layers suggests that groundwater levels were at or above the ground surface level for most of the depositional history. Periodically, peat growth in the swamp was abruptly terminated by debris flows that would fill portions of the valley, capping the organic material and providing a fresh surface for new vegetation to cultivate.

The section from the modern surface down to Peat 100 (~1500 BP) has been extensively studied and dated (Figure 2; Biasi and Weldon, 1994; Biasi et al., 2002; Fumal et al., 2002; Weldon et al. 2002). An isopach map of the depth of Peat 100 relative to the ground surface was constructed from the network of trenches (Figure 3). The site spans two geomorphically obvious traces of the San Andreas fault that contain an area of distributed deformation. Right lateral movement on these structures creates a depression on the northwest side, clearly defined by the increased thickness of Peat 100, and oblique compression across the southeast side of the site. Based on these structural observations, secondary zone was shown to be the surface expression of a flake or petal of a flower structure (Weldon et al., 2002).

3. FY2002 Accomplishments

During the academic year, our efforts were focused on analyzing data from the 2001 excavations and significantly reducing the back-log of uncompiled trench logs from previous years. Specifically, we accomplished the following tasks:

- Finalized the large photomosaics from 2000/2001 of trenches 30, 31, 35, 36, 37, and 38,
- Readied for publication many figures showing the quality of the event evidence from the 2001 trenches,
- Assembled 138 trench meters of photographs from the southeast wall of Trench 21 and began an accompanying interpretation, and
- Assembled old photographs of Trench 22, which documents multiple offsets on an older reverse fault that was cut obliquely by Trench 21.

All of these accomplishments improve our ability to document paleoearthquakes, either due to a detailed search of deformation in the logs, or by improving our understanding of the structure of the site, which enables our further field investigations.

FY2002 Field Investigations

Given the quantity and quality of evidence for earthquakes between ~3000 to 4100 years BP compiled over the past year, we focused this field season on the strata aged between 1500 and approximately 3000 years old (Figure 2). The placement of our FY2002 trenches was guided by the Peat 100 isopach map (Figure 3), which was the result of a decade of work at Wrightwood. In the map, untrenched regions that are yellow locate Peat 100 to within ~1 meter of the ground surface, and indicate areas where the 1500 years BP and older stratigraphy should be accessible by trenching. After reviewing our previous results, we decided to focus on two areas in 2002:

Trench 39/40 Our first excavation was a 55-meter long bulldozer excavation centered on the middle part of Trench 10. In Trench 10, thickening strata below Peat 100 suggested that with deeper exposures, we could find event evidence in the 1500 to 2500 years BP range. To expose this older section, a seven meter wide cut (identified as Trench 39) was bulldozed over the trace of Trench 10 (providing two additional exposures of units including Peats 100 through 120), and then Trench 40 was excavated through the base of the bulldozer cut to expose the older stratigraphy. This method is safer than cutting a single deep trench, and has the benefit of exposing new information on the upper section. We compiled the photomosaic of the northeast side of Trench 39, and both walls of Trench 40. The photomosaic of T39 and T40 was submitted with the 2002 Progress Report. We observe evidence for three events in Trench 40 that predate the deposition of Peat 100.

Trench 41 Our third excavation was guided by a ground penetrating radar study (Foxx, 2002). Her radar images show that the region between Trenches 11 and 21 contains interesting folds and deformation with potential event information. By the end of the field season, we excavated, cleaned, photographed and logged 90 meters of Trench 41/41A. Meters 0 to 25 were included with the 2002 Pregress Report; meters 25 through 75 of T41 and all of T41A are included with this report (Figures 4 and 5). We dated a layer from exposed stratigraphy, which indicated that the strata were within the expected age (1500 to 2500 BP). The trench shows broad wavelength deformation such as progressive folds, but contains little evidence that could be used to identify the event horizons of earthquakes during this time interval. Based on a preliminary correlation of the units, the lower event horizon in Trench 41 is older than the stratigraphy in Trench 40, suggesting that we have documented a total of four, and possibly five events in the 1500 to 3000 year old stratigraphy.

4. FY2003 INVESTIGATIONS

In FY2003, we completed the following tasks:

- Analyzed >100 organic samples by carbon-14 at Lawrence Livermore Laboratories.
- Began writing a manuscript documenting the events between 1200 and 3000 BC.
- Created a composite stratigraphic column that bridges the upper, published section with the deep section (Figure 2).

We presented posters and talks on Wrightwood at AGU, GSA, and the XVI INQUA Congress (Scharer, 2003a, b, c).

FY2003 Field Investigations

In 2003, we excavated, cleaned, photographed and logged a new trench connecting T36 and T38. In light of the relatively undeformed section exposed in Trench 41, we decided to move our excavations towards the perimeter of the site, where deformation tends to be more localized. Deformation of the colluvium in Trench 38 suggested that the southeastern thrust system is recent, and younger than the thrusts exposed in Trenches 31 and 35. If the thrust sequences stepped eastward through time, the region under the proposed extension of 36 should have been deformed during intermediate times (i.e., 1500 AD to 3000 BC). However, in the T36 to 38 connector trench we saw folding and minor fold-related faulting of units that likely span the lower part of the "deep section" shown on Figure 1 and extends the record to about 4000 BC. Spectacular evidence for individual earthquakes is found in fissures associated with small faults and thickening and thinning of sediments on the growing folds. We are currently working on making a photomosaic and integrating the field mapping. In addition, the relationships in this trench tell us that southeastern-most edge of the "flake" structure was in T38 or farther southeast; thus evidence for earthquakes in the critical 1500 to 3000 BP period of time have not been preserved in this part of the site.

We also excavated a deep, ~6 m, pit near the intersection of trenches 3, 6, 9, and 11 to collect samples of units inferred to have formed between 1500 and 3000 years old. These units have been directly tied to the trench logs of deep trenches T8, 9,11 that contain subtle evidence for earthquakes during this time. We have begun to digitize the paper logs of these exposures with the goal of retro-deforming critical units to determine earthquake vents.

5. Non-Technical Summary

We study the temporal pattern of large earthquakes on the San Andreas fault over the past few thousand years. This research will benefit society by improving our ability to assess the likelihood and frequency of future earthquakes. Building on a decade of previous field work at a site near Wrightwood, California, our goal is to document when the last ~40 earthquakes occurred on the San Andreas fault. We know when the last 14 earthquakes occurred, and are working on the previous 24. Through field work we have narrowed the gap to approximately 10 missing earthquakes that we intend to investigate in 2004.

6. Available Data

Photomosaics and interpretations of most of the trenches at Wrightwood are available. They are large (~300 MB) Adobe Photoshop and Illustrator files, and can be obtained by contacting Kate Scharer at the University of Oregon (ph 541-346-4647, email kscharer@darkwing.uoregon.edu). Reprints of publications focusing on the past 1500 years are available from Ray Weldon (ph 541-346-4584, email: ray@newberry.uoregon.edu).

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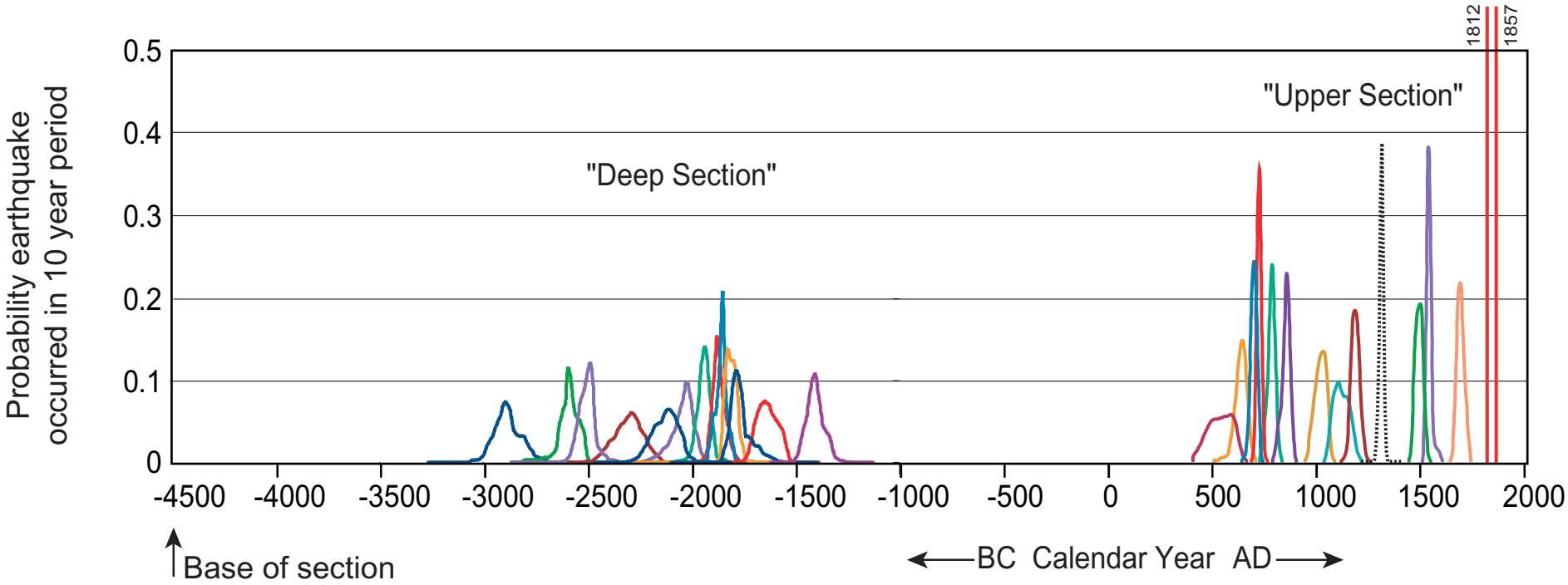
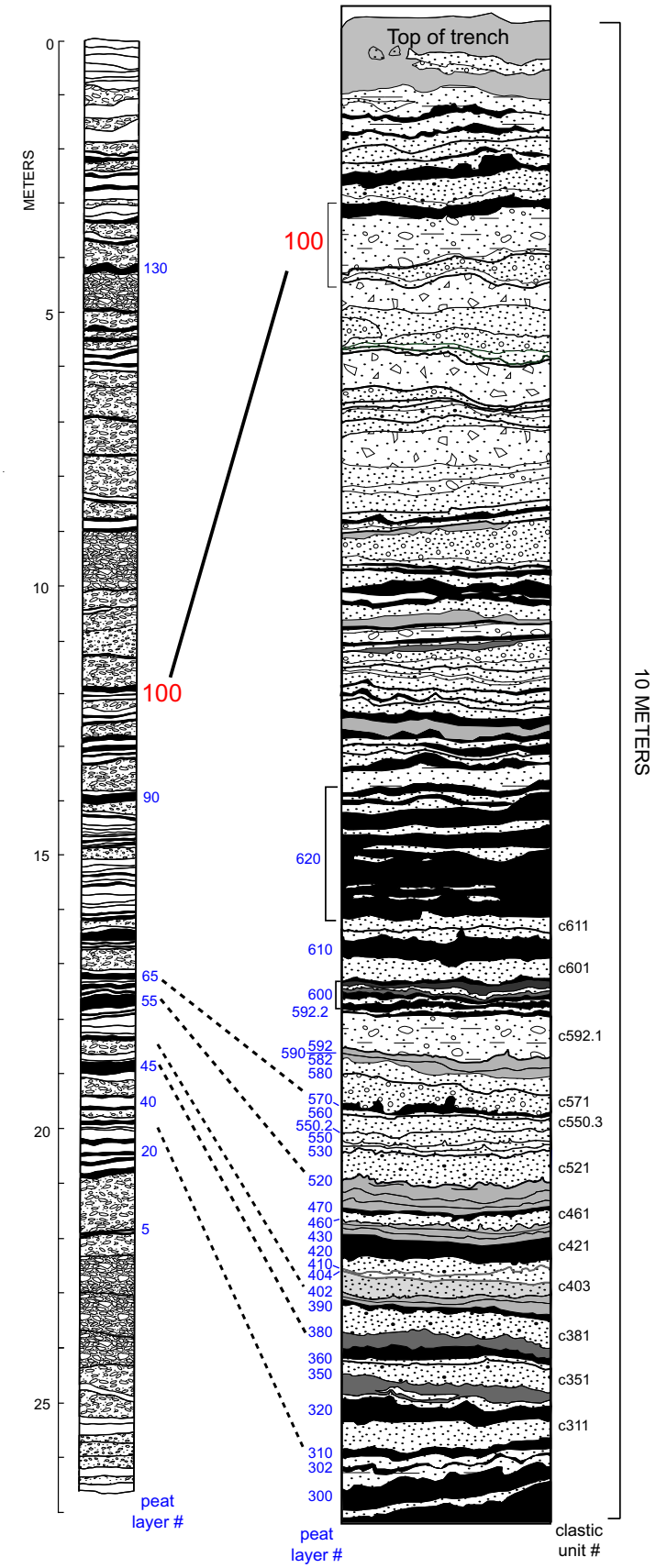


Figure 1. Probability distribution functions (pdfs) for age of paleoearthquakes documented at the Wrightwood paleoseismic site. The upper section, from the present to ~500 AD contains 14 paleoearthquakes. The dashed black pdf is Event T, from the Pallett Creek paleoseismic site. The event series for the deep section is under revision, but currently includes ~13 paleoearthquakes from ~1200 BC to 3000 BC. Compared to the upper section, the pdfs are broader and less peaked in the deep section because the peat accumulation rate has not been incorporated. Future analysis will include the peat accumulation constraint. Both the upper and deep sections have average recurrence intervals of ~110 years. During the 2002 and 2003 field seasons, we focused on exposing stratigraphy in the gap between the deep and upper sections. Five to seven events are now documented in this age range, but the dates of the events have not been determined. The current recurrence interval for the middle section is ~300 years, which suggests that we have not captured all of the events in this section.



(A) Original composite stratigraphic section of the Wrightwood site (Fumal et al., 2002.

(B) Composite stratigraphic section older than peat 100 from T30, T37, and T41A.

Figure 2. Composite stratigraphic column relating "Upper Section" and "Deep Section" of the Wrightwood paleoseismic site. Units were tied by physically tracing unique beds across the site. Peat and organic-rich layers are in black or grey, relative texture of clastic units indicated by patterns. Target section extends from peat 100 to peat 600.

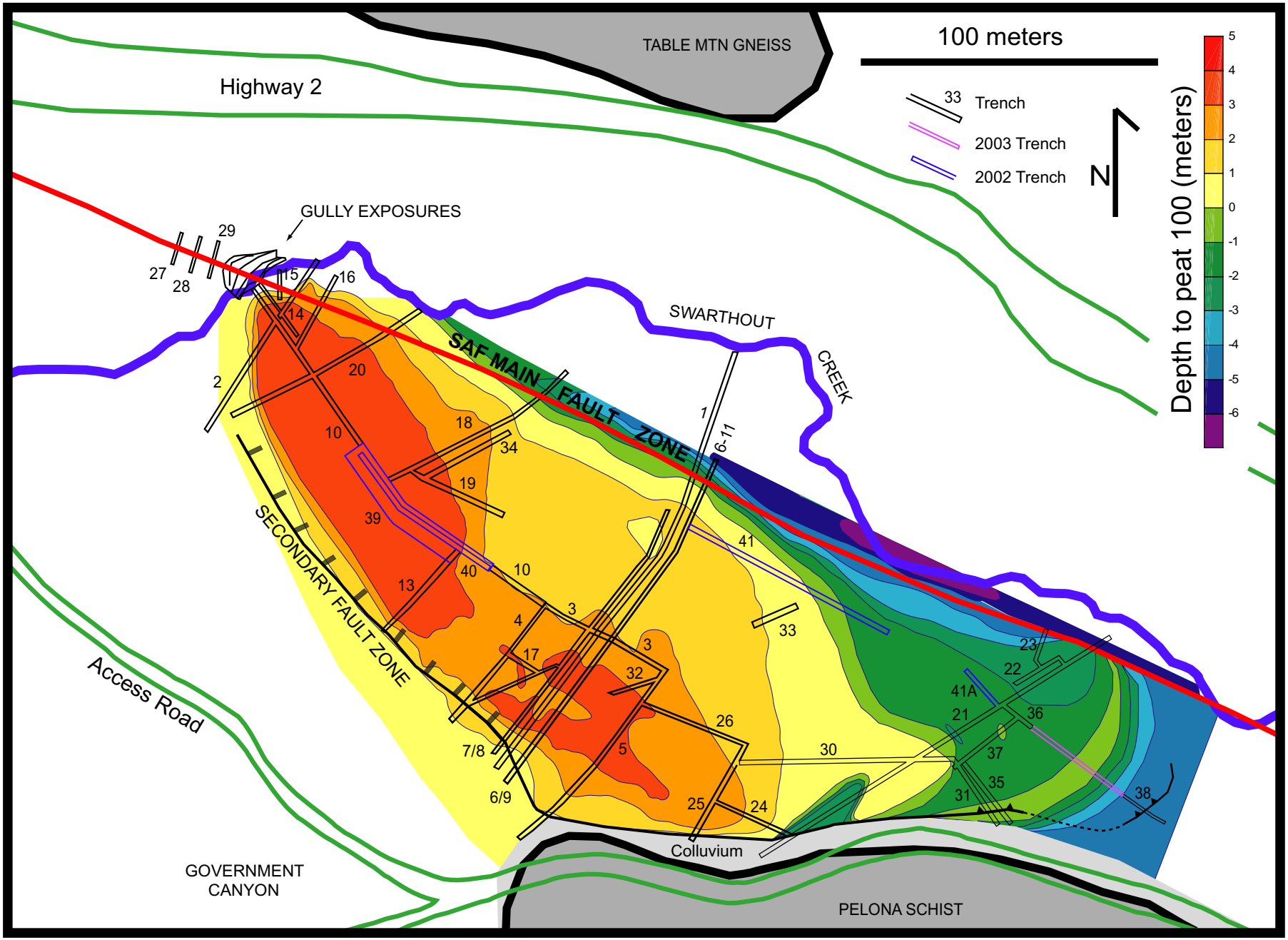


Figure 3. Structure and trench map of the Wrightwood paleoseismic site. Warm colors show depth to peat 100 below the modern topography, cool colors show inferred height of peat 100 above ground surface. Trenches 39, 40, 41 and 41A were excavated in 2002, and the trench 36-38 connector was excavated in 2003. Roads are outlined in green, bedrock exposures colored by grey.

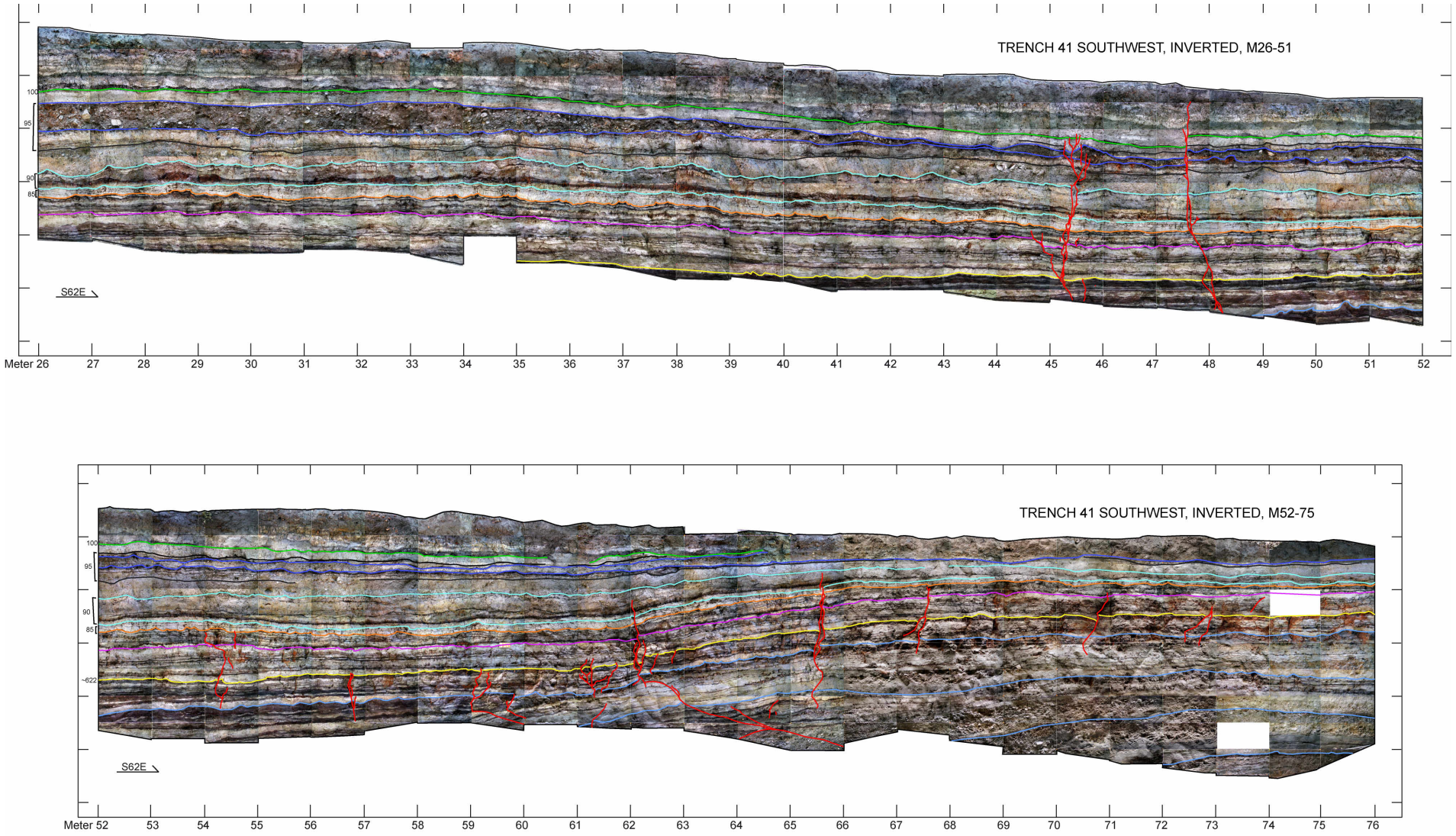


Figure 4. Photomosaic and interpretations of eastern end of Trench 41. Meters 26 through 51 show young, vertical faults, but relatively no distributed deformation. Beds lift and thin across a monocline at meter 63, bringing a peat (yellow line) dated to ~ 2000 BP closer to the surface.

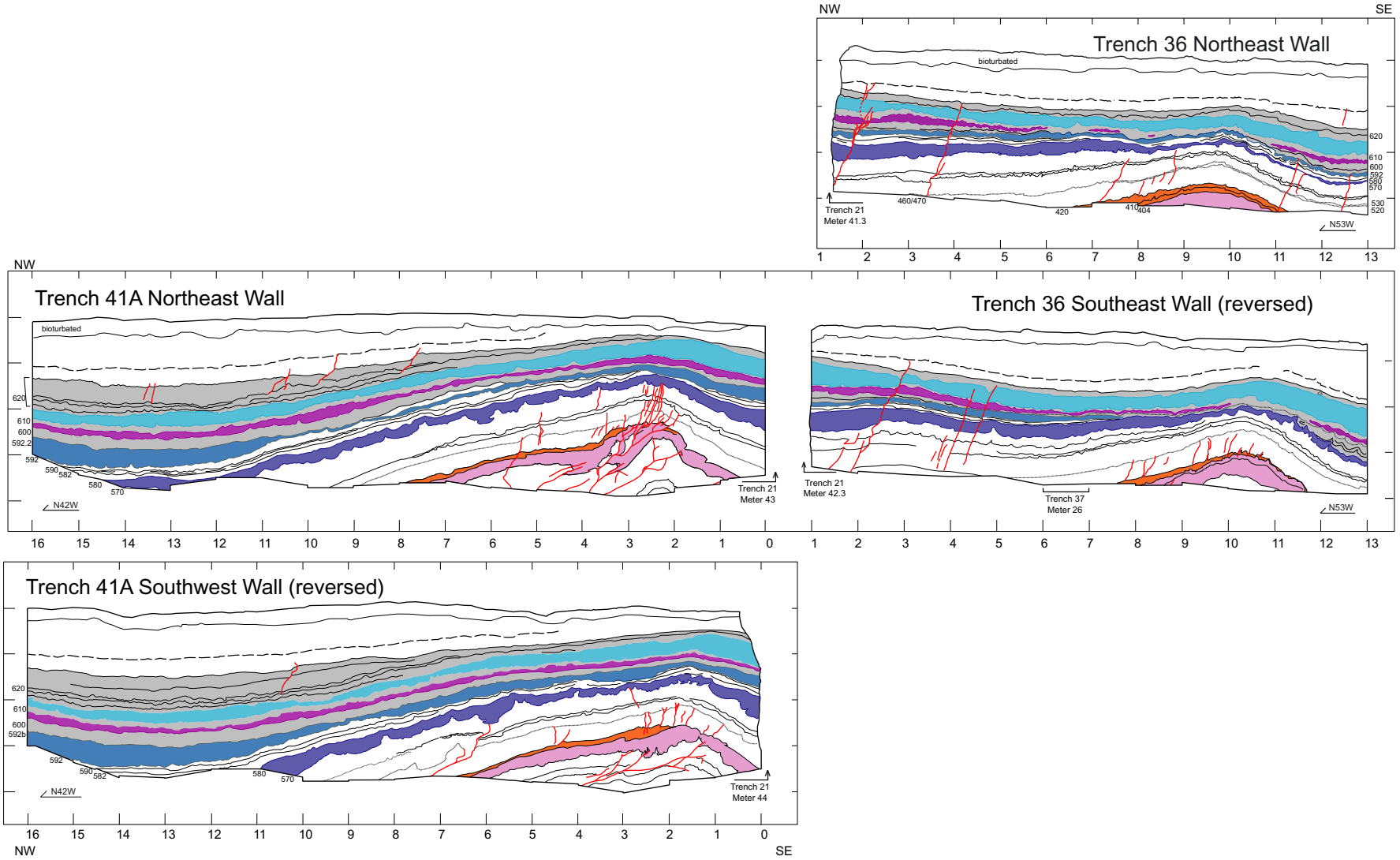


Figure 5. Interpretations of sub-parallel trenches 41A and 36. Trench walls are organized in sequence from southernmost (bottom) to northernmost (top). Packages of organic-rich layers are grey, clastic units showing thickness changes across the anticlines are colored (blue, purple, orange). These units are equal and older than the strata exposed at the eastern end of Trench 41.