FINAL TECHNICAL REPORT

ASSESSMENT OF POSSIBLE SURFACE RUPTURE ON THE NORTHERN CALAVERAS FAULT, EASTERN SAN FRANCISCO BAY AREA

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ABSTRACT

This research provides information on the timing of the most-recent surface rupture along the 42-km-long Northern Calaveras fault, based on paleoseismic evidence at a site in the City of Pleasanton, California. The results of this investigation will help improve probability estimates for future earthquake occurrence in the San Francisco Bay area. Data on the timing of the most-recent surface-rupturing earthquake along the Northern Calaveras fault remain poorly resolved, yet understanding the timing of large earthquakes on this fault are necessary to reduce uncertainties estimates of seismic hazard throughout the region. Previous trenching and geophysical profiling at the North Foothill site demonstrate that the fault is a single, well-defined fault strand. This strand has geomorphic expression where it displaces middle to late Holocene deposits, but has no geomorphic expression across latest Holocene alluvial-fan deposits. Our exploration involved three fault-perpendicular and two fault-parallel trenches within or adjacent to a swale containing a thick section of late Holocene alluvium. The trenches extended into Plio-Pleistocene or Cretaceous bedrock to capture the recorded Holocene depositional history at the site. Based on site stratigraphy and cross-cutting relationships, this investigation provides evidence of historical fault creep and at least one surface-rupturing earthquake. The trench exposures exhibit prominent evidence of active fault creep as a well-developed shear fabric that extends upward from the prominent bedrock fault zone and into prehistorical and historical deposits. The shears decrease in prominence, width, and overall development in progressively younger deposits. Three distinct gravel-filled paleochannels are deformed within the fault zone, which probably reflects both creep-related deformation and coseismic rupture. Evidence for surface rupture at this site is indirect and based on deformation of paleochannel deposits along a non-creeping, secondary reverse-oblique fault strand. Based on these trench exposures and limited age estimates, the most-recent surface rupture along the Northern Calaveras fault at this site probably occurred between about AD 1660 and AD 1776.

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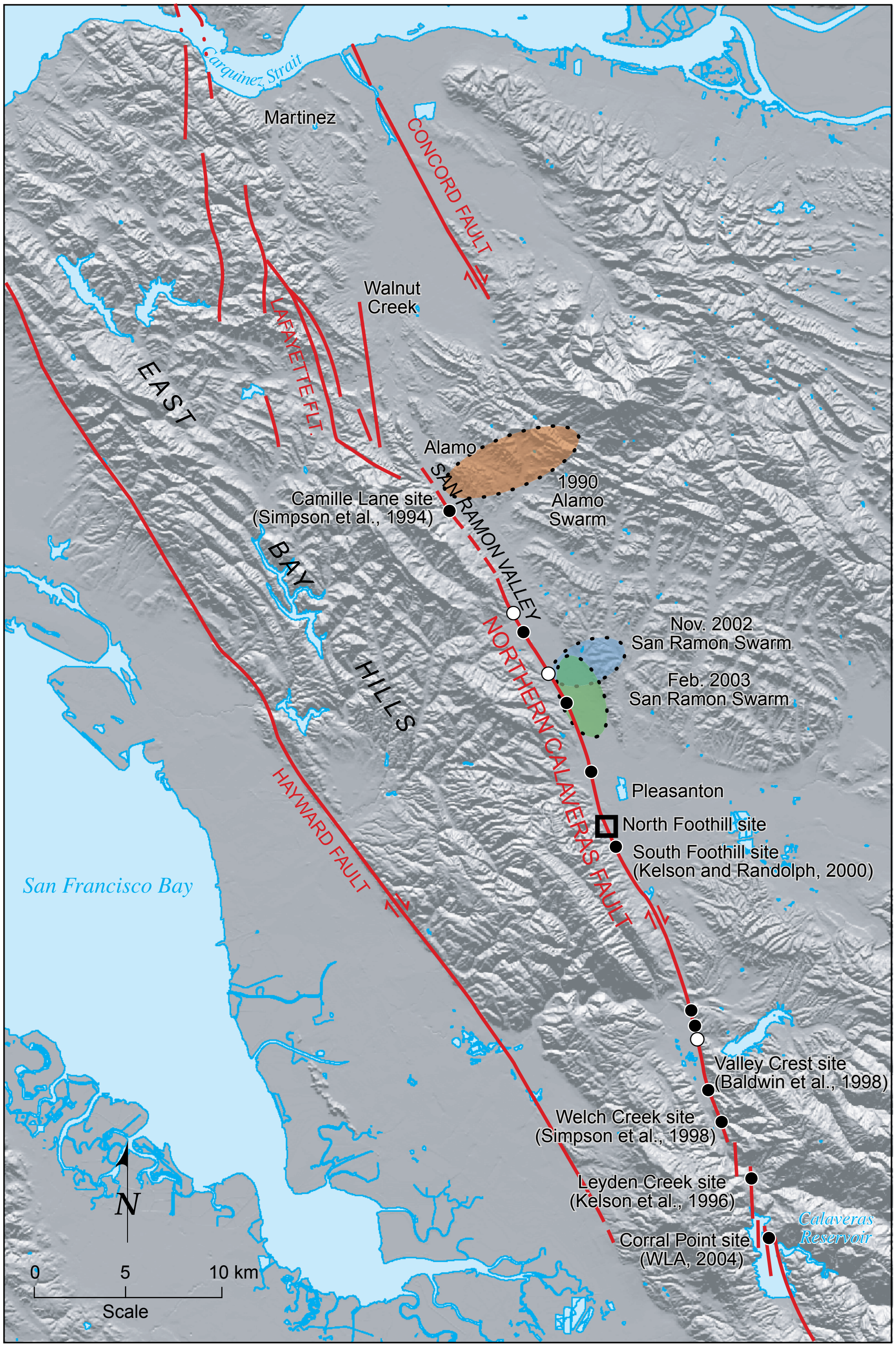
1.0 INTRODUCTION

Geologic data on the timing of late Holocene surface-rupturing earthquakes on the Northern Calaveras fault are essential for estimating the probabilities and magnitudes of future earthquakes in the San Francisco Bay region (Working Group on California Earthquake Probabilities [WGCEP], 2003). Developing rupture chronologies at different locations along the fault helps determine how the fault has behaved during past rupture events and will hopefully help predict how it will act in the future. The Calaveras fault is interpreted to consist of three primary sections (Kelson et al., 1999; Kelson, 2001; WGCEP, 2003), including the Northern, Central, and Southern sections (Figure 1). The Northern Calaveras fault traverses the suburban and commercial corridor known as the San Ramon Valley in the eastern San Francisco Bay area, and extends from Calaveras Reservoir northward to the town of Danville. The Northern Calaveras fault is considered to be the most likely to generate a large ($\mathbf{M} \geq 6.75$) or moderate earthquake in the foreseeable future (WGCEP, 2003).

Previous paleoseismic investigations on the Northern Calaveras fault show the occurrence of multiple surface-rupturing earthquakes within the past several thousands of years (Kelson et al., 1992, 1996; Simpson et al., 1999). However, these studies provide little or no definitive information on the most-recent surface rupture. Information on the elapsed time since this earthquake is critical for accurately evaluating the probabilities of future earthquakes in the San Francisco Bay region (WGCEP, 2003). The purpose of this study is to develop information on the most-recent surface rupture along the northern Calaveras fault, and thus help improve probabilistic seismic hazard analyses in the San Francisco Bay region.



Regional map of the Northern Calaveras fault showing previous paleoseismic sites (filled circles), creep observation sites (open circles), and this study site (open square). Faults northwest of Alamo are from Unruh and Kelson (2002).

NORTHERN CALAVERAS FAULT
NORTH FOOTHILL SITE

Regional Map of the Northern Calaveras Fault

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2.0 OVERVIEW OF THE NORTHERN CALAVERAS FAULT

2.1 Current Understanding of Late Holocene Fault Characteristics

The Northern Calaveras fault extends from Calaveras Reservoir on the south, to the town of Danville on the north (Figure 1), and is 42 ± 5 km long (WGCEP, 2003). The current understanding of the late Holocene earthquake behavior of the Northern Calaveras fault is based primarily on data from the Leyden Creek and Welch Creek sites, which are about 2 and 5 km north of Calaveras Reservoir, respectively (Figure 1). Trench exposures at Leyden Creek and Welch Creek provide evidence for five or six surface ruptures in the past 2,500 years, with an average recurrence of about 550 years and range in recurrence of 250 to 850 years (Kelson et al., 1996, Simpson et al., 1999). Neither of these previous investigations, however, provides conclusive evidence addressing the timing of the most-recent large earthquake. At both sites, fractures extend close to the present-day ground surface, but the ages of the youngest faulted deposit and the oldest un-faulted deposit are poorly constrained. Kelson et al. (1996) interpret that the most-recent rupture may have occurred as much as 840 years ago, and Simpson et al. (1999) interpret that the most-recent rupture probably occurred between 525 and 1,295 years ago. However, nearby evidence of surface creep (at a rate of about 2 to 3 mm/yr) complicates interpretations of whether the near-surface fractures and faults are related to surface rupture or fault creep. Preliminary data from the Valley Crest Nursery site (also in Sunol Valley) suggest that the most-recent earthquake may have occurred prior to about AD 1570, and perhaps sometime between A.D. 1100 and 1300 (Baldwin et al., 1998; Figure 1). Exploratory test pits and trenches at several other sites along the Northern Calaveras fault did not yield well-constrained data on earthquake timing (Simpson et al., 1994; Kelson et al., 2000a, 2000b, 2000c). For example, the South Foothill site in Pleasanton yielded evidence of large ruptures within the past 2,500 years, but no well-constrained event chronology (Kelson and Randolph, 2000). Lastly, ground cracking associated with the 1861 **M**5.6 earthquake occurred along a relatively short 13-km-long section of the fault near San Ramon (Toppozada et al., 1981), but this cracking may have been related to movement of the large-scale landslides that mantle the Northern Calaveras fault near San Ramon. Thus, the timing of the most-recent large earthquake on the Northern Calaveras fault remains unknown (Kelson et al., 1996, 1999).

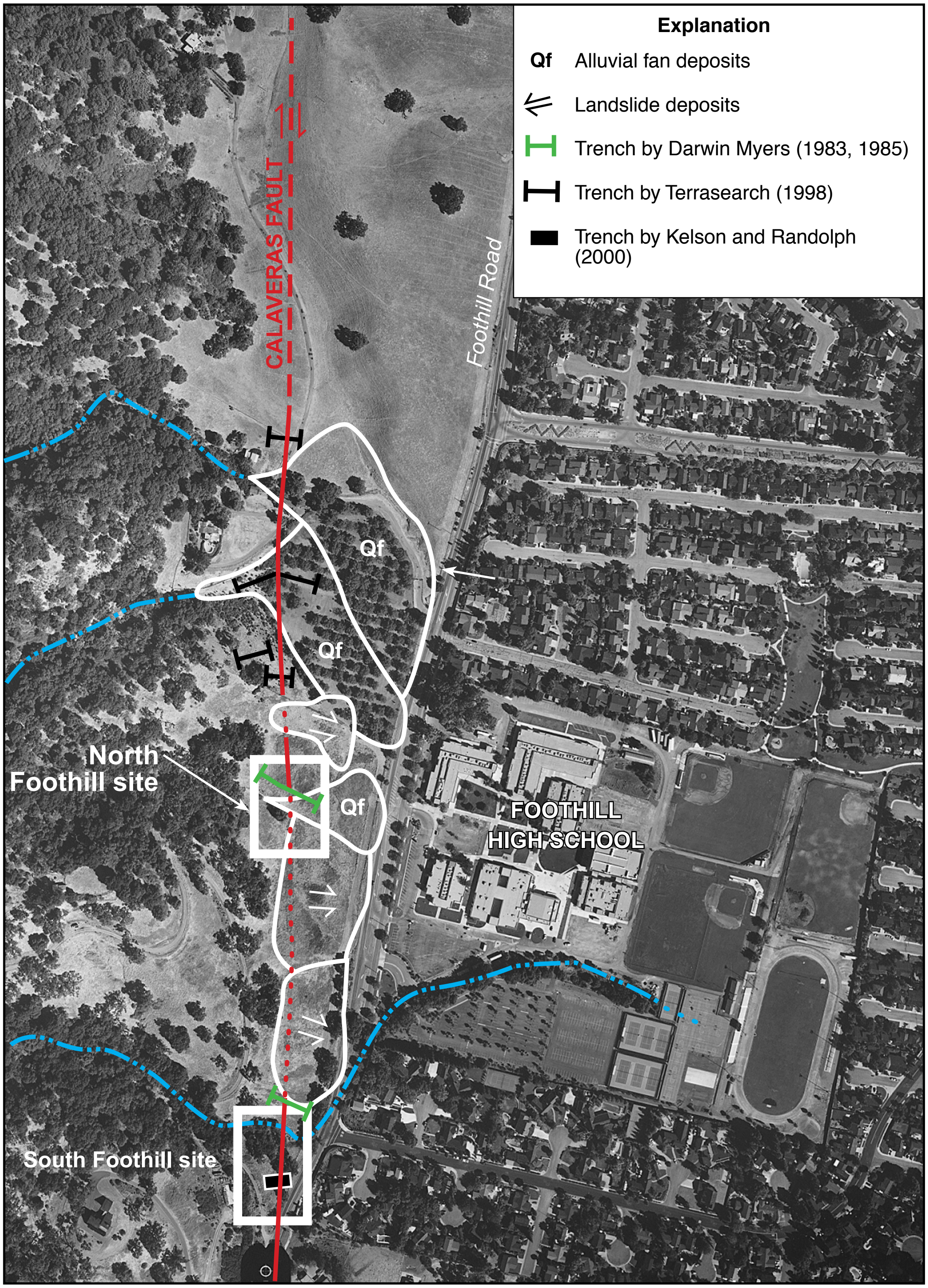
The Northern Calaveras fault exhibits little contemporary microseismicity compared to the Central Calaveras fault (Oppenheimer and Lindh, 1992; Oppenheimer and MacGregor-Scott, 1992). Only one moderate or large historical earthquake has been attributed to the Northern Calaveras fault: the 1861 **M**5.6 San Ramon Valley earthquake, which was associated with surface cracking in the area that is now occupied by the cities of San Ramon and Dublin (Toppozada et al., 1981). The 2007 **M**5.6 Calaveras

Reservoir earthquake occurred at or near the boundary between the Northern and Central Calaveras faults, and was not associated with surface rupture. Microseismicity swarms occurred in the vicinity of the fault in 1990, 2002, and 2003 (Figure 1), although these episodes probably do not reflect subsurface rupture along the primary fault. Oppenheimer and Lindh (1992) interpreted that the relative scarcity of contemporary microseismicity along the Northern Calaveras fault north of Calaveras Reservoir suggests that the fault is locked and could generate a M7 earthquake. They also interpreted that the fault alternatively may rupture in M6 earthquakes along shorter sections, as also suggested by Simpson et al. (1992). Oppenheimer and Lindh (1992) stated that there are insufficient data to calculate the probability of a M7 event on the fault, but estimated a probability of one or more events of $M \geq 6$ of 0.33. Current source characterization and probabilistic earthquake models suggest that there is a 7% probability of a large ($\mathbf{M} \geq 6.7$) earthquake on the Calaveras Fault (WGCEP, 2008).

2.2 Geologic Setting of the Northern Foothill Site

The Northern Calaveras fault is being rapidly modified by extensive urbanization in the San Ramon valley. In addition, several long reaches of the fault are covered by large landslide complexes, or have been eroded by large stream channels. As a result, there are only a handful of locations north of Calaveras Reservoir where evidence of recent faulting is not destroyed by urbanization, affected by landslides, or eroded away. Recent digital mapping by Kelson and Sundermann (2007) provides a comprehensive database of fault investigations and interpretation of primary and secondary strands of the fault. Based on previous field experience and the compilation by Kelson and Sundermann (2007), the North Foothill site was identified as a viable location for characterizing the surface-rupture history of the Northern Calaveras fault.

The Northern Calaveras fault at the North Foothill site consists of a prominent topographic break-in-slope across late Holocene alluvial-fan deposits, as well as a distinct vegetation lineament and alignment of springs in landslide deposits (Figure 2). In general, Cretaceous sandstone and siltstone of the Panoche Formation underlies the area west of the fault, deposits on the eastern side of the fault are composed of Livermore Formation gravel (Dibblee, 1980; Crane, 1988). Detailed geologic and geomorphic mapping at the North Foothill site provide excellent data on the fault location (Herd, 1978; Hart, 1980; Dibblee, 1980), and trenching and geophysical profiling at the site demonstrate that the fault consists of a single, well-defined fault strand (Figure 2; Darwin Myers Associates, 1983, 1985; Terrasearch, 1998). In particular, trench DM-3 (Darwin Myers Associates, 1983, 1985; Figure 3) extended both up-slope and down-slope from the present area of investigation, and identified the Northern Calaveras fault zone within Holocene colluvium and underlying bedrock. The bedrock relationships exposed in trench DM-3 demonstrate that landsliding has not affected young stratigraphy at the North Foothill site, such as in areas to the north and south (Kelson and Sundermann, 2007). The North Foothill site was chosen for this research, in part, because the previous work by Darwin Myers Associates (1983, 1985) and Terrasearch (1998) demonstrated the presence of a single, well-defined fault strand projecting beneath young alluvium (Figure 3).



Vertical aerial photograph of the North Foothill site and trench locations by Darwin Myers (1983, 1985), Terrasearch (1998), and Kelson and Randolph (2000).

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NORTH FOOTHILL SITE

Aerial Photograph of North Foothill Site

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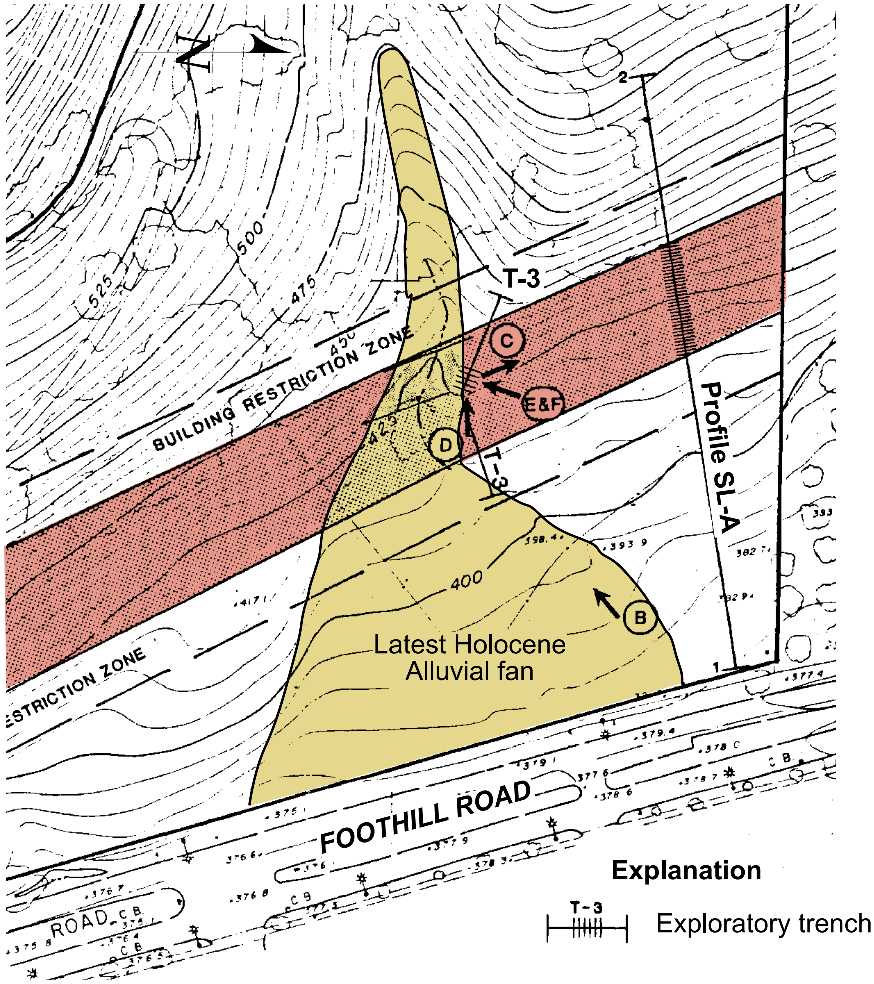
A)



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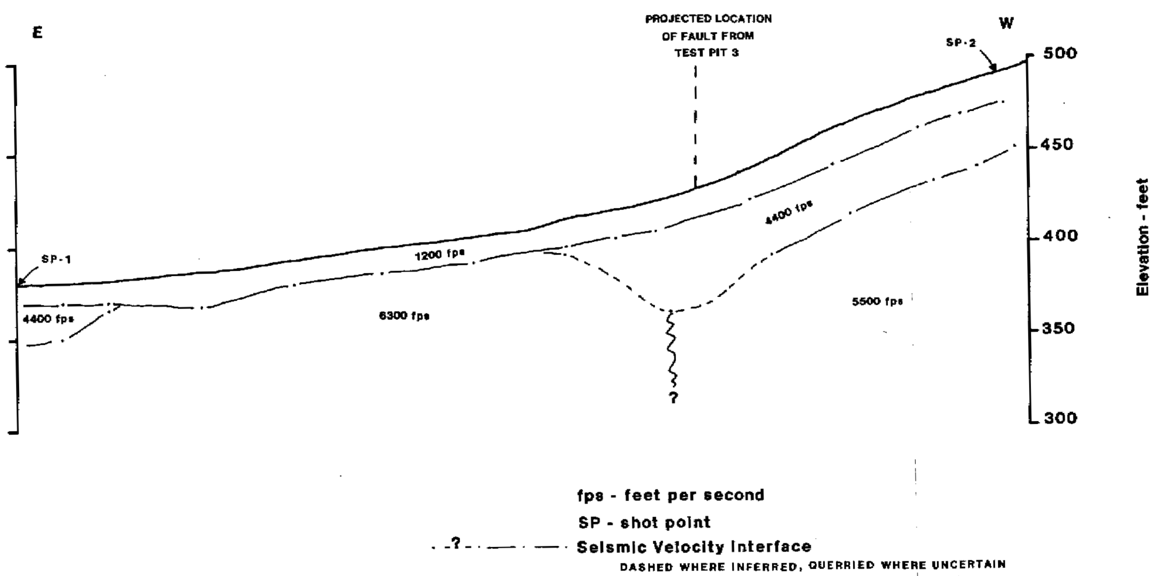

A) Detailed topo map of North Foothill site from Darwin Myers Associates (1985), showing location of Trench T-3, Northern Calaveras fault, and unfaulted latest Holocene alluvium. B) Seismic refraction profile SL-A from DMA (1985).

NORTHERN CALAVERAS FAULT
NORTH FOOTHILL SITE

Previous Investigations at the North Foothill Site

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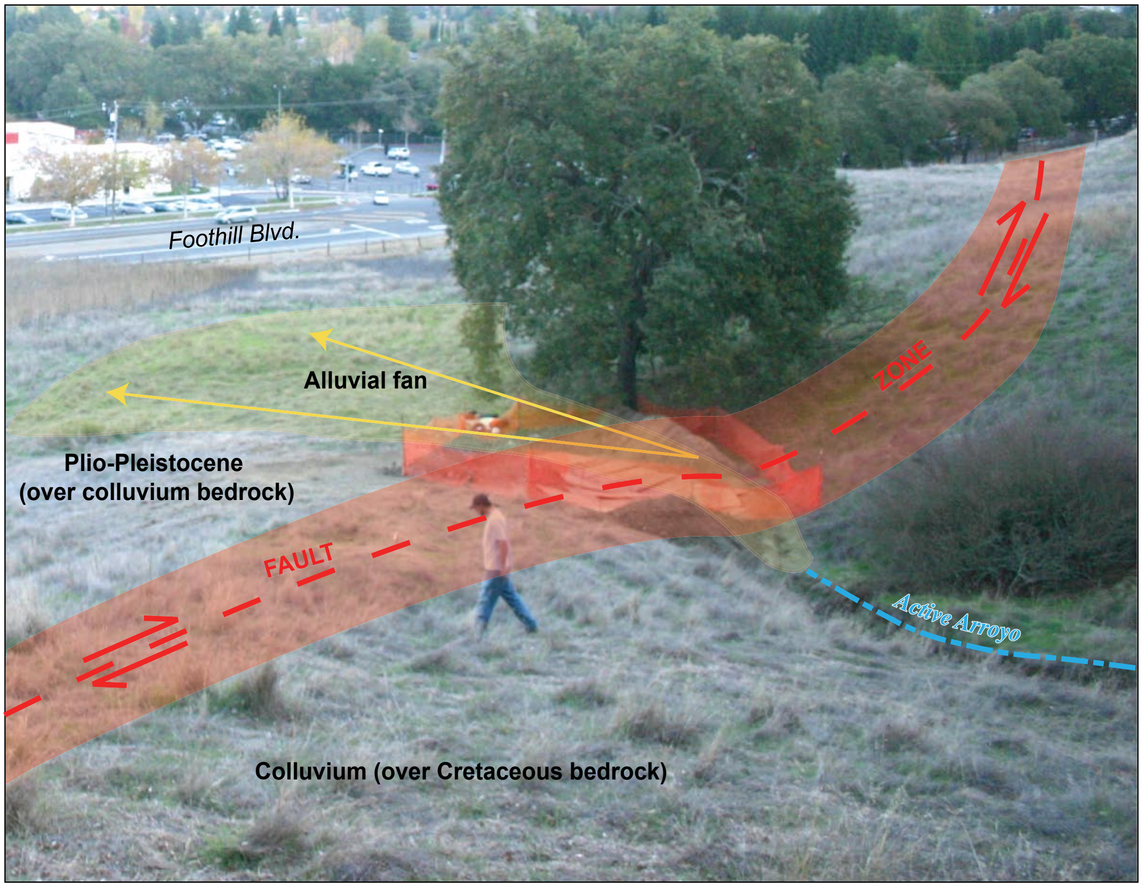
Directly south of trench DM-3, the fault crosses a narrow, flat-floored swale underlain by latest Holocene alluvium (Figures 3 and 4). The swale is approximately 3 to 4 m deep and is incised into Cretaceous bedrock west of the fault and Plio-Pleistocene Livermore Gravel east of the fault (Figure 5). Upstream of the fault, the swale is less than about 5 m wide, and is filled with alluvium shed from a small watershed developed in Cretaceous siltstone and sandstone (Dibblee, 1980). Downstream of the fault, alluvium within the swale grades into alluvial-fan deposits that overlie Livermore Gravel and possibly late Quaternary colluvium and landslide deposits. This investigation specifically targeted exposing the young, Holocene alluvial deposits in the narrow swale, where they cross the projection of the Northern Calaveras fault (Figure 5). The study consisted of five trench excavations, with one trench positioned adjacent to the previous trench DM-3, and four trenches located within the late Holocene alluvial swale (Figures 4 and 5).

Northeast

Southwest



Photograph of site showing local geology, view is to the southeast.

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Ground Photograph of the Northern Foothill Site

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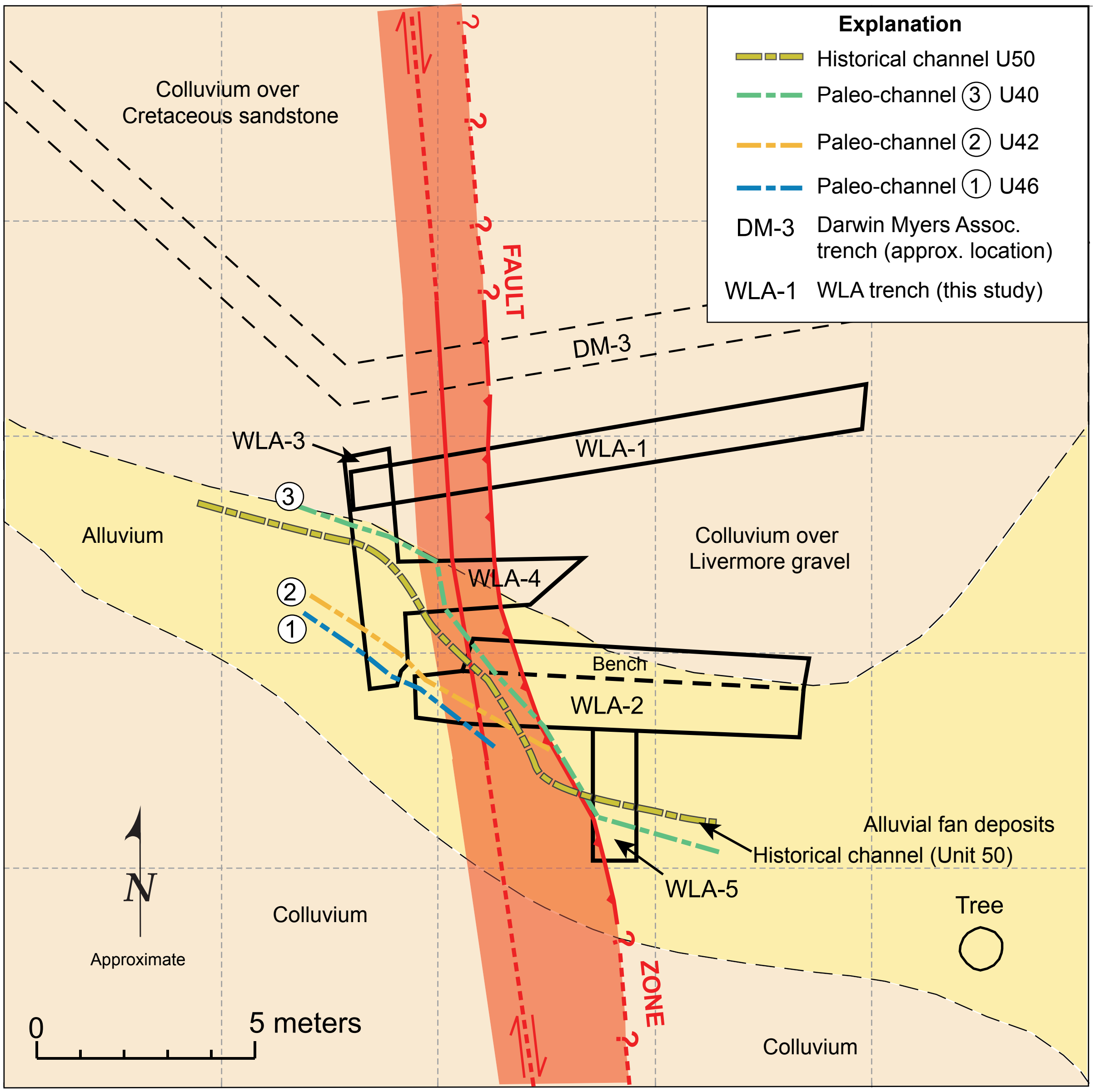

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Generalized Geologic Map of Trench Site

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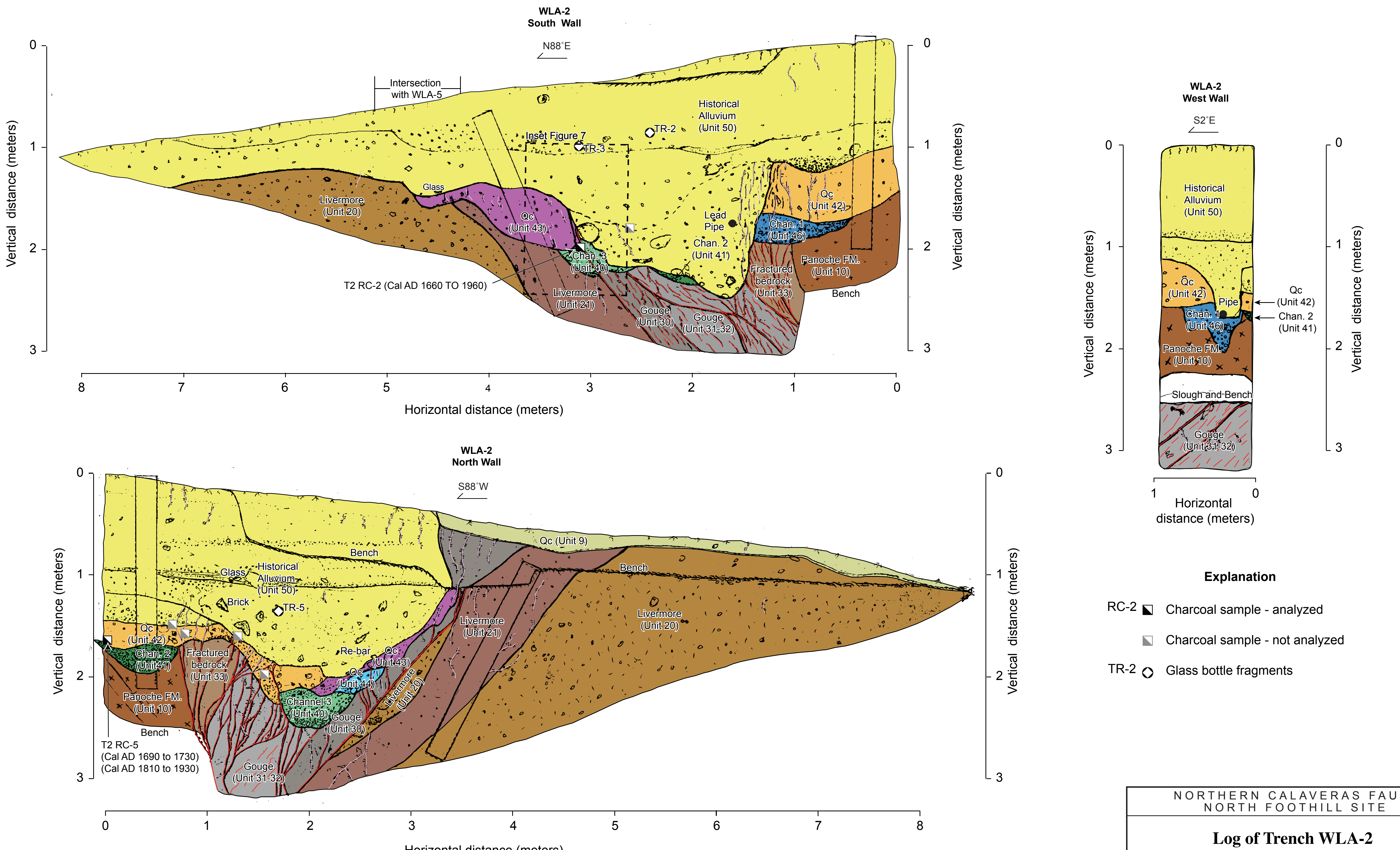
3.0 TRENCH GEOLOGIC STRUCTURE AND STRATIGRAPHY

The field exploration involved excavation of three fault-perpendicular and two fault-parallel trenches (one on each side of the fault; Figure 5), with the goal of exposing late Holocene sediments in the alluvial valley that could provide information on the timing of recent surface ruptures. The first excavation (trench WLA-1, Figure 5) was located on the east-facing colluvial slope adjacent to the previous trench DM-3, and was designed to confirm the location and width of the fault zone. Trench WLA-1 exposed the fault zone in bedrock, as described below, and provided a basis for siting subsequent trenches in younger alluvium. Trenches WLA-2 and WLA-4 were oriented parallel to and south of trench WLA-1, across the southward projection of the fault zone into the swale. Trenches WLA-3 and WLA-5 were oriented parallel to the fault zone to expose buried paleochannels on the western and eastern sides, respectively, of the fault zone, and to provide a three-dimensional documentation of the site stratigraphy (Figure 5). Trenches WLA-2 and WLA-4 provided excellent exposures of the fault zone, and trench WLA-5 documents the eastern edge of the zone. Trenches WLA-2, WLA- 3, WLA-4, and WLA-5 all exposed young alluvium beneath the swale floor, and document the presence of three paleochannels intersecting or overlying the fault zone (Figures 6 to 10). The trenches were logged in detail by hand, during a limited field program in late October and early November, 2007.

3.1 Generalized Fault Structure

In all the trenches, bedrock was encountered between about 0.5 and 2 meters depth, with Cretaceous siltstone west of the fault and Livermore Gravel east of the fault. The fault zone itself consists of a primary vertical shear zone that is approximately 1 to 1.5 meters wide, and a secondary, west-dipping reverse fault strand separating fault gouge from Livermore bedrock. The fault zone is a convex-up flower structure containing complexly deformed bedrock, fault gouge, and colluvium, and is overlain by unfaulted colluvium and historical alluvium. The primary strand has a general strike of about N10W (Figure 5), and the secondary western splay dips moderately west in areas close to the primary strand but dips progressively less at higher structural levels. In trench WLA-1, for example, the secondary fault strand shallows in dip to horizontal near the surface and, where affected by near-surface downslope processes changes to an east-dipping plane accommodating downslope soil creep. The fault zone exposed in trench WLA-1 is very similar to that exposed in trench DM-3 (Darwin Myers Associates, 1983, 1985), which was approximately 1 to 2 meters north of trench WLA-1 (Figure 5). In all of the trench exposures of fault planes, the primary vertical fault planes exhibited sub-horizontal slickenlines indicating right-lateral offset, whereas secondary, west-dipping planes contained slickenlines that suggest reverse-right-oblique movement. These relationships are consistent with the development of a local positive flower structure as part of the Northern Calaveras fault.



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Log of Trench WLA-2

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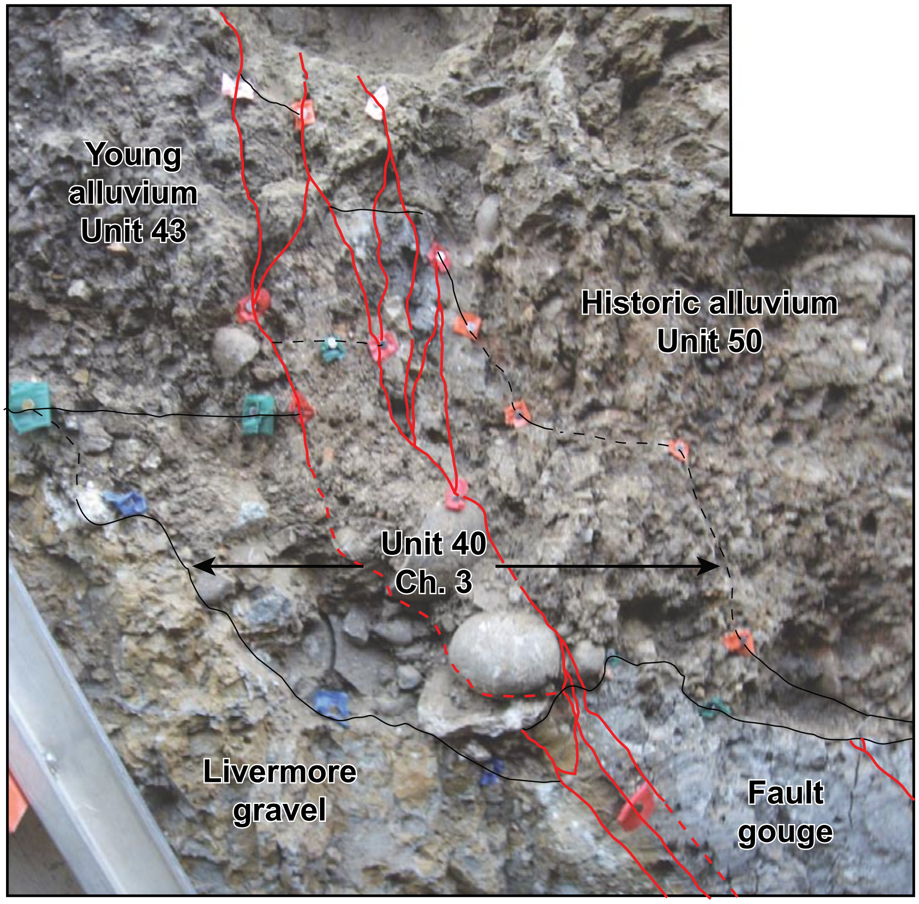
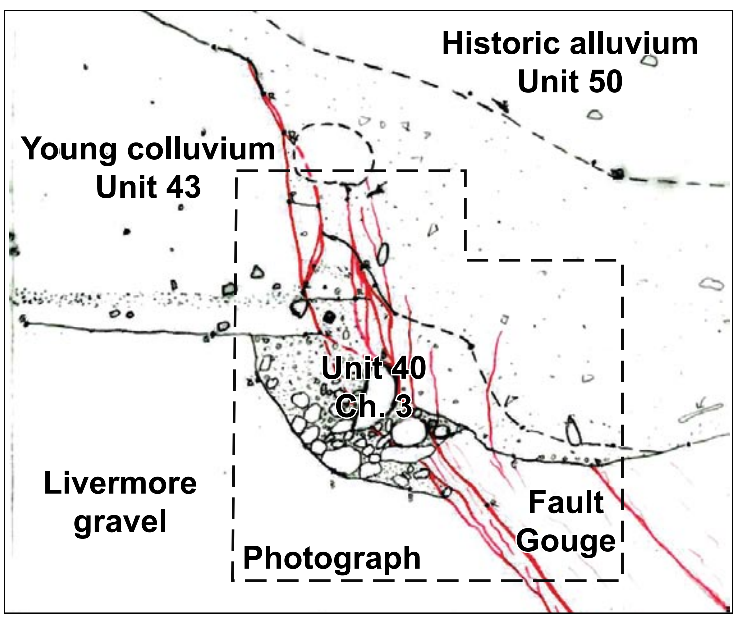


Detailed close-up of T-2 south wall fault zone



Interpretation

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Log of Trench WLA-2 (South Wall Detail)

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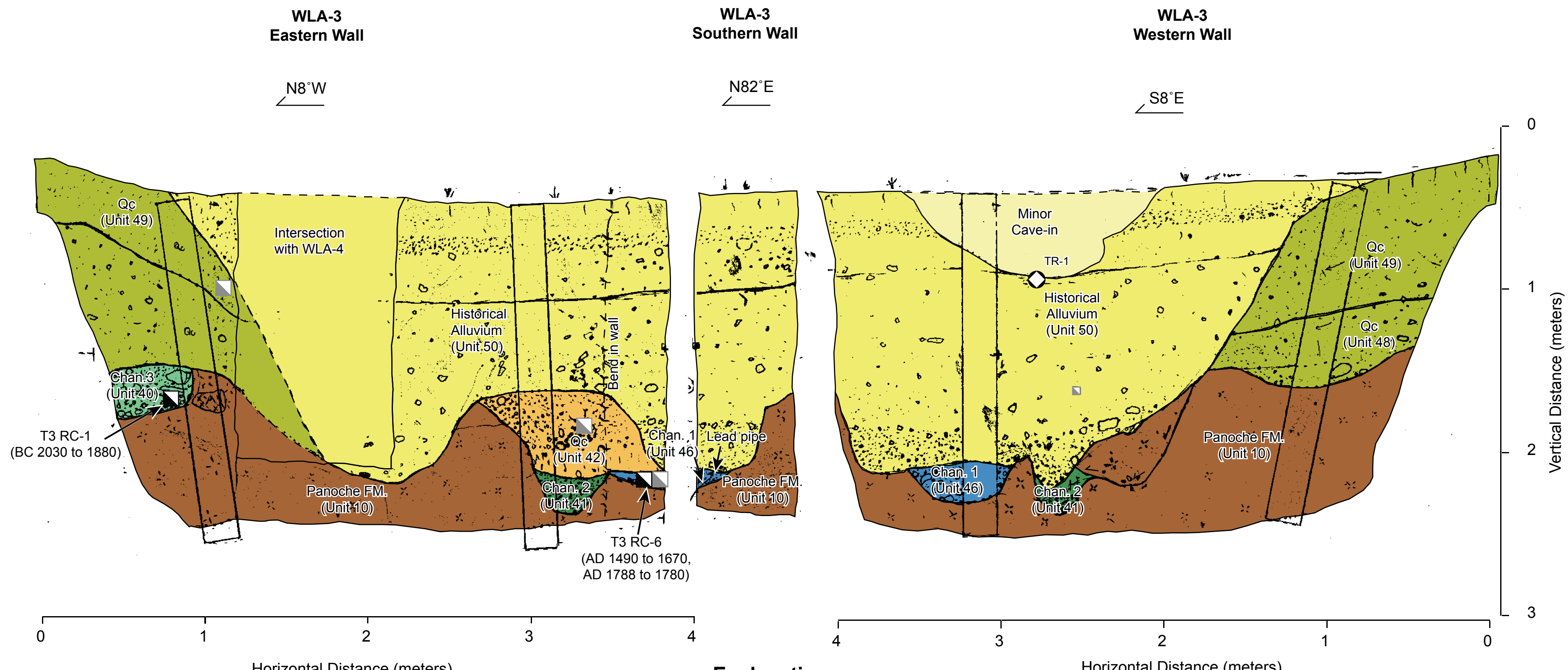

Explanation

T-3 RC-6 Charcoal sample - analyzed

Charcoal sample - not analyzed

TR-1 Glass bottle fragments

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Log of Trench WLA-3

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Figure 8

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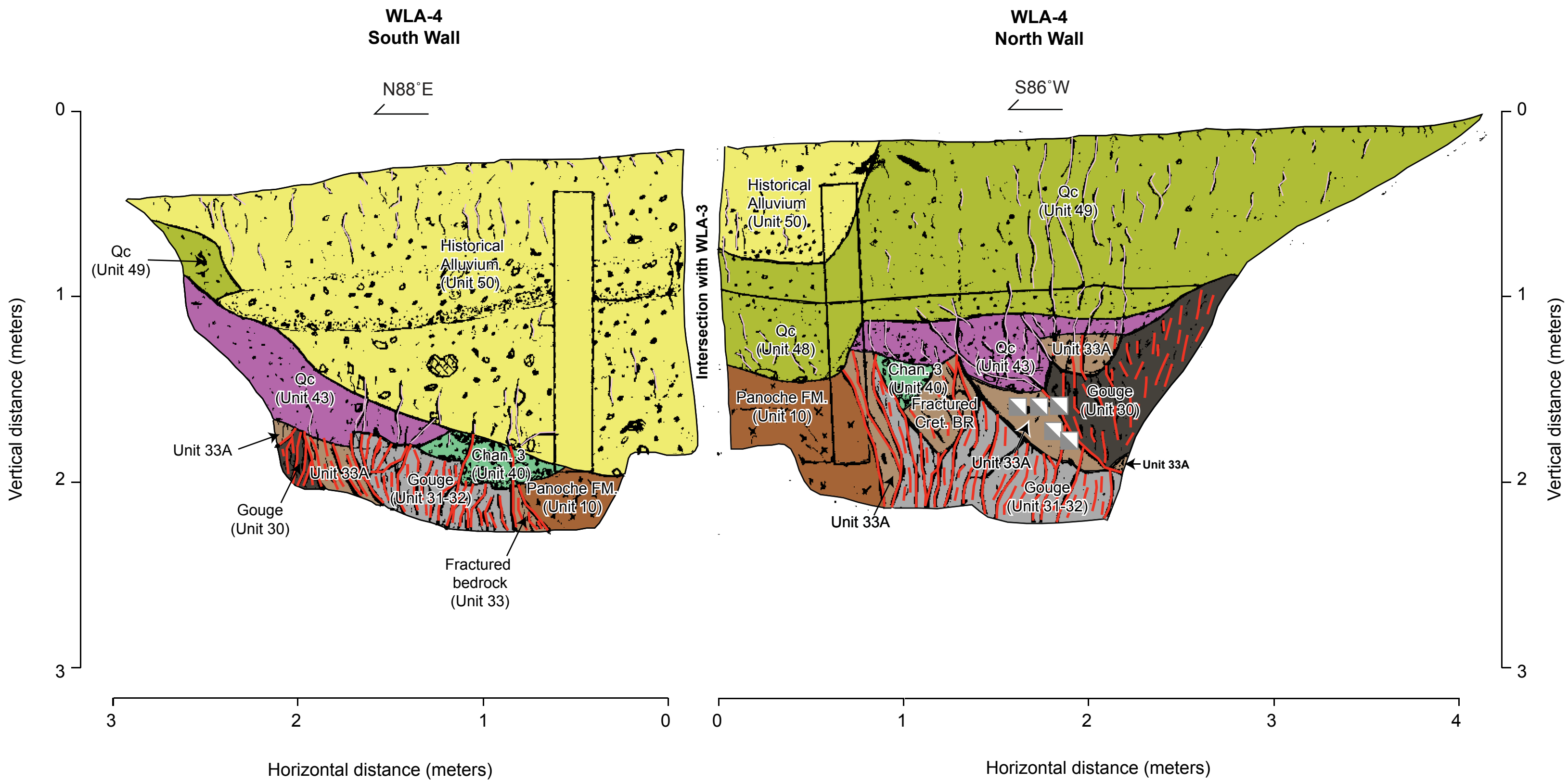

Explanation

Charcoal sample - not analyzed

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Log of Trench WLA-4

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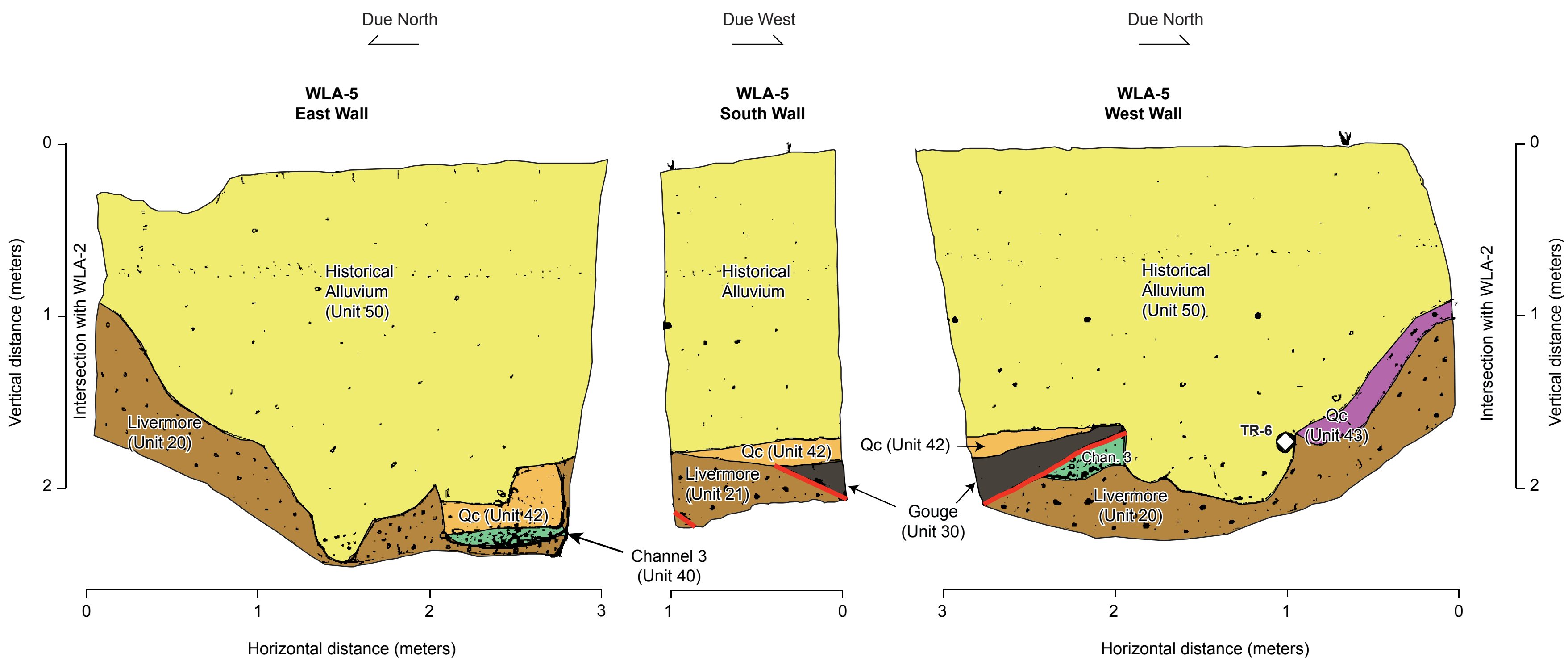

Explanation

T5 TR-1 ◇ Glass bottle fragments

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Log of Trench WLA-5

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3.2 Generalized Trench Stratigraphy

The trenches completed exposed late Holocene alluvium and alluvial-fan deposits, with some locally derived hillslope colluvium. Sedimentary deposits are correlated among trenches WLA-1 to WLA-5 based on lithologic characteristics, deposit continuity, relative stratigraphic position, and presence of historical debris. Additionally, all sedimentary units are correlated among exposures within trenches that intersect or are separated by less than 0.5 meters. General descriptions of deposits encountered in WLA-1 through WLA-5 are given below, and detailed descriptions are included in Appendix A.

Trench WLA-1 exposed Cretaceous siltstone bedrock, conglomerate of the Livermore Gravel, and a series of late Quaternary colluvial deposits. Bedrock and surficial deposit characteristics exposed in trench WLA-1 are similar to those in the adjacent trench DM-3 (Darwin Myers Associates, 1983, 1985), which was approximately 1 to 2 meters to the north. The fault zone consists of a convex-up flower structure and includes fault gouge and deformed colluvium. The colluvial deposits are deformed by the upward-splaying fault strands, and are stacked in a complex set of thrust slivers overlying the Livermore Gravel. Directly below the ground surface, active colluvium overlies bedrock and the fault zone, and is undeformed. Only a preliminary analysis of this tectonic structure was completed, because the primary focus of this trench was to locate the fault zone and use this information to estimate where it projects into young alluvium directly south of trench WLA-1 (Figure 5).

Trenches WLA-2 through WLA-5 exposed a sequence of young colluvial and alluvial deposits (Figures 6 to 10) that fill the swale. Correlation of deposits amongst all of the trenches is possible because of the proximity of the exposures and physical connection of trenches WLA-2 and WLA-5 and of trenches WLA-1, WLA-3, and WLA-4 (Figure 5). Figure 11 schematically illustrates the correlation of major sedimentary packages within the North Foothill site based on all of the trench exposures. Overall, the Holocene deposits overlying bedrock at the site include:

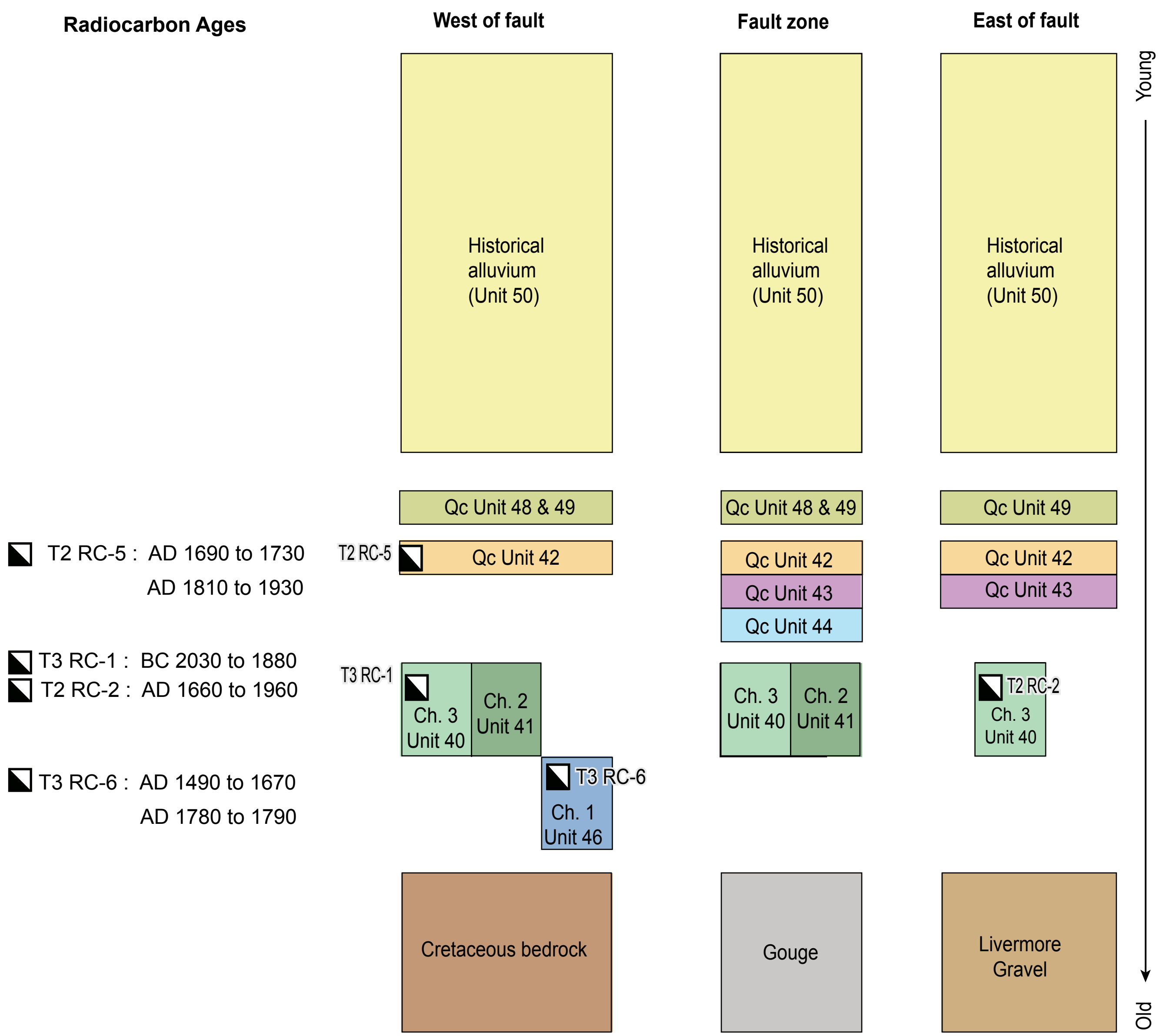
- Three distinct arroyo paleochannels, numbered arbitrarily Channel 1 to 3 (units 46, 41, and 40, respectively);
- Young colluvium derived from the northern margin of the swale (units 44, 43, and 42);
- Probable historical colluvium, also derived from the northern margin of the swale (units 48 and 49); and
- Historical swale-fill alluvium (unit 50).

These deposits rest unconformably on the Cretaceous bedrock, Plio-Pleistocene bedrock, or fault gouge within the fault zone. The three paleochannels are incised into these older materials, and are filled with poorly to moderately sorted gravel and sand. The paleochannel deposits commonly are bedded and have sandstone, siltstone, and Franciscan clast lithologies, but have other characteristics that make each channel-fill deposit distinct. Channel 1 (unit 46) generally contains rounded to subangular clasts as large as about 10 cm in a sandy to silty clay matrix, and is slightly firmer than the other channel-fill deposits. Channel 2 (unit 41) contains clasts that generally are smaller (as much as about 5 cm diameter), and slightly better sorted than those in Channel 1. This channel deposit has a consistent brownish yellow color and rounded to angular gravel with fine to coarse sand. Channel 3 (unit 40) contains a brown to dark brown matrix composed of silty clay with sand, and clasts that are larger (up to 30 cm diameter) than in the other channels. This channel also includes sections that contain very well bedded sand and pebble gravel lenses with little or no matrix. All of the channel deposits are discontinuous in the trench exposures, because of fault displacement and removal by historical erosion. All three of the channel-fill deposits appear to be displaced by fault creep and possibly by coseismic rupture.

A sequence of three colluvial units (units 42, 43 and 44) overlies the gravel-filled channels (Figure 11). These colluvial deposits generally are very dark gray to very dark grayish brown clay with gravel composed of siltstone, claystone and chert, and are mottled to strong brown and dark reddish brown. The lowermost of these colluvial deposits (unit 44) is only locally preserved in trench WLA-2, and is a stiff dark gray clay that is mottled dark reddish brown and contains subangular to subrounded clasts of siltstone, claystone, and chert. As noted above, the three local colluvial deposits were derived from topographically higher parts of the site flanking the northern edge of the swale (Figure 5). Younger colluvial deposits (units 48 and 49) are similar to, and unconformably rest on, these lower colluviums. All of the colluvial deposits exposed in the trenches exhibit evidence of faulting or creep-related shearing.

Historical alluvial deposits associated with the present-day swale are inset into the deposits noted above (Figure 11). These deposits (unit 50) locally are thick and represent substantial erosion and subsequent deposition during historical time. The very dark grayish brown to dark brown alluvium generally contains coarse gravel at its base, although it contains clasts and historical debris throughout the exposures. Locally, the deposit contains individual beds that likely represent distinct floods. Included within this deposit is a variety of historical debris, including glass bottles, metal, lead pipe, wood, masonry, and flatware. Notably, lower parts of this historical alluvium contain abundant shearing along the upward projections of faults in older alluvium or bedrock; however, upper parts of the historical alluvium contain relatively lesser amounts of shearing, and appear to have experienced lesser amounts of fault creep. In the southern wall of trench WLA-2 (Figure 6), for example, the main vertical fault strand developed in bedrock (at station 1.5 m) extends upward into the lower part of historical alluvium as a 30-

cm-wide shear zone; in the upper part of the alluvium, the shearing consists of only a few individual vertical fractures that extend nearly to the ground surface. In each of the six cross-fault exposures (trenches WLA-1, WLA-2. and WLA-4) shearing extends upward to or near the ground surface and thus probably represents active creep deformation.



Note: Vertical scale is arbitrary

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Site Stratigraphic Correlation Chart

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3.3 Deposit Age Estimates

Age estimates for surficial deposits at the Northern Foothill site are based primarily on radiometric analyses of charcoal fragments, and secondarily on the presence of historical debris within the alluvium. Deposits are correlated based on cross-cutting relationships, deposit characteristics, and ages of datable samples (i.e. charcoal and glass bottles). Several charcoal samples were collected from trenches WLA-2, WLA-3, and WLA-4, and several debris items were collected from the historical alluvium (unit 50) in various trenches. Four charcoal samples from trenches WLA-2 and WLA-3 were analyzed for radiocarbon age determination using Accelerator Mass Spectrometry (AMS) methods (Table 1; Appendix B). Analyses were completed on one sample from Channel 1 (unit 46), two samples from Channel 3 (unit 40), and one sample from the overlying colluvium (unit 42). The sample from Channel 1 yielded a calibrated age estimate of AD 1490 to 1670 or AD 1780 to 1790 (2 sigma range; Beta-238057, Appendix B). The stratigraphically higher Channel 3 deposit yielded one reliable calibrated age estimate of AD 1660 to 1960 (2 sigma range; Beta-238053, Appendix B), and one age estimate that appears unreasonable (2030 to 1880 BC; Beta-238056; Table 1). The stratigraphically highest sample analyzed was taken from colluvial unit 42 (Figure 11), and yielded a calibrated age estimate of AD 1690 to 1730 or AD 1810 to 1930 (2 sigma range; Beta-238054, Appendix B).

Age estimates for five glass bottle fragments, collected from Unit 50 in WLA-2, WLA-3, and WLA-5 were determined based on symbols and numbers on the bottles. Sample locations ranged from the upper part of the deposit to the very bottom of the deposit at the bedrock/alluvium interface, and were manufactured by 4 different bottling companies, and span at least 25 years, and more likely a longer period of time. The oldest bottle (TR5 WLA-2) was manufactured between 1905 and 1917, but is stratigraphically positioned above younger bottles, indicating that the deposit is not older than the bottle at the lowest stratigraphic position in the deposit. The bottle collected at the lowest point within the colluvial unit is located at the interface between historical colluvium and Livermore bedrock (within WLA-5), and was manufactured by Anchor Hawking Company in San Leandro, CA after 1937. The year code on the bottle suggests the bottle came from a year ending in a six – thus indicating the bottle is 1946 vintage or younger. The three other bottles have potential ages that do not pre-date 1946 (Table 1) suggesting the historical alluvial deposit Unit 50 was deposited after 1946.

Table 1. Radiocarbon and Historical Debris Age Estimates.

Radiocarbon Age Estimates

BETA Sample Number	WLA Sample Number	Location	Geologic Unit	Measured Radiocarbon Age	Accuracy	2-sigma Calibrated Age
238054	T2 RC5	WLA-2	Unit 42	90 ybp	+/- 40 years	AD 1690 to 1730, AD 1810 to 1930
238053	T2 RC2	WLA-2	Unit 40	130 ybp	+/- 40 years	AD 1660 to 1960
238056	T3 RC1	WLA-3	Unit 40	3580 ybp	+/- 40 years	2030 to 1880 BC
238057	T3 RC6	WLA-3	Unit 46	270 ybp	+/- 40 years	AD 1490 to 1670, AD 1780 to 1790

Historical Debris Age Estimates

Sample Number	Location	Geologic Unit	Bottle Manufacturer	Estimated Bottling Date	Preferred Age
T3 TR-1	WLA-3	Unit 50	Alexander H. Kerr Co.	1943-1992	1963
T2 TR-5	WLA-2	Unit 50	American Bottle Co.	1905-1925	1905 to 1926
T2 TR-3	WLA-2	Unit 50	Owens Illinois Glass Co.	1946-present	1952 or 1962
T2 TR-2	WLA-2	Unit 50	Owens Illinois Glass Co.	1946-present	1948 or 1958
T5 TR-1	WLA-5	Unit 50	Anchor Hawking Co.	1937-present	1946

4.0 SURFACE-RUPTURING EARTHQUAKES

The North Foothill site provides limited information on the timing of late Holocene surface-rupturing earthquakes on the Northern Calaveras fault. Stratigraphic relationships in trenches WLA-2 thru WLA-5 provide evidence of fault creep, and at least one late Holocene surface-rupturing event. The thick package of historical alluvium (unit 50) represents significant recent erosion and deposition, and indicates that a substantial part of the stratigraphic record has been removed at the North Foothill site. This resulted, unfortunately, in the removal of geologic data that could have yielded information on the timing of past surface ruptures along the Northern Calaveras fault. Through careful documentation of the existing remnants of the geologic record, this analysis provides some constraints on the timing of the most-recent surface rupture at the site.

Collectively, the five trenches in this investigation document the location and width of the active Northern Calaveras fault. The fault consists primarily of a zone usually less than about 3 m wide, with the primary vertical, right-lateral fault strand at or near the western edge of the zone, and an upward-splaying secondary reverse-oblique fault strand forming the eastern margin of the zone. Abundant faulting and complex deformation has occurred between these strands, and the materials within this zone include pulverized fault gouge and highly sheared bedrock material. Interpretation of the number and timing of late Holocene surface-rupturing earthquake relies on the characteristics of the remnants of surficial deposits remaining within and adjacent to the fault zone, and preserved between deformed bedrock materials and overlying, relatively undeformed historical alluvium. These scraps are identified as the three late Holocene channel-fill deposits (units 46, 41, and 40; Figures 6 to 10) and directly superjacent colluvial deposits (units 44, 43, and 42). Each of these deposits is faulted along either the vertical main fault strand or the west-dipping reverse-oblique fault (or both), although the degree of deformation is less than that within underlying bedrock units. The overlying historical alluvium (unit 50) also exhibits shearing where it overlies the vertical fault strand, although (as noted above) the development and width of shearing is substantially less than in underlying surficial deposits (i.e., Figure 6). The historical alluvium is not sheared where it overlies the west-dipping reverse-oblique fault (Figure 6), suggesting that this eastern strand does not accommodate substantial active fault creep.

The stratigraphic record and structural features exposed in the five trenches do not provide geologic evidence of specific surface ruptures, such as scarp-derived colluvial deposits or upward fault truncations that commonly have been utilized to identify ruptures on the Northern Calaveras fault (e.g., Kelson et al., 1996; Simpson et al., 1999). For example, if scarp-derived colluvial deposits existed following surface rupture at this site, subsequent erosion and depostion of the unexpectedly thick historical swale-fill alluvium effectively removed the geologic data necessary for interpretation of earthquake timing.

Some of the deformation of the late Holocene channel-fill deposits is clearly related to active fault creep, although geologic relationships suggest that some deformation is related to coseismic surface rupture. There is a substantial degree of deformation within the late Holocene channel-fill deposits, including sheared fine-grained matrix, rotation of gravel clasts, and juxtaposition of distinct stratigraphic units, which is consistent with significant fault deformation resulting from instantaneous coseismic rupture. Across the west-dipping secondary reverse-oblique fault, the channel-fill deposits also are strongly deformed or juxtaposed with substantially different units. Because the west-dipping reverse-oblique fault exhibits no evidence of active fault creep, it is likely that the deformation of late Holocene channel-fill deposits (unit 40, Figure 6) by the eastern fault strand is related to coseismic rupture rather than fault creep. In contrast, deformation of surficial deposits by the western primary strand clearly is associated with active creep; some of this deformation may also be a result of coseismic rupture.

The limited age estimates for the channel-fill deposits (Table 1; Appendix B) provide information on the timing of this deformation. Of the four radiocarbon analyses, three can be reasonably assumed to represent the ages of their respective deposits. Sample T3 RC1 (Beta-238056, Table 1) probably does not represent an accurate age estimate for channel-fill unit 40, because it is anomalously old and may have been a charcoal fragment that was re-worked from the watershed. The other three samples yielded overlapping, but internally consistent calibrated age estimates at the 2-sigma confidence level (Table 1; Appendix B). In summary, these data suggest that Channel 1 is probably younger than AD 1490, Channel 3 is probably younger than AD 1660, and colluvial unit 42 is probably younger than AD 1690.

Although all three of these deposits are deformed by the western vertical fault strand (which may be related to fault creep), only Channel 3 is clearly displaced by the eastern reverse-oblique fault strand. If the deformation of Channel 3 is a result of coseismic rupture, then this deformation occurred after AD 1660, the maximum limiting age for Channel 3 (unit 40, Table 1). The timing of this postulated rupture also is constrained by historical records, which suggest an absence of large earthquakes in the San Francisco Bay region between 1776 and 1838, based on records from Mission Dolores in downtown San Francisco (Toppozada and Borchardt, 1998). A large, surface-rupturing earthquake along the Northern Calaveras fault would likely cause significant shaking in San Francisco, and probably would have been identified in the historical record. On this basis, we interpret that a large coseismic rupture may have occurred along the Northern Calaveras fault at the North Foothill site between about AD 1660 and 1776.

However, the level of confidence in this timing is relatively low, because of the sparseness of age-estimates on displaced deposits and definitive stratigraphic evidence of surface-fault rupture.

The pattern of trench exposures developed during this investigation provides data for delineating the map pattern of the three paleochannel thalwegs through the site, as well as defining the thalweg of the historical arroyo prior to deposition of the historical alluvium (Figure 5). The thalwegs of all three paleochannels were identified in trenches WLA-2, WLA-3, and WLA-4, and have southeasterly trends and shallow gradients that are consistent with the site geomorphology. Channels 1 and 2 have relatively straight thalwegs that trend southeast into the fault, but were not exposed east of the fault zone because of logistical restrictions on the limits of trench excavations. Channel 3 and the historical arroyo have thalwegs that trend southeast into the fault zone, have a slight deflection within the fault zone, and were exposed east of the fault in trench WLA-5. The apparent right-lateral deflection of Channel 3 across the fault zone is approximately 3 to 6 m, although some of this deflection clearly is related to channel sinuosity and is not tectonic. Using a maximum age for Channel 3 of AD 1660 (347 years old) and assuming a minimum tectonic offset of 3 m, a minimum slip rate of 8.6 mm/yr can be calculated; this value is deemed unreliable based on the geologic slip rate (Kelson, 1999) and indicates that the thalweg map pattern may be mostly related to geomorphic sinuosity rather than fault offset. The historical thalweg also is relatively sinuous, and has an apparent deflection of as much as 5 m. Developing information on the amounts of geomorphic channel deflection and tectonic offset was beyond the scope of this investigation; with the present level of information on channel age and map pattern, the paleochannel thalwegs do not provide adequate resolution on the late Holocene slip rate of the Northern Calaveras fault.

5.0 CONCLUSIONS

Paleoseismic trenching at the Northern Foothill site provides data on the late Holocene earthquake history along the Northern Calaveras fault. The fault location and width are defined based on previous trenching and geophysical profiling, and are further documented herein based on an additional five trenches. This investigation involved three fault-perpendicular and two fault-parallel trenches within or adjacent to a swale that contains a thick section of late Holocene alluvium. Correlation of deposits among the five trenches is based on lithologic characteristics, deposit continuity, stratigraphic position, cross-cutting relationships, and presence of historical debris. Trenches across the fault zone provide stratigraphic and structural evidence for active fault creep on the vertical, right-lateral primary fault strand, and deformation within a 3-m-wide zone bordered on the east by a reverse-oblique, west-dipping secondary fault. The trench exposures exhibit prominent evidence of active fault creep as a well-developed shear fabric that extends upward from the prominent bedrock fault zone and into prehistorical and historical deposits. The shears decrease in prominence, width, and overall development in progressively younger deposits. Three distinct gravel-filled paleochannels are deformed within the fault zone, which probably reflects both creep-related deformation and coseismic rupture. Evidence for surface rupture at this site is indirect and based on deformation of paleochannel deposits along a non-creeping, secondary reverse-oblique fault strand. Based on these trench exposures and limited age estimates, the most-recent surface rupture along the Northern Calaveras fault at this site probably occurred between about AD 1660 and AD 1776.

6.0 ACKNOWLEDGEMENTS

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7.0 REFERENCES

Baldwin, J.N., Kelson, K.I., and Randolph, C.E., 1998, Timing of the most-recent surface faulting event on the northern Calaveras fault, near Sunol, California [abs.]: American Geological Union 1998 Fall 1998 Fall Meeting, EOS Supplement, v. 79, n. 4.

Crane, R., 1988, Geologic map of the Dublin quadrangle: Northern California Geological Society Field Trip Guide to the Geology of the San Ramon Valley and environs.

Dibblee, T.W., Jr., 1980, Preliminary geologic map of the Dublin quadrangle, Alameda and Contra Costa Counties, California: U.S. Geological Survey, Open-file Report 80-537, scale 1:24,000.

Darwin Myers Associates, 1983, Fault hazards reconnaissance, Yee Property, APN 941-2100-1-1, Pleasanton, California: unpublished consultant's report for Dr. and Mrs. William Yee, dated February 1, 1983.

Darwin Myers Associates, 1985, Fault hazards investigation, Yee Property, APN 941-2100-1-1, Pleasanton, California: unpublished consultant's report for Dr. and Mrs. Yee, dated August 5, 1985.

Hart, E.W., 1980, Calaveras and Verona faults (Dublin quadrangle): California Division of Mines and Geology, Fault Evaluation Report FER-108.

Herd, D., 1978, Map of Quaternary faulting, along the northern Calaveras fault zone: U.S. Geological Survey Open-file Report 78-307, scale 1:24,000.

Kelson, K.I., 2001, Geologic characterization of the Calaveras fault as a potential seismic source, San Francisco Bay area, California: California Division of Mines and Geology Special Publication 212, p. 179-192.

Kelson, K.I., and Baldwin, J.N., 2000a, Paleoseismic feasibility study of the northern Calaveras fault at Norris Canyon Road, San Ramon, California: Final Technical Report submitted to the U.S. Geological Survey Bay Area Paleoseismological Experiment (BAPEX), Contract Number 98WRCN1012, CLIN0012, 11 p.

Kelson, K.I., and Baldwin, J.N., 2000b, Paleoseismic feasibility study of the northern Calaveras fault at Forest Home Farm, San Ramon, California: Final Technical Report submitted to the U.S. Geological Survey Bay Area Paleoseismological Experiment (BAPEX), Contract Number 98WRCN1012, CLIN0013, 16 p.

Kelson, K.I., and Baldwin, J.N., 2000c, Paleoseismic feasibility study of the northern Calaveras fault at Martin Canyon, Dublin, California: Final Technical Report submitted to the U.S. Geological Survey Bay Area Paleoseismological Experiment (BAPEX), Contract Number 98WRCN1012, CLIN0011, 15 p.

Kelson, K.I., and Randolph, C.E., 2000, Paleoseismic study of the northern Calaveras fault at 4120 Foothill Road, Pleasanton, California: Final Technical Report submitted to the U.S. Geological Survey Bay Area Paleoseismological Experiment (BAPEX), Contract No. 98WRCN1012, 21 p.

Kelson, K.I., and Sundermann, S.T., 2007, Digital compilation of Northern Calaveras fault data for the Northern California Quaternary Fault Map Database: Final Technical Report submitted to the U.S. Geological Survey NEHRP, Award No. 05HQGR0023; summary at http://earthquake.usgs.gov/research/external/reports/05HQGR0023.pdf

Kelson, K.I., Lettis, W.R., and Lisowski, M., 1992, Distribution of geologic slip and creep along faults in the San Francisco Bay region, *in* Borchardt, G. and others, eds., Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology, Special Publication 113, p. 31-38.

Kelson, K.I., Simpson, G.D., Lettis, W.R., and Haraden, C., 1996, Holocene slip rate and earthquake recurrence of the northern Calaveras fault at Leyden Creek, northern California; Journal of Geophysical Research, v. 101, no. B3, p. 5961-5975.

Kelson, K.I., Tolhurst, J., and Manaker, D., 1999, Earthquakes on the Calaveras fault: Fact or Fiction? The geology, seismology and paleoseismology of the Calaveras fault: California Division of Mines and Geology, Special Publication 119, Geological Society of America Field Trip Guidebook for Cordilleran Section, p. 58-73.

Oppenheimer, D.H., and Lindh, A.G., 1992, The potential for earthquake rupture of the northern Calaveras fault: California Division of Mines and Geology Special Publication 113, p. 233-240.

Oppenheimer, D.H., and Macgregor-Scott, N., 1992, The seismotectonics of the eastern San Francisco Bay region: in Borchardt, G., et al., eds., Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: Calif. Div. Mines Geol. Spec. Pub. 113, p. 11-16.

Simpson, G.D., Lettis, W.R., and Kelson, K.I., 1992, Segmentation model for the northern Calaveras fault, Calaveras Reservoir to Walnut Creek: California Division of Mines and Geology Special Publication 113, p. 253-260.

Simpson, G.D., Lettis, W.R., Williams, C.R., Haraden, C.C., and Bachhuber, J.L., 1994, Paleoseismic investigation of the Northern Calaveras fault, Contra Costa and Alameda Counties, California: U.S. Geol. Surv. National Earthquake Hazard Reduction Program, Award Number 1434-93-G-2339, 26 p.

Simpson, G.D., Baldwin, J.N., Kelson, K.I., Lettis, W.R., 1999, Late Holocene slip rate and earthquake history for the northern Calaveras fault at Welch Creek, eastern San Francisco Bay area, California: Bulletin of Seismological Society of America, v. 89, p. 1250-1263.

Terrasearch, Inc., 1998, Geologic/Seismic Investigation on Proposed Residential Development, 4456 Foothill Road, Pleasanton, California: unpublished consultant's report for Delco Builders & Developers, dated November 9, 1998.

Toppozada, T.R., and Borchardt, G., 1998, Re-evaluation of the 1836 "Hayward Fault" and the 1838 San Andreas fault earthquakes: Bulleting of the Seismological Society of America, v. 88, p. 140-159.

Toppozada, T.R., Real, C.R., and Parke, L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes: California Division of Mines and Geology Open-file Report 81-11 SAC, 182 p.

Unruh, J.R., and Kelson, K.I., 2002, Critical evaluation of the northern termination of the Calaveras fault, eastern San Francisco Bay area, California: unpublished Final Technical Report submitted to the USGS NEHRP, Award Number 00-HQ-GR-0082; 28 p.

Working Group on California Earthquake Probabilities (WGCEP), 2003, Earthquake probabilities in the San Francisco Bay region: 2002-2031: U.S. Geological Survey Open-File Report 03-214.

WGCEP, 2008, The Uniform California Earthquake Rupture Forecast, Version 2 (UCERF 2): U.S. Geological Survey Open-File Report 2007-1437 and California Geological Survey Special Report 203 (http://pubs.usgs.gov/of/2007/1437/.

APPENDIX A

Lithologic Descriptions of Deposit in Trench at the North Foothill Site, Pleasanton

Unit 50
CLAY, gravelly, with trace sand, (CL); very dark grayish brown to dark brown (10YR 3/2 to 3/3); dry to damp; very stiff; 5% to 10% fine to coarse sand, 45% to 50% fine pebbles to large gravel; gravel is well rounded to subangular with occasional angular clasts, composed of poorly graded and poorly sorted siltstones, claystones, and chert; unit contains historical debris and locally has well expressed laminations; [Historical Alluvium/Colluvium].

Unit 49
CLAY with silt, sand and gravel, (CL); brown (10 YR 4/3); dry to damp; soft to medium stiff; approximately 75% clay, 15% silt and 5% sand and gravel; sand and gravel is angular to well rounded; low plasticity, contains rootlets; [Colluvium/Active Soil].

Unit 48
CLAY with trace gravel, (CL-CH); very dark grayish brown and very dark gray (10 YR 3/2 and 3/1); damp; very stiff; massive; approximately 5% gravel, medium to fine pebbles, occasionally coarse pebbles consisting of siltstones and claystones moderately to heavily weathered with local caliche development; [Colluvium].

Unit 42
CLAY, with gravel, (CL); very dark gray to very dark grayish brown (10YR 3/1 – 3/2), mottled with strong brown (7.5Y 4/6) and oxidized dark reddish brown (5YR 3/4); damp; very stiff; 25% gravel, very fine pebbles to coarse pebbles, 5% coarse sand; gravels are well rounded to subangular and mostly siltstones and claystones, with less than 5% chert; rootlets and woody debris are present [Colluvium].

Unit 43
CLAY, gravelly, (CL); very dark gray to very dark grayish brown (10YR 3/1 – 3/2), very similar to Unit 42, but more gravel, 30-35% gravel; gravel is generally very fine to medium pebbles, with rare large gravel; gravels are well rounded to subangular, siltstone and claystone with occasional chert; [Colluvium].

Unit 43*
Similar to Unit 43, but additionally has weathered caliche; [Colluvium].

Unit 44
CLAY, with gravel, (CL-CH); dark gray (N4), mottled with dark reddish brown (5YR 3/4); damp; very stiff; 15% sub-rounded to sub-angular gravels, up to large gravel-sized; gravels are poorly graded with trace clay matrix, and composed of siltstone, and claystone, with sparse chert; [Colluvium].

Unit 46
GRAVEL with sand and silt (GP), yellowish brown (10YR 5/8); dry; loose; ~60% gravel, 35% sand, 5% silty clay; gravels are well rounded to subangular, poorly graded, and composed of claystone, siltstone, chert, one instance of quartzite; sand content varies between exposures; [Paleochannel 1/Alluvium].

Unit 41
GRAVEL, with sand, (GW-GP); brownish yellow (10YR 6/8); dry; loose to medium dense; 75% gravel,

25% sand, 5% silty clay; gravels are well rounded to angular, mostly rounded, composed of chert, claystone, and siltstone; gravel size is up to 6 cm, and generally less than or equal to 3cm; center of channel contains very coarse pebbles and is well graded; sand is rounded to subangular very fine to coarse grained; [Paleochannel 2/Alluvium].

Unit 40
GRAVEL, with silty clay and sand, (GW-GC); gray (10YR 6/1 to 5/1) with localized zones of weathering/oxidation resulting in brownish yellow coloring (10YR 6/8); dry; medium dense to loose; unit is 70% gravel, 20% sand, 10% silt and clay; gravels are well rounded to sub angular; range in size from very fine to very coarse pebbles (up to 6cm); gravel is well graded, fining upwards, and composed of chert, siltstone, claystone, and rare quartz gravel; sand is rounded to subangular very fine to coarse grained; some rootlets; clast supported; [Paleochannel 3/Alluvium].

Unit 36
CLAY with trace gravel, (CL-CH); dark grayish brown and gray to dark gray (10 YR 4/2 and 10 YR 5/1 – 4/1); damp; very stiff; massive; <5% gravel, fine to medium grained sub-rounded claystone gravels, generally well sorted; [Colluvium (mix of unit 30 and 48?)].

Unit 33A
CLAY with gravel and silt, CL-CH; dark grayish brown to brown (10 YR 4/2 to 4/3); damp to dry; medium stiff; approximately 30% gravel; poorly sorted; mainly angular occasional large gravel consisting of heavily weathered subangular to subrounded siltstone and claystone; [Buried Colluvium].

Unit 35
Clay with trace gravel, CL-CH; very dark gray to very dark grayish brown (10 YR 3/1 to 10 YR 3/2) with dark yellowish brown mottling (10 YR4/4); damp; very stiff; massive; 5-10% gravel; fine to medium pebbles' heavily weathered claystone, sparse cobbles, sparse chert, gravels are subangular to well rounded; blocky; [Weathered Livermore Bedrock].

Unit 34
CLAY with trace gravel, CH; dark yellowish brown (10 YR 3/4 to 10 YR 4/4); damp; very stiff; massive; ~5% fine to medium fine siltstone and chert pebbles; heavily weathered and oxidized, fracturing, blocky; [Weathered Livermore Bedrock].

Unit 9
CLAY with gravel, CL; clasts are angular to subangular with some rounded; siltstone and sandstone clasts up to 1cm; clay matrix; [Krotovena or Fissure Fill?].

Unit 11
CLAYSTONE to sandy siltstone, very dark gray and brownish yellow (10YR 3/1 to 4/1 and 10YR 6/8); completely weathered to residual soil, very weak, locally rocky, highly oxidized locally, sparse to no caliche/calcium carbonate; appears massive to faintly laminated locally; sharp contact with overlying unit; [Weathered Cretaceous Bedrock].

Unit 30,
Clay, CH; Dark gray to gray (10 YR 4/1 to 5/1); damp to moist; medium stiff; massive; approximately 1% yellowish brown siltstone clasts, 4mm in size; unit contains prominent calcium carbonate development with caliche gravel development at base of unit; [Gouge].

Unit 31 and 32,
Clay, CH; Gray to Dark gray (10 YR 4/1 to 5/1); damp to moist; medium stiff; massive "flow" structure;

no calcium carbonate development; Unit 31 is a darker gray; [Gouge].

Unit 33,
Same as Unit 10 (described below) but fractured, and slightly weathered; [Fractured Cretaceous Bedrock].

Unit 20
GRAVEL with sand and clay, GP; mottled, light yellowish brown (2.5 Y 6/3) and yellowish brown (10 YR 5/8); dry to damp, dense to hard; 25-40% sand, very fine to coarse, subangular, 15% clay and 50-55% gravel, gravels are well rounded to angular, up to 13 cm, generally 3mm to 3cm, include claystones, chert, Franciscan meta-gravels; massive; poorly sorted; poorly graded; trace caliche; [Livermore Gravel Bedrock].

Unit 10
CLAYSTONE to sandy siltstone; color ranges between very dark gray to dark gray (10yr 3/1-4/1), to grayish brown (10YR 5/2) and Gray (10YR 6/1); moderately weathered to completely weathered locally; very weak (R1); laminated; highly disturbed by adjacent fault, locally blocky; oxidized; strong to violent HCL reaction; moderately to well indurated; [Cretaceous Bedrock].

APPENDIX B
Laboratory Analysis Results from Radiocarbon Analyses for the North Foothill Site, Pleasanton

Mr. Jeff Hoeft — Report Date: 1/10/2008

William Lettis & Associates, Inc. — Material Received: 11/29/2007

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 238053	130 +/- 40 BP	-24.8 o/oo	130 +/- 40 BP

SAMPLE : WLA1875T2RC2
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal AD 1660 to 1960 (Cal BP 280 to 0)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 238054	90 +/- 40 BP	-27.1 o/oo	60 +/- 40 BP

SAMPLE : WLA1875T2RC5
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal AD 1690 to 1730 (Cal BP 260 to 220) AND Cal AD 1810 to 1930 (Cal BP 140 to 20)
Cal AD 1950 to beyond 1960 (Cal BP 0 to 0)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 238056	3580 +/- 40 BP	-24.4 o/oo	3590 +/- 40 BP

SAMPLE : WLA1875T3RC1
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal BC 2030 to 1880 (Cal BP 3980 to 3830)

Sample Data	Measured Radiocarbon Age	13C/12C Ratio	Conventional Radiocarbon Age(*)
Beta - 238057	270 +/- 40 BP	-24.5 o/oo	280 +/- 40 BP

SAMPLE : WLA1875T3RC6
ANALYSIS : AMS-Standard delivery
MATERIAL/PRETREATMENT : (charred material): acid/alkali/acid
2 SIGMA CALIBRATION : Cal AD 1490 to 1670 (Cal BP 460 to 280) AND Cal AD 1780 to 1790 (Cal BP 160 to 160)

CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.8:lab. mult=1)

Laboratory number: **Beta-238053**

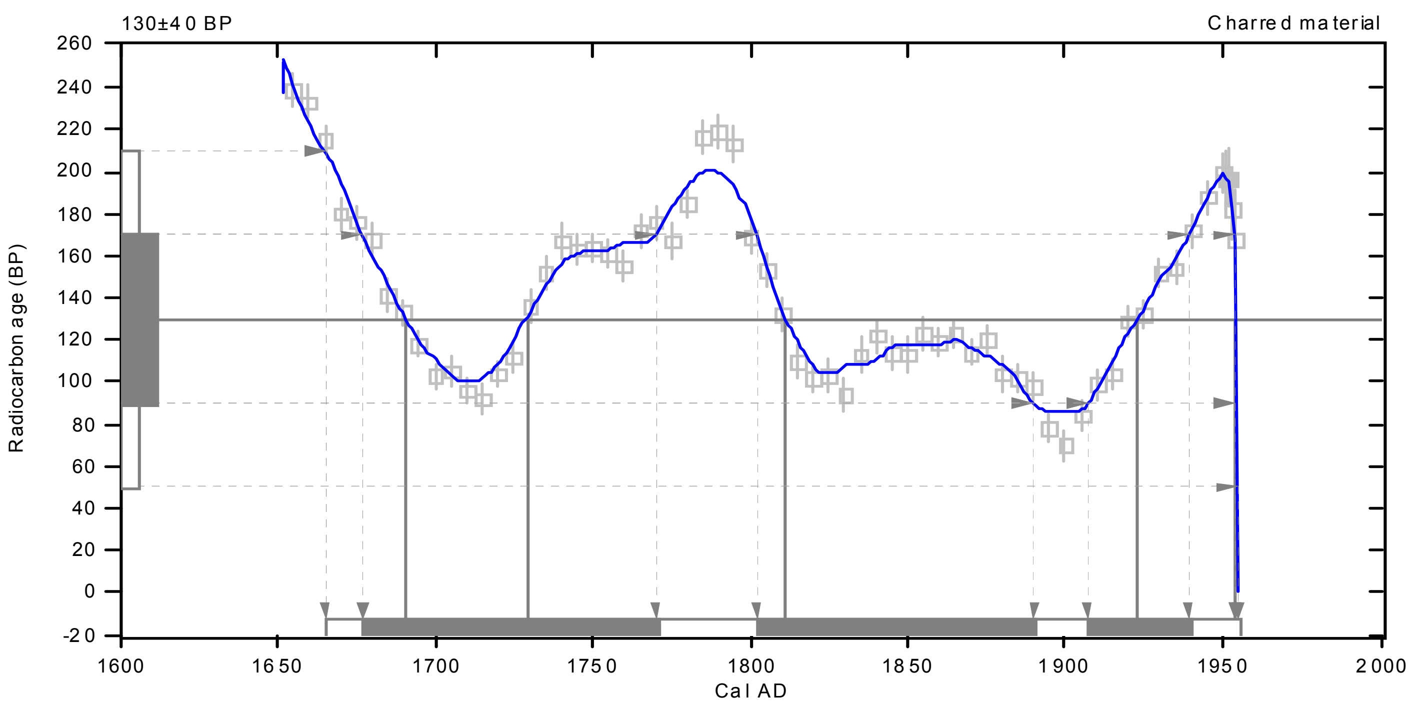
Conventional radiocarbon age: **130±40 BP**

2 Sigma calibrated result: (95% probability) **Cal AD 1660 to 1960 (Cal BP 280 to 0)**

Intercept data

Intercepts of radiocarbon age with calibration curve:
Cal AD 1690 (Cal BP 260) and
Cal AD 1730 (Cal BP 220) and
Cal AD 1810 (Cal BP 140) and
Cal AD 1920 (Cal BP 30) and
Cal AD 1950 (Cal BP 0)

1 Sigma calibrated results: (68% probability)
Cal AD 1680 to 1770 (Cal BP 270 to 180) and
Cal AD 1800 to 1890 (Cal BP 150 to 60) and
Cal AD 1910 to 1940 (Cal BP 40 to 10) and
Cal AD 1950 to 1950 (Cal BP 0 to 0)



References:

Database used
INTCAL04
Calibration Database
INTCAL04 Radiocarbon Age Calibration
IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).
Mathematics
A Simplified Approach to Calibrating C14 Dates
Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

Beta Analytic Radiocarbon Dating Laboratory

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-27.1:lab. mult=1)

Laboratory number: **Beta-238054**

Conventional radiocarbon age: **60±40 BP**

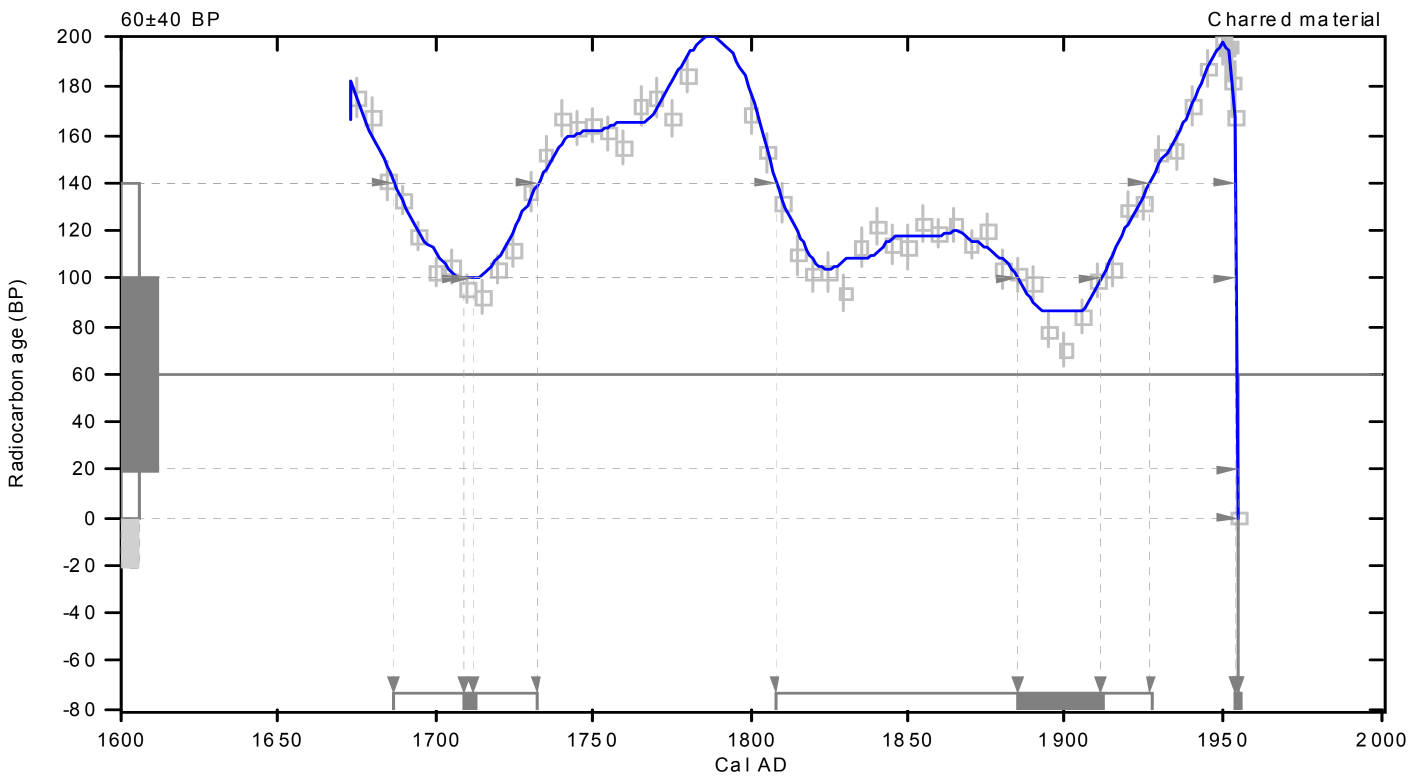
2 Sigma calibrated results[2]: **Cal AD 1690 to 1730 (Cal BP 260 to 220) and**
(95% probability) **Cal AD 1810 to 1930 (Cal BP 140 to 20) and**
Cal AD 1950 to beyond 1960 (Cal BP 0 to 0)

[2] 2 Sigma range being quoted is the maximum antiquity based on the minus 2 Sigma range

Intercept data

Intercept of radiocarbon age with calibration curve: Cal AD 1960 (Cal BP 0)

1 Sigma calibrated results: Cal AD 1710 to 1710 (Cal BP 240 to 240) and
(68% probability) Cal AD 1880 to 1910 (Cal BP 60 to 40) and
Cal AD 1950 to 1960 (Cal BP 0 to 0)



References:

Database used
INTCAL04
Calibration Database
INTCAL04 Radiocarbon Age Calibration
IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).
Mathematics
A Simplified Approach to Calibrating C14 Dates
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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.4:lab. mult=1)

Laboratory number: **Beta-238056**

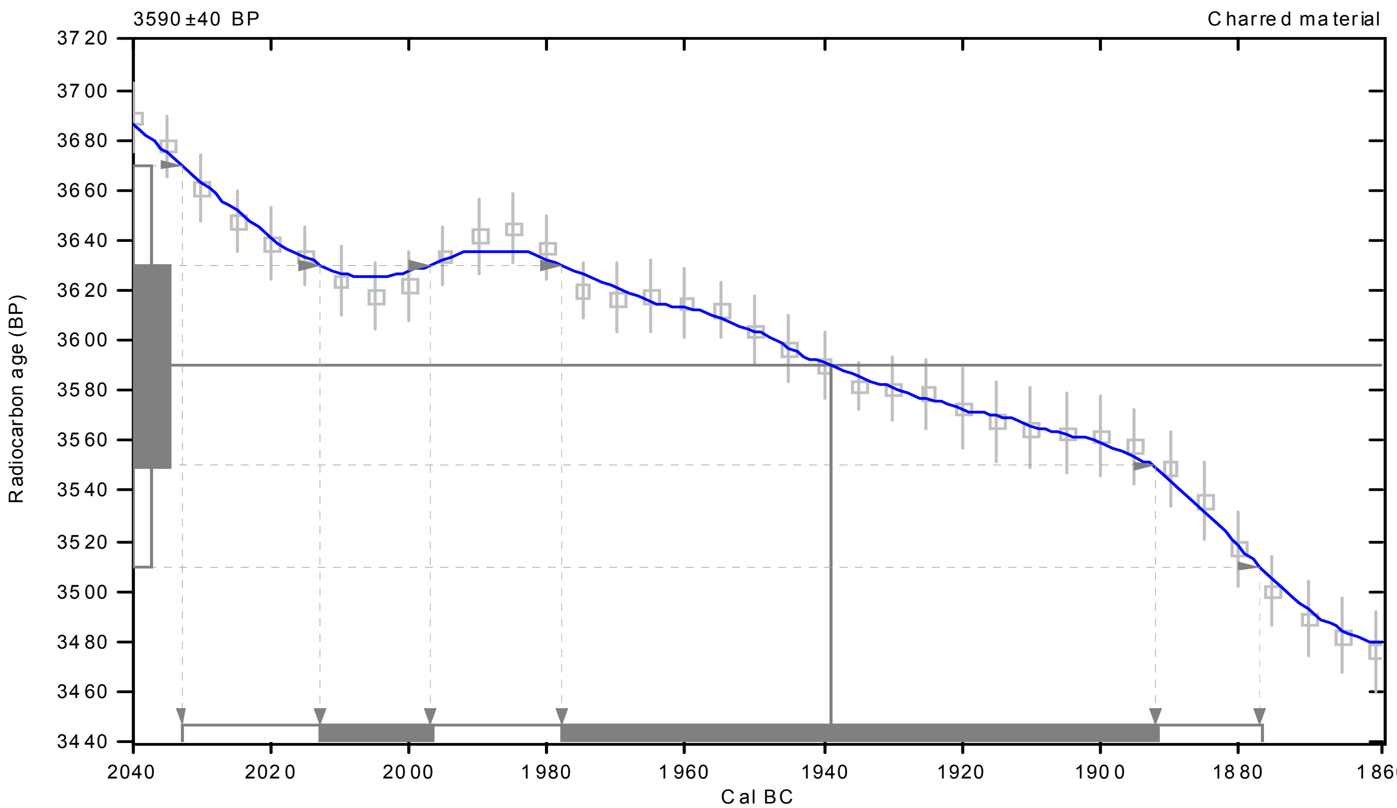
Conventional radiocarbon age: **3590±40 BP**

2 Sigma calibrated result: (95% probability) **Cal BC 2030 to 1880 (Cal BP 3980 to 3830)**

Intercept data

Intercept of radiocarbon age with calibration curve: Cal BC 1940 (Cal BP 3890)

1 Sigma calibrated results: (68% probability) Cal BC 2010 to 2000 (Cal BP 3960 to 3950) and Cal BC 1980 to 1890 (Cal BP 3930 to 3840)



References:

Database used

INTCAL04

Calibration Database

INTCAL04 Radiocarbon Age Calibration

IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).

Mathematics

A Simplified Approach to Calibrating C14 Dates

Talma, A. S., Vogel, J. C., 1993, Radiocarbon 35(2), p317-322

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CALIBRATION OF RADIOCARBON AGE TO CALENDAR YEARS

(Variables: C13/C12=-24.5:lab. mult=1)

Laboratory number: **Beta-238057**

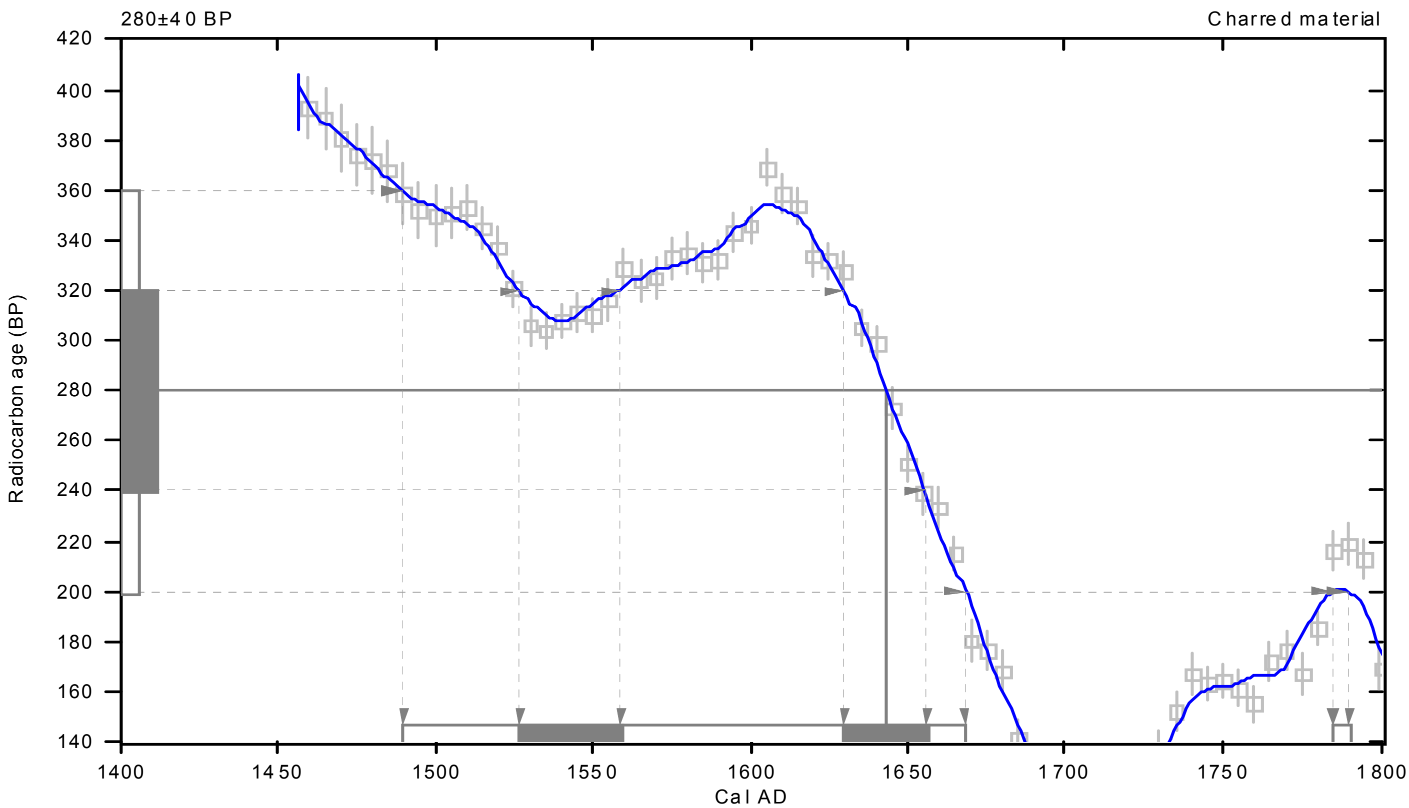
Conventional radiocarbon age: **280±40 BP**

2 Sigma calibrated results: **Cal AD 1490 to 1670 (Cal BP 460 to 280) and**
(95% probability) **Cal AD 1780 to 1790 (Cal BP 160 to 160)**

Intercept data

Intercept of radiocarbon age
with calibration curve: Cal AD 1640 (Cal BP 310)

1 Sigma calibrated results: Cal AD 1530 to 1560 (Cal BP 420 to 390) and
(68% probability) Cal AD 1630 to 1660 (Cal BP 320 to 290)



References:

Database used
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IntCal04: Calibration Issue of Radiocarbon (Volume 46, nr 3, 2004).
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