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

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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 (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

As of the date of this Annual Report, we are at the Wrightwood paleoseismic site conducting our first NEHRP-funded field season. 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 NEHRP proposal (Figure 1). These trenches show fantastic evidence for ~10 events between ~3000 and 4100 years BP. 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 have 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. Gaps in the record present special problems to interpreting the recurrence behavior, so we will attempt to find a complete record. Because the 2001 trenches had a significant effect on our current field efforts, and our anticipated results, we review them briefly, and then report on our 2002 field investigations.

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 (Figure 1). 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:

Debris flow units. These layers range from one-half meter subangular cobbles to medium grained gravel to fine sand and silt. In many cases, the layers are continuous across the site, with centimeter scale variation in thickness. These layers comprise approximately 70% of the stratigraphy. 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 high 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 (Biasi and Weldon, 1994; 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 1). The site spans two geomorphically obvious traces of the San Andreas fault (Figure 1) and many other traces in between exposed in excavations. Right lateral movement on these structures create a depression on the northwest side, clearly defined by the 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. 2001 Accomplishments

From August through mid-October 2001, we excavated four trenches in the southeast corner of the site. The location of the trenches was based on observations in Trenches 21, 30 and 31 (Figure 1), which showed that units older than Peat 100 were accessible at trenching depths (3 to 4 meters).

Our trenching methodology was similar to previous years, trenches were excavated by backhoe, shored, and cleaned. We then created a 100 by 50 centimeter grid system on both walls of the trench, which provides a reference frame for individual photographs and subsequent logging. In 2001, we began using a digital camera to take photographs of the trench walls. The photographs

are compiled and then one-meter vertical columns are printed at a scale of ~1:9. We log on the prints, documenting layer color and grain size, deformation, and presence of faults and fissures. Photologs are beneficial because they preserve textural and tonal information of each layer, and objectively document the evidence for events. The trench logs are then used to annotate a large photomosaic of the entire trench.

Trench 35 was cut parallel to Trench 31, so that we could provide additional evidence for the events in Trench 31, and to improve our understanding of the large reverse fault located at the southeastern end. Trench 37 was cut parallel to Trench 21 (excavated 5 to 6 years before) to provide multiple lines of evidence for events. Trench 36 connects Trench 37 and 21, and provides a route for us to connect Trench 38 to the existing network. We located Trench 38 to cross the prominent surface slope observed in the southeast corner of the site, which we hypothesized was a continuation of the reverse faulting observed in Trenches 31 and 35. Figures 2 and 3 present reduced photomosaics and discussions of the 2001 trenches. Important debris flow layers are outlined in colors to highlight the overall deformation patterns in the stratigraphy. Earthquake horizons are marked with yellow stars; many horizons have more than one line of evidence (i.e., growth strata and fissures). These results were presented on a poster at the 2001 American Geophysical Union annual meeting.

4. FY2002 Accomplishments

During the academic year, our efforts were focused on analyzing 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 2001 (Figures 2 and 3),
- Readied for publication many figures showing the quality of the event evidence from the 2001 trenches,
- Finalized a photomosaic and interpretation of Trench 30,
- Finished the photomosaic of the northeast wall of Trench 31,
- 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.

Current Field Investigations

Given the quantity and quality of evidence for earthquakes between ~3000 to 4100 years BP compiled over the past year, we have focused this field season on the strata aged between 1500 and approximately 3000 years old. The placement of our current trenches was guided by the Peat 100 isopach map (Figure 1), which was the result of a decade of work at Wrightwood. In the map, untrenched regions which 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 this year (Figure 1).

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 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 have compiled the photomosaic of the northeast side of Trench 39, and both walls of Trench 40 (Figure 4). We observe evidence for three events in Trench 40 that predate the deposition of Peat 100 (see caption of Figure 4 for discussion).

Trench 41 Our third excavation was guided by a ground penetrating radar study conducted as a Master's Thesis project by Ms. Reina Foxx (University of Oregon). Her radar images show that the region between Trenches 11 and 21 contains interesting folds and deformation with potential event information. At this time, we have excavated 66 meters of Trench 41, and have completed a photomosaic for the first 25 meters of the northeast wall (Figure 5). There are two discrete event horizons in this trench.

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. Future Plans

Although the Peat 100 isopach map indicates places where we can access the target 1500 to 3100 years BP stratigraphy, it does not precisely show locations where the target stratigraphy was deformed during its deposition. In order to better locate our 2003 trenches, we will incorporate this years results into the structural model for the site, adjusting and revising as necessary. Future trench locations may include (Figure 1):

- A continuation of Trench 41 into Trench 21. The ground penetrating radar image of this route displays a strong monoclinal shape approximately ten meters from Trench 21. A hypothesis of the structural model is that we could see evidence of compressional features in the target stratigraphy between the current end of Trench 41 (Meter 70) and the thrust system in Trenches 31 and 35.
- Trench 42, a northwest extension of Trench 41, connecting Trench 18 with Trench 11. The logs of Trench 18 show some folding and fissures in the target section, which is accessible at trenching depths.
- Trench 43, a trench cutting across Trenches 21 and 30. Trench 21 shows some faulting and fissures at meter 95, which exhibit predominantly strike slip movement along the southern edge of the site. A trench in this location would show this deformation, and evidence for the depositional or structural nature of the onlapping section and could contain growth strata-style event information.
- A continuation of Trench 36 into Trench 38. Deformation of the colluvium in Trench 38 suggests that this thrust system is recent, and younger than the thrusts exposed in Trenches 31 and 35. If the thrust sequences have stepped eastward through time, the region under the

proposed extension of 36 would be deformed during intermediate times (i.e., 1500 to 3000 years ago).

During the remainder of the year we will continue to process, interpret and itemize the ~14 events that were documented over the last two years. We also need to improve the composite stratigraphic column of the older section.

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 ~38 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 earthquakes which we intend to investigate in 2003.

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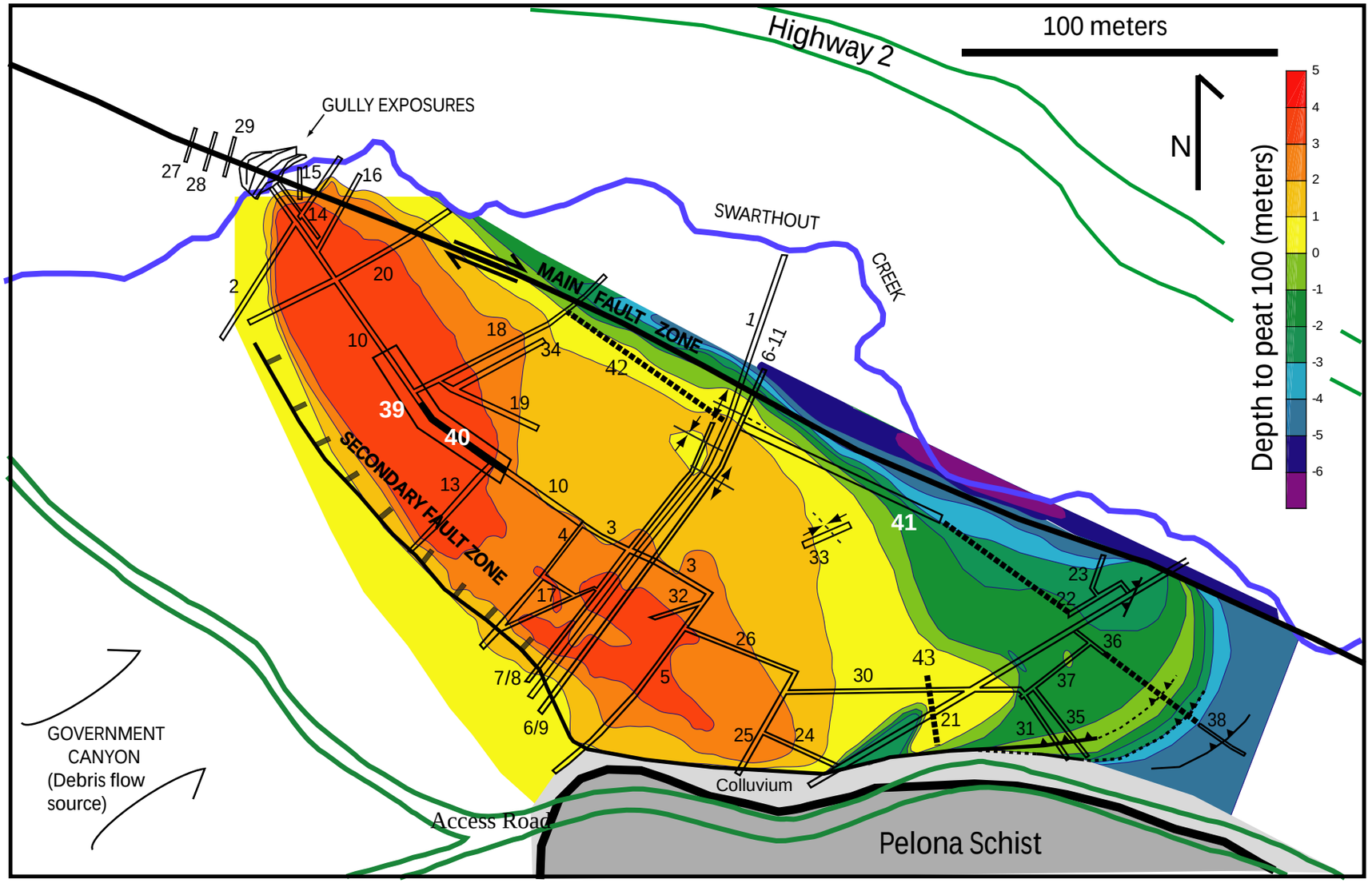
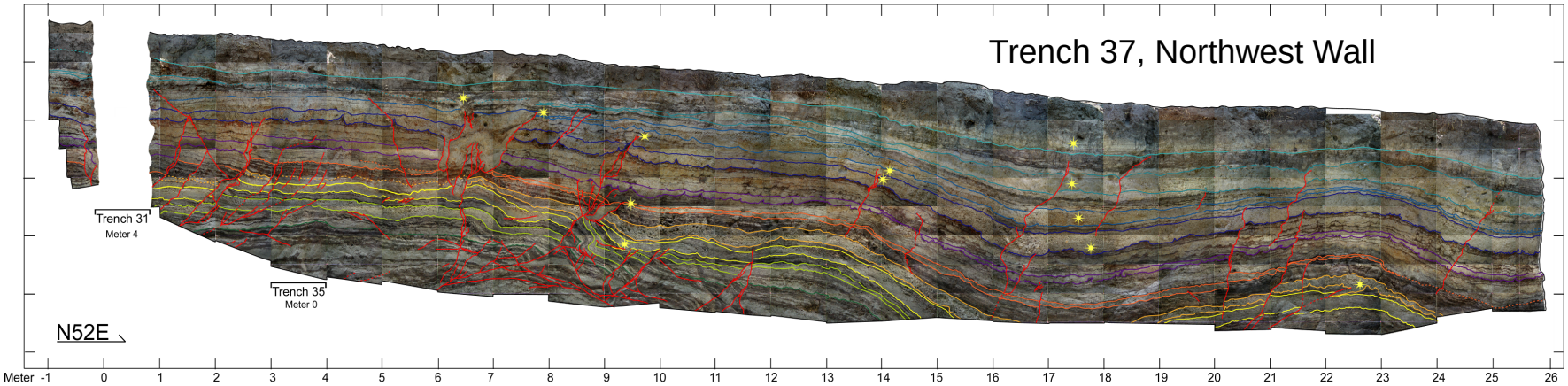
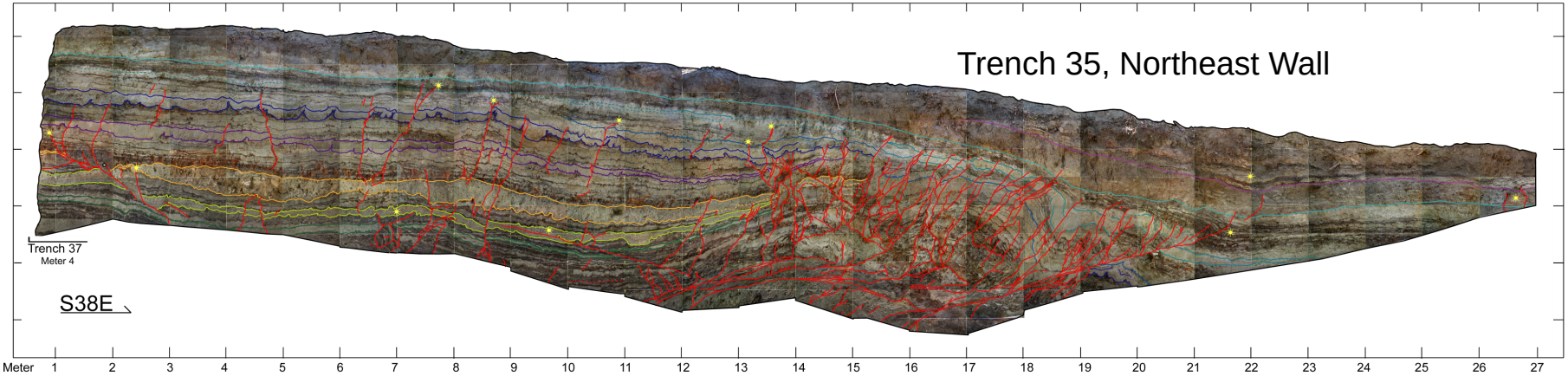


Map of Wrightwood paleoseismic site, with geographic features and trench locations. The colored polygons represent the depth to (or height above) of Peat 100 relative to the ground surface. Regions with warm colors are associated with extensional structures (Peat 100 is below the ground surface) and cool colors result from reverse structures (Peat 100 has been thrust up and eroded). Trenches 35 through 38 were excavated in 2001; we are now working on Trenches 39, 40 and 41 (labeled in white). Future trenches (marked with thick, dashed lines) include: the continuation of Trench 41 to Trench 21; Trench 42, northeastward extension of 41 to 18; Trench 43, a cross trench between 21 and 30; and a continuation of Trench 36 to Trench 38. Based on the isopach map, Trenches 41 through 43 are located to target the 1500 to 3000 year BP stratigraphy, which correlates with the yellow and green shades.

Figure 1.

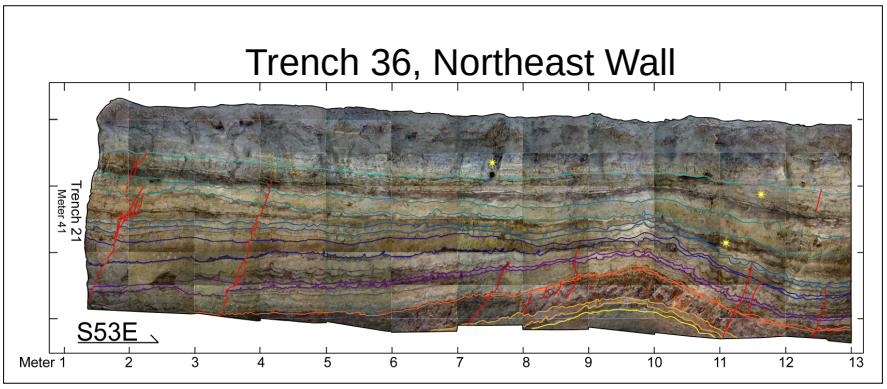


Deformation in Trench 37 varies from fissures and fractures in the SW (left) to gentle folding in the NE (right). Although the general, apparent dip of the units is to the NE, the true dip includes an easterly component. Note the transformation of the light orange unit from a thin sandy layer (M1) to a thick, poorly sorted debris flow (M15). The medium and light blue layers exhibit similar changes in thickness and grain size, suggesting that the SW corner (the nexus of T31, T30, T21 and T37) has endured as a topographic high during the deposition of these strata.

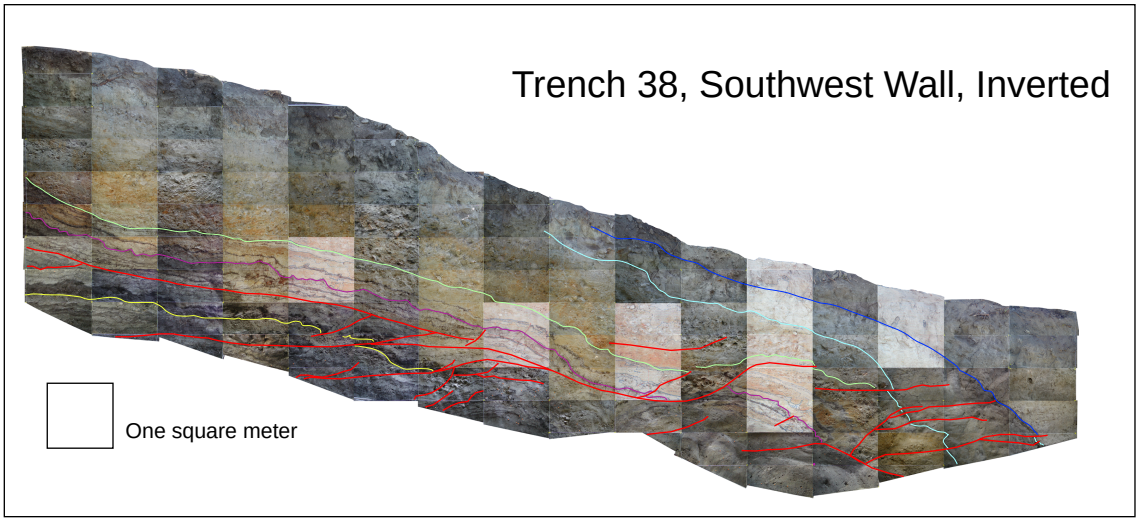


Subparallel Trenches 31 and 35 both show a complex reverse fault at the SE (right) end which has been active over several event cycles. Multiple fissures and fractures which disrupt the NW (left) end of Trench 31 do not appear ~5 meters away in Trench 35. Reverse faults similar in geometry but larger and younger than these were observed in Trench 38.

Figure 2



Trench 36 contains gently folded strata with fanning growth strata (M8-9 and 11-12) and minor fractures to the NW (right). Dark red stained fractures are visible in the thick peaty unit at the base of the anticline.



In Trench 38, older units (based on C-14 dating, the green unit is ~5700 years old) are thrust over presumably younger peats. This suggests that reverse faults are stepping eastward over time, and a thrust sequence in our target stratigraphy may be located between trenches 36 and 38. We determined that there is a northwestward component of slip on these long faults.

Figure 3.

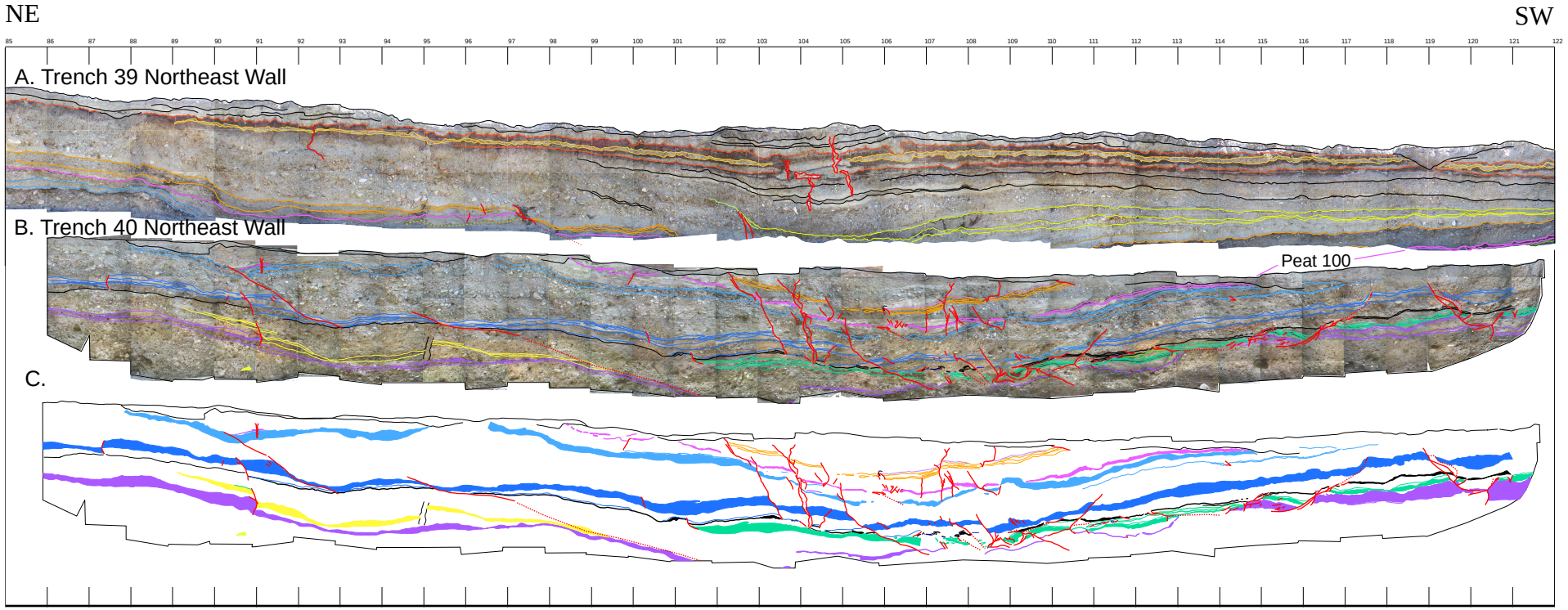


Figure 4. Trench 40 (B) is currently a 36-meter long trench excavated in the bottom of Trench 39 (A), a wide bulldozer excavation. The bench between the two exposures is approximately one meter wide. The units in Trench 39 exhibit gentle folding and thickness changes. In the deeper exposure, the faults which probably control the unit character in Trench 39 are exposed. All of the faults exhibit normal separation, indicating that this region is under extension. In meters 88 through 101 the faults are low angle, in meters 102 though 109 the faults steepen and change to a northeast dip. Low angle, down to the northeast faulting occurs in meters 115 to 119. The true dip of the units has a southwest component, which results in the appearance of units near the bench in both photomosaics.

Our preliminary interpretation of events below Peat 100 (C) includes an event between the two blue units due to the significant thinning of the gravel unit to the southwest. Additional event horizons are between the black and dark blue units due to thinning and textural changes to the northeast, and an event between the green and black units, due to the absence of the green unit in the northeast half of the trench. Later this summer we will extend Trench 40 to the northeast, in hopes of providing additional support for these preliminary interpretations.

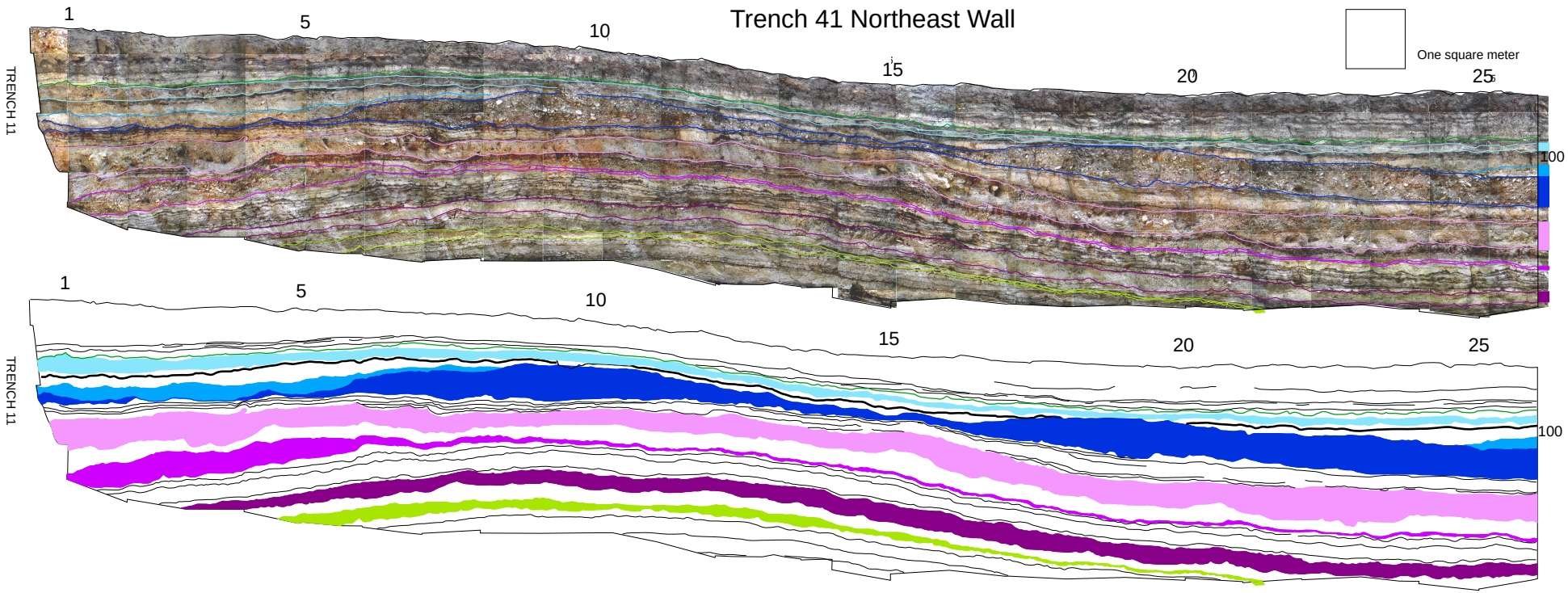


Figure 5. Preliminary interpretation of Trench 41. This trench is connected to Meter 65 of Trench 11. The exposed stratigraphy are folded in an open anticline but no faulting is observed. Peat 100 is located near the top of the trench, under the light blue unit. By evaluating the shape of the folds and thickness changes across the folds, we are able to identify likely event horizons. At the bottom of the trench, the brown and lime green units exhibit essentially concentric folding, in contrast to the abrupt thinning of the medium purple unit on the northwest (left) end of the trench. The medium purple unit changes from a poorly sorted coarse gravel to fine-grained sand as it thins across the fold. The sedimentologic and geometric evidence indicates that the medium purple unit was deposited across a monoclinal limb produced during a paleoearthquake. Above this horizon, subtle thickness changes in the pink debris flow and progressive thickening of the thinly bedded peats and sands above suggest that earthquakes occurred during this time period, but did not produce significant folding in this area. The shape of the dark blue unit is complex, but significant thickening to the southeast suggests that an anticline, centered at meter 15 formed just before the dark blue unit was deposited. Subsequent debris flow units (in medium blue and white) were deposited on the flanks of the recently formed fold. Alternatively, this onlapping relationship could indicate that an additional earthquake occurred during this time period. The last earthquake that deformed this section occurred after the deposition of Peat 100 and the light blue debris flows. In total, before the deposition of Peat 100, two discrete paleoearthquakes are identifiable (and datable) in this trench, and two additional earthquakes probably deformed the stratigraphy, but discrete horizonsvfor these events are not discernible.