FINAL TECHNICAL REPORT

MAPPING OF THE WEST NAPA FAULT ZONE FOR INPUT INTO THE NORTHERN CALIFORNIA QUATERNARY FAULT DATABASE

USGS External Award Number
05HQAG0002

Investigators

John R. Wesling
Department of Conservation
Office of Mine Reclamation
801 K Street, MS 09-06
Sacramento, CA 95814-3529
(916) 323-9277, FAX (916) 322-4862
John.Wesling@conservation.ca.gov

Kathryn L. Hanson
AMEC Geomatrix Consultants, Inc.
2101 Webster Street, 12th Floor
Oakland, California 94612
(510) 663-4146, FAX (510) 663-4141
kathryn.hanson@amec.com

Note This final technical report also summarizes work that was completed as part of U.S. Grant Number 1434-98-GR-00018. Mr. Andrew Thomas, Dr. Frank (Bert) Swan, and Ms. Jennifer Thornberg participated in the earlier study.

TABLE OF CONTENTS

TABLES

FIGURES

PLATE

APPENDIX

MAPPING OF THE WEST NAPA FAULT ZONE FOR INPUT INTO THE NORTHERN CALIFORNIA QUATERNARY FAULT MAP DATABASE

USGS NEHRP External Award Number 05HQAG0002

Napa, California

1.0 INTRODUCTION

The West Napa fault zone historically has been considered to be a 30- to 35-km-long fault that trends parallel to the western margin of the Napa Valley and extends to the southeast along the eastern margin of marshlands that border northeastern San Pablo Bay (Figure 1). The fault has been mapped as a late Pleistocene-Holocene active fault, with the southern part zoned as an Alquist-Priolo Earthquake Fault Zone (Helley and Herd, 1977; Pampeyan, 1979; Bryant, 1982; Wagner and Bortugno, 1982; Fox, 1983; Jennings, 1994). The fault is inferred to be predominantly a right-slip fault based on its geomorphic expression and its north-northwest trend, which is roughly parallel to major right-slip faults of the San Andreas fault system. Opinions that the West Napa fault has low slip rate are based on judgments that the fault has poor geomorphic expression relative to major active right-slip faults, and on regional balancing of slip rates across the San Francisco Bay Area (WGNCEP, 1996; Petersen et al., 2008). However, the slip rate and other important paleoseismic parameters, such as number, timing, and magnitude of Holocene and late Pleistocene events, are largely unknown because detailed systematic study of the fault previously had not been completed. Previous investigations of the fault primarily have focused on site-specific trenching (e.g., DMA, 1983) or regional mapping (e.g., Sims et al., 1973; Helley and Herd, 1977; Fox, 1983), although the California Geological Survey recently has mapped the bedrock trace of the fault on a series of 1:24,000-scale quadrangles (Bezore et al., 2002, 2005; Clahan et al., 2004, 2005; Wagner et al., 2004).

The purpose of this study is the development of a Quaternary fault map and associated database for the West Napa fault in a digital format consistent with that being developed by the USGS for the Northern California Quaternary Fault Map Database project. Specific objectives of this effort, which builds on previous mapping and paleoseismic investigations reported by Wesling et al. (2000, 2001), are as follows:

(1) Develop a strip map of the West Napa fault at a scale of 1:24,000 using an orthophotographic base that designates recency of activity of traces of the fault, and depicts locations of sites where site-specific investigations have been conducted.

(2) Provide links to a database that summarizes results of previous paleoseismic and fault mapping investigations on the West Napa fault.

1.1 APPROACH

Photogeologic interpretation and field reconnaissance were conducted along the entire length of the West Napa fault as part of the original NEHRP-funded studies (Wesling et al., 2000, 2001) to provide data on the (1) recency of activity based on geomorphic expression; (2) estimated ages of faulted and unfaulted deposits; (3) amount of displacement of varying geomorphic surfaces and datums, and (4) bedrock relationships and kinematic indicators (e.g., slickenlines, fault-zone geometries) that can be used to assess the style of faulting. The mapping program emphasized documentation of the character, distribution and relative ages of Quaternary surficial deposits and geomorphic surfaces and the location and kinematic nature of Quaternary deformation along the traces of the fault. Available geologic information was reviewed and incorporated where possible. Aerial reconnaissance of the study area from Carquinez Strait to the City of Calistoga was conducted from a fixed-wing aircraft under low-angle sunlight conditions on April 25, 1998 (Figure 1).

Numerous faulting studies completed during the past 30 years for residential and commercial developments along the central to southern part of the West Napa fault have been compiled to help constrain the location and recency of fault traces (Plate 1; Table 2). These studies have been completed by numerous consultants, whose work varies in quality and level of detail. It is important to note that some of the studies, especially the earlier ones, do not appear to meet current standards of practice for fault-rupture hazard investigations. Stratigraphic units and structural features identified in some studies are either poorly documented, highly interpretive, and/or show apparently significant geologic features but fail to recognize their potential importance. For example, one study concluded that no evidence was found that would lead to the conclusion that a fault was present on a particular site even though highly deformed Plio-Pleistocene sediments were depicted on trench logs. An interpretation of "intense folding" was made based on the presence of a 10- to 30-m-wide zone of deformation in Cretaceous Great Valley Sequence rocks that separate horizontally bedded Plio-Pleistocene Huichica Formation on one side against steeply dipping Huichica Formation on the other side. The author of the study interpreted the sequence as an overturned anticline instead of a fault even though abundant slickensides were present and apparent northwest-trending fault-like contacts are shown on trench logs.

In another example, a southwest-dipping stratigraphic contact with the Cretaceous Great Valley Sequence overlying the Plio-Pleistocene Huichica Formation was observed to be coincident with a strongly expressed lineament and an alignment of other fault-related features. Unfortunately, the importance of the contact, which later, was trenched and documented to be an active fault, was not recognized in the original study. As with these examples, we critically evaluated each study and, if warranted, reinterpreted some of the trench logs, considering all study results, more recent study results, and our experience in systematically mapping the fault.

A variety of stereo aerial photographs flown at different scales and dates were used in the mapping effort (Table 1). The primary coverage includes 1:20,000-scale photographs of the entire fault. These were supplemented by a limited number of 1:36,000- and 1:54,000-scale aerial photographs for the part of the fault from the Napa County Airport and north to the City of Napa. Also, 1:7,200-scale photos of the Napa County airport and lands directly south of the airport were used to identify fault traces and locations for paleoseismic trenching investigations.

Data from previous studies, the interpretation of aerial photographs, and ground reconnaissance mapping were compiled on 1:24,000 USGS 7.5-minute orthophoto and topographic quadrangle base maps. Both fault strand and point specific data were incorporated into an Arc/Info GIS database following guidelines developed by the USGS and Northern California Quaternary Fault Map Database (NCQFMD) working group. The Quaternary strip maps showing the interpreted locations of fault-related geomorphic features and lineaments associated with recently active traces of the West Napa fault zone are presented on Plate 1.

The geologic and tectonic setting of the West Napa fault is described in Section 2. Geologic mapping of six defined reaches of the fault is described in Section 3. Paleoseismic trenching investigations at the Napa County airport site and logging of a natural exposure of the fault along Napa Creek are described in Section 4. A discussion of the likely slip rate, based on inferences of our studies and recently completed studies, is given in Section 5. The summary and conclusions are presented in Section 6.

1.2 ACKNOWLEDGMENTS

This report describes the results of studies that were funded by two USGS NEHRP external grants: Award Number 05HQAG0002 and Award Number 1434-98-GR-00018. Ms. Kathryn

Hanson and Mr. John Wesling[1] are co-principal investigators for Award Number 05HQAG0002, which is the currently funded project to convert the mapping of the West Napa fault into a digital GIS database. Mr. Wesling, Ms. Hanson, and Mr. Andrew Thomas[2] were co-principal investigators for Award Number 1434-98-GR-00018, which funded the basic geologic mapping of the fault, the trenching study at the airport site, and the logging of the natural exposure of the fault along Napa Creek. Various Geomatrix personnel participated in the detailed paleoseismic and mapping investigations conducted along the West Napa fault zone. Mr. Wesling conducted the photogeologic interpretation, field reconnaissance mapping, and development of the regional strip map from 1998 to 2000. Mr. Thomas and Dr. Frank (Bert) Swan[3] were chiefly responsible for paleoseismic trenching investigations at the airport site. They were assisted by Ms. Jennifer Thornberg.[4] Ms. Hanson provided peer review for the initial study and is the project manager for the current map compilation and database effort.

We wish to acknowledge the useful comments and discussions with other researchers who visited the Airport trench site, including Dr. Glenn Borchardt, Mr. Earl Hart, Ms. Suzanne Hecker, and Dr. David Schwartz. We also gratefully acknowledge recent discussions with Mr. Kevin Clahan, who was part of the California Geological Survey's effort to map bedrock traces of the West Napa fault.

2.0 GEOLOGIC AND TECTONIC SETTING

Napa Valley is a relatively large northwest-trending alluvial valley located within the Northern Coast Range geomorphic province. The valley is at the southernmost end of the Mayacmas Mountains, and it extends from the City of Calistoga and to the southern part of the City of Napa. South of the City of Napa, the hills on the western side of the valley terminate at the marshes bordering the northern end of San Pablo Bay; whereas the hills on the northeast continue to near Sulphur Springs Mountain near the City of Vallejo. The bedrock ridges on each side of the Napa Valley trend northwest, parallel to the general north-northwest structural trend of the Northern Coast Ranges. The trend of the valley and bedrock ridges changes from a N20°W trend to a N35°W at about the latitude of Yountville, and the valley extends along this trend as far north as St. Helena. The valley narrows considerably and has a more westerly trend from north of St. Helena to Calistoga. These changes in trend also appear to be reflected in isostatic gravity anomalies documented by Langenheim et al. (2006a, b).

---

[1] Present Affiliation: California Department of Conservation, Office of Mine Reclamation
[2] Present Affiliation: Unknown
[3] Present Affiliation: Independent Consultant
[4] Present Affiliation: California Department of Conservation, California Geological Survey

Bedrock is generally restricted to the foothills, but locally there are low knolls or hills of bedrock in the central and western parts of the valley (Figure 2). The oldest bedrock in the study area chiefly consists of marine clastic rocks of the Lower Cretaceous Great Valley Sequence, although small areas of the Jurassic to Cretaceous Franciscan Complex are mapped locally in the hills to the west of the valley. Sandstone and siltstones of the Great Valley Sequence underlie prominent ridges on the west side of Napa Valley and also underlies the area from about Oat Hill and to the south. Eocene marine sandstone and shale (e.g., Domengine Sandstone and the Markely Sandstone member of the Kreyenhagen formation) and Miocene Briones Sandstone are mapped along the eastern and southeastern margins of the valley. These units form the southwestern flank of Sulphur Springs Mountain and underlie several low bedrock knolls adjacent to and within the valley northwest of Oat Hill, although recent quadrangle mapping by the California Geological Survey shows these units to be “Tertiary” Huichica[5] formation.

The Miocene to Pliocene Sonoma Volcanics comprise the southern end of the Mayacmas Mountains to the north of the Eocene formations. These consist of andesite, basalt, rhyolite, and pyroclastic rock units. A thin strip of Sonoma Volcanics occurs along the southwesternmost margin of the Napa Valley from St. Helena and south, and the volcanic lithologies underlie the valley and hills to the northeast to the Green Valley fault, where it trends near the Howell Mountains (Figure 2). On a regional scale, the West Napa and Green Valley faults border the western and eastern margins of a relatively large Tertiary basin in which the Sonoma Volcanics were deposited.

Quaternary alluvial fan and fluvial deposits associated with the Napa River and its tributary valleys comprise the youngest deposits with the Napa Valley (Sowers et al., 1995; Bezore et al., 2002, 2005; Clahan et al., 2004, 2005; Wagner et al., 2005). Late Pleistocene estuarine deposits formed during the last interglacial stage (correlative with Stage 5 of the marine oxygen isotope record [Shackelton and Opdyke, 1973]) are postulated to underlie a broad geomorphic surface in the southern end of the valley. These deposits and surfaces are discussed in more detail in Section 4.0.

Fault traces in the vicinity of the West Napa fault were first mapped by Weaver (1949), and subsequent mapping indicated that the fault consists of northwest-trending anastomosing fault

---

[5] The Huichica formation is long considered to be Pliocene to Pleistocene in age. Graymer et al. (2002) assigned an early Pleistocene and Pliocene age for these same deposits on their small-scale map. The basis for assigning only a Tertiary age to these deposits by the California Geological Survey was not given on their maps.

traces that extend for a distance of 30 to 35 km along the western margin of the Napa Valley (Fox et al., 1973; Helley and Herd, 1977; Pampeyan, 1979; Wagner and Bortugno, 1982; Fox, 1983; Jennings, 1994). The fault is the northernmost element of a series of relatively short north-to-northwest-trending en echelon faults that also includes the Franklin and Southampton faults (Figure 1). These faults traverse the East Bay Hills and lie between the Hayward – Rodgers Creek fault zone on the west and the Calaveras – Concord – Green Valley fault zone on the east.

Based on the pattern of bedrock faulting north and south of Carquinez Strait, Figuers (1991) theorized that slip may transfer between the northern Calaveras fault and the West Napa fault via the Franklin and/or Southampton faults, and/or from the Concord fault to the West Napa fault via the Sulphur Springs thrust zone. Although he considered the Franklin fault to be the master fault, Figuers appeared to favor a model where slip primarily is transferred via the Southampton fault, because the northern mapped terminus of the Southampton fault is near the southern end of West Napa fault.

Geomatrix (1998) suggested that slip transfer between the northern Calaveras and West Napa faults is accommodated through a series of faults in the East Bay Hills including the Franklin, Southampton, Reliez Valley, Lafayette, and other faults in the East Bay Hills, several of which show evidence of late Quaternary fault activity; however, additional studies are needed to address the seismogenic potential and rate of slip on these faults. Paleoseismic trenching studies by Geomatrix (1998) along the southern part of the Southampton-Franklin fault in the Walnut Creek area indicated the presence of late Pleistocene and probable Holocene right-normal-oblique fault activity. Based on the trenching results and existing regional mapping, Geomatrix hypothesized that the apparent recent activity on these and possibly other faults in the East Bay Hills accommodate the transfer of slip from the northern Calaveras fault to the West Napa fault.

Unruh et al. (2002) and Kelson et al. (2005) also proposed slip transfer from the northern Calaveras fault to the West Napa fault through a series of left-stepping, en echelon dextral faults and lineaments that they collectively term the Contra Costa Shear Zone (CCSZ). The CCSZ is comprised of the Reliez Valley, Lafayette, Southampton, and other faults and lineaments south of Carquinez Strait where prominent geomorphic features suggestive of recent fault activity are associated with these structures. Further evidence of the existence and level of activity on the CCSZ is its association with microseismicity. Specifically, the 1977 “Briones swarm” of earthquakes aligns along the CCSZ trend and appears spatially associated with one of the lineaments. Their studies include mapping of uplifted Quaternary marine terraces across the Franklin and Southampton faults along Carquinez Strait. This mapping strongly indicates that the terraces are displaced across the Southampton fault but not the Franklin fault with a resolution of about 3 m, and it indicates that the East Bay Hills block to the west of the Southampton fault is being uplifted without substantial tilting at a rate of 0.05 ± 0.01 mm/yr.

Evidence for Holocene activity on the West Napa fault previously has been reported by Bryant (1982), Fox (1983) and Wagner and Bortugno (1982), and a portion of the fault is classified as active by the California Geological Survey (Hart, 1990; Jennings, 1994). Wagner and Bortugno (1982) indicate Holocene activity along a zone of fault traces about 27 km long. Fox (1983) reports evidence of activity along an 18-km-long northwest-trending fault trace within the West Napa fault zone, which is believed to be the same trace reported by Jennings (1975). Fox (1983) also shows a semi-parallel fault trace extending 35 km to the northwest that forms the contact between Mesozoic basement rocks and the Miocene Sonoma Volcanics. This may be a major trace within the West Napa fault zone; however, unlike the 18-km-long trace, there are no previous detailed studies or reports of recent fault activity for this trace. Fox (1983) indicates that, based on more detailed mapping and trenching, some of the previously identified photolineaments (Fox et al., 1973) do not represent active faults, but that several strands of the West Napa fault zone are active. Jennings (1994) shows the southern 8.5 km of the fault as Holocene active from American Canyon to the Napa River, and the northern 20 km as late Quaternary active from the Napa River to Yountville.

The southern 8.5 km of the fault zone is designated as an Alquist-Priolo Earthquake Fault Zone (Bryant, 1982; Hart, 1990). As a result, numerous subsurface investigations have been completed to locate recently active traces of the fault as part of geologic and geotechnical studies for commercial and residential developments (e.g., ENGEO, 1977; EMRI, 1979; DMA, 1983; DHA, 1984; GEI, 1996; Giblin Associates, 2005; Raney Geotechnical, 2003a, b, 2007). The late Quaternary fault trace was identified in trenches in at least three locations (ENGEO, 1977; Western Geological Consultants, 1980; DHA, 1984). Although these studies contribute to our knowledge of location or absence of young faulting, determination of important paleoseismic parameters, such as slip rate, slip per event, and recurrence interval was beyond the scope of those studies. Key observations and conclusions that relate to the evaluation of these parameters are summarized in Table 2.

As shown on Figure 1, no historical strong or larger earthquakes (i.e., larger than magnitude 6.0) are associated with the West Napa fault, although a moderate earthquake in 2000 (the **M**

5.0 Mt. Veeder earthquake [also referred to as the Yountville earthquake]) has been linked with the fault (Langenheim et al., 2006a). Strong earthquakes inferred to have occurred in the area are the "Mare Island" earthquakes from 1886 to 1900. One of these earthquakes with an estimated magnitude of 6.2 occurred in 1898 and was originally postulated to have occurred on the northern segment of the Franklin fault. More recent studies, however, indicate that the Modified Mercalli VIII isoseismal of the 1898 Mare Island earthquake is centered approximately on the southern end of the Rodgers Creek fault, which is the probable source of that earthquake (Toppozada et al., 1992).

The **M** 5.0 Yountville earthquake occurred on 3 September 2000 and was centered about 5 km west of the West Napa fault as defined by Helley and Herd (1977) and less than 1.5 km west of a main basin-bounding fault that juxtaposes Cretaceous Great Valley Sequence on the west and Tertiary Sonoma Volcanics on the east (Figure 2). The focal mechanism for the earthquake is consistent with right-lateral strike-slip on a near-vertical, northwest-trending fault plane. Strong ground shaking during the earthquake caused a substantial amount of damage in the City of Napa and locally in the epicentral region; however, no definitive evidence of surface rupture was identified along the mapped traces of the West Napa fault, including the basin-bounding fault, following the earthquake. On the basis of geophysical data, Langenheim et al. (2006a) infer that the Yountville earthquake occurred on this basin-bounding fault.

3.0 MAPPING OF THE WEST NAPA FAULT ZONE

Mapping and paleoseismic investigations indicate that the West Napa fault zone is approximately 57 km long and trends northwest from Carquinez Strait to an area directly west of the City of St. Helena (Plate 1). The fault traverses several different types of terrain that influence its expression in the landscape: (a) forested and agricultural land along narrow valleys and hill fronts; (b) agricultural land on low-relief alluvial fans and terraces; (c) low-relief bedrock hills and late Quaternary alluvial fans, alluvial terraces, and alluvium along hill fronts; (d) low-relief salt marsh/floodplain that is subject to diurnal tidal fluctuations; and (e) gently sloping marine terraces. Some of the landscape along the fault remains relatively unmodified; however, agricultural activities, locally extensive urban development, and active erosional and depositional processes have masked/muted the expression of the fault on some relatively large tracts of land. As a result, the geomorphic expression of the fault varies along strike depending on the interplay between active tectonic processes, active geomorphic processes, and agricultural and urbanization activities.

For this report, the West Napa fault is divided into five reaches that are based on differences in geomorphic position and expression of the fault, distinctive terrain traversed by the fault, and/or the type and availability of mapping data. From north to south, the reaches include St. Helena – Dry Creek, Yountville – North Napa, North Napa – Napa River, Napa River – American Canyon, and American Canyon – Carquinez Strait. Figure 3 shows the extent of the various reaches, and Table 3 lists the general characteristics of each reach. Appendix 1 shows the numbers of each lineament type that were mapped along each reach. The reaches are not intended to be fault rupture segments. This section describes the geomorphic expression, general geologic conditions and Quaternary fault mapping along each reach from north to south.

3.1 St. Helena – Dry Creek

The St. Helena – Dry Creek reach of the fault trends N 35° W and is parallel to the western margin of Napa Valley for about 23.5 km from in the hills directly west of St. Helena to the prominent westerly bend in the fault in north Napa (Plate 1). Along the northern half of this reach, the fault generally lies within 500 m of the western margin of the Napa Valley and is commonly separated from the valley margin by elongate, low bedrock hills. Along the southern half of the reach, the fault trends along Dry Creek and unnamed drainages that are separated from the Napa Valley by a somewhat large upland area with a local relief of about 335 m. The fault juxtaposes Cretaceous Great Valley sequence rocks (Kgv) on the northwest against Sonoma Volcanics (Tsv) on the southeast through the reach (Sims et al., 1973; Fox, 1983; Bezore, 2002, 2005; Wagner et al., 2004; Clahan et al., 2004, 2005).

The understanding that the St. Helena – Dry Creek reach probably represents the northern extension of the West Napa fault is supported by the (a) alignment of possible fault-related geomorphic features, (b) association these lineaments with a previously identified bedrock fault that parallels the western margin of the Napa Valley, and (c) along-strike alignment with a mapped trace of the West Napa fault to the south. Linear valleys and topographic escarpments (i.e., linear steps in topography) first observed during the aerial reconnaissance appear to be coincident with the bedrock fault mapped by Fox (1983); however, the identification of geomorphic features indicative of active faulting is complicated by the presence of landslides along the northern part of the reach and locally dense tree cover. Mapping along this reach focused on identifying probable fault-related lineaments on aerial photographs and performing field reconnaissance where possible.

Most fault-related geomorphic features along this reach are shown as lineaments on Plate 1 because of the limited field reconnaissance that could be accomplished to assess their origin. The majority of features that define the overall geomorphic expression of this reach include linear drainages, alignment of saddles, topographic escarpments, and breaks in slope that appear consistent with the overall observations of the aerial reconnaissance (Table 3). Although these features may indicate the presence of a fault, they are not necessarily robust indicators of geologically young fault activity. However, other geomorphic features along this reach that strongly indicate the presence of young fault activity include right-deflected drainages, east-facing scarps, side-hill benches, and right-deflected ridges. Many of these features are concentrated along the middle portion of the reach from about station 5+00 to 14+00. The pattern of these features, and presumably the active fault trace appears relatively simple, although some parts of this reach may have parallel or secondary fault traces that define a zone about 250 m wide. To our knowledge, no trenching or other paleoseismic investigations have occurred along this reach, although some features indicative of young faulting were observed during field mapping studies by the California Geological Survey (Mr. Kevin Clahan, William Lettis & Associates, personal communication, 2006).

Langenheim et al. (2006a, b) show the southeastern part of an isostatic gravity low below this part of the Napa Valley. The mapped trace of the West Napa fault is coincident with the relatively steep southwestern margin of the gravity low. The northeastern margin of the gravity low is less steep and not as well defined as on the southwest.

3.2 YOUNTVILLE – NORTH NAPA

The Yountville – North Napa reach trends N 15° W along the base of the hills forming the western margin of the Napa Valley for about 9 km from Yountville to the prominent westerly bend in the fault that also defines the southern extent of the St. Helena – Dry Creek reach (Plate 1). These two reaches overlap, but the Yountville – North Napa reach trends about 20 degrees in a more northerly direction. The fault lies along the edge of the Napa Valley near the bedrock-alluvium contact. The relatively large upland area directly to the west of this reach and east of the previous reach are underlain by Tsv, and Quaternary alluvial deposits and isolated hills of Tsv are on the east (Sims et al., 1973; Sowers et al., 1995; Bezore, 2002, 2005; Wagner et al., 2004; Clahan et al., 2004, 2005). Additionally, isolated hills of Kgv occur further to the east near the northeastern margin of the Napa Valley. Bezore et al. (2005) and Clahan et al. (2005) map the fault through the Yountville Hills where Tsv occurs on both sides of the fault.

Previous studies traditionally have considered the Yountville – North Napa reach to be the northernmost part of the West Napa fault with features indicative of late Quaternary activity (Fox et al., 1973; Sims et al., 1973; Helley and Herd, 1977; Bryant, 1982; Jennings, 1994). Photolineaments, a groundwater barrier and geophysical anomalies were reported to be coincident with the fault; however, to our knowledge, no trenching or other paleoseismic studies have been completed along this section of the fault. Indistinct tonal lineaments/contrasts, topographic escarpments, and possible east-facing scarps were observed during the aerial reconnaissance investigation. Much of the reach has been converted to agriculture, and significant urban development occurs where the fault trends through Yountville. Mapping focused on identifying probable fault-related lineaments on aerial photographs and field reconnaissance as access allowed.

Most mapped features along this reach are shown as fault-related geomorphic features on Plate 1. Readily identifiable fault-related features that generally define the overall geomorphic expression of this reach include linear tonal contrasts and topographic escarpments. More subtle features that more strongly indicate the presence of young fault activity include east-facing scarps, right-deflected drainages, and a possible closed depression. These features occur along a nearly 1.5-km-long zone near the middle of the reach. Several right-deflected drainages occur along the southern part of the reach; however, some of the deflections may represent channel improvements for agriculture rather than young fault activity. The pattern of fault-related features appears relatively simple and somewhat discontinuous. The discontinuous nature of the features in the south appears to be a result of young fluvial deposition and erosion, and agricultural activities that may obscure some subtle geomorphic features.

Active fluvial processes along the base of the hills likely obscures fault-related geomorphic features along portions of this reach. In the south, Dry Creek emerges from the hills and flows south, east and then north around the southern margin of the prominent hills between Dry Creek and the Napa Valley instead of a taking a more direct route to a confluence with the Napa River. After flowing northward along the western margin of the valley for about 1.0 km, the creek abruptly changes course and flows eastward. The impingement of Dry Creek against the hills appears anomalous and may be a result of active tectonic processes; however, fluvial processes apparently obscure fault-related geomorphic features.

3.3 NORTH NAPA – NAPA RIVER

The North Napa – Napa River reach trends about N 20° W for approximately 11.5 km along the western margin of the valley and within the low hills directly west of the valley (Plate 1). The fault has a relatively simple pattern north of Station 25+00, where a prominent fault scarp juxtaposes Kgv and/or Tsv against a thick sequence of unconsolidated alluvial deposits. South of this scarp, the fault steps left across low elongate hills separating the Napa Valley from Browns Valley. South of this apparent restraining step, the fault has a complex pattern of parallel traces that variously juxtaposes Kgv on the southwest against Tsv on the northeast, Tsv on both sides of the fault, and Tsv on the southwest against younger and older alluvium on the northeast (Sims et al., 1973; Sowers et al., 1995; Bezore, 2002, 2005; Wagner et al., 2004; Clahan et al., 2004, 2005).

Previous studies have identified strong lineaments including fault scarps along this reach, which traditionally has been mapped as having late Quaternary activity (Fox et al., 1973; Sims et al., 1973; Helley and Herd, 1977; Bryant, 1982; Jennings, 1994). Helley and Herd (1977) report a 24-m-high scarp in “older” terrace deposits north of Redwood Creek. Geologic maps report broad age ranges for these terrace deposits, including Pliocene to early Pleistocene (Helley et al., 1979), early or middle Pleistocene (Sowers et al., 1995), and early to late Pleistocene (Clahan et al., 2004); however, no quantitative dating of these or similar deposits have been completed in the map area. The eastern margin of Browns Valley is marked by scarps and a groundwater barrier (Helley and Herd, 1977); however, Bryant (1982) indicated that the evidence for young faulting is less compelling in this area than to the south.

Several trenching studies were completed along this reach for urban development prior to a decision in the early 1980s that this part of the fault was not included in the Alquist-Priolo Earthquake Fault Zone for the West Napa fault. Since then, faulting studies along this reach either have largely been absent or not readily available for public review. A couple of the earlier studies identified evidence of possible Holocene activity in the northern part of the reach. ENGEO (1977) found evidence for young shearing in a trench in Browns Valley (Table 2; Plate 1, Location C-352), however, the fault was not observed in other trenches. Bryant (1982) subsequently interpreted this young shearing to be of landslide origin. Western Geological Consultants (1980) identified a fault in a trench that is oriented N 10° W, 75°E that displaces the contact with the claystone and overlying soil about 0.3 m (i.e., 1 foot) down on the west (Table 2; Plate 1, Location C-396). A study in 2008 for a fire station in the western portion of the City of Napa identified potentially active fault traces in the vicinity of Napa Creek, as reported in the Napa Valley Register (Kisliuk, 2008). However, Ms. Shirley Perkins (City of Napa Fire Department, personal communication, September 9, 2008) indicated that the study was based solely on mapping, and no trenching was completed to support the interpretations.

Strong evidence of late Pleistocene and Holocene faulting occurs locally along the northern part of this reach (i.e., Stations 23.5 km to 26.0 km) reach where urban development is less concentrated; whereas, extensive urban development obscures much of the southern part of the reach. Readily identifiable fault-related features that help define the overall geomorphic expression of this reach are prominent east-facing fault scarps that displace late Pleistocene terraces and probable Holocene alluvial deposits. More subtle features, such as right-deflected drainages, linear hill/range fronts, slope breaks, linear tonal contrasts and topographic escarpments, also are indicative of geologically young faulting. The pattern of apparent fault-related geomorphic features appears locally complex along this reach, with apparent parallel traces at the valley margin and in the hills directly west of Napa and an apparent left-step across the low hills separating Browns Valley from the Napa Valley proper.

Evidence of geologically young fault activity is most apparent along the northern part of the reach where two relatively large tributaries of the Napa River flow across the fault and urban development is somewhat minimal. Two areas were studied in more detail to document recurrent late Quaternary and probable Holocene activity along this reach. These areas include the older alluvial deposits faulted across the well-developed fault scarp in the Alston Park area and a natural exposure of the fault along Napa Creek. The natural exposure of the fault will be described in a subsequent section, and the Alston Park terraces are described below.

Aerial photographic interpretation and field mapping indicate that a sequence of up to six Quaternary terraces is identified in the Redwood Creek – Browns Valley area in the northwestern part of the City of Napa (Figures 4 and 5). Profiling of the terraces and scarps on the 1:24,000-scale topographic map indicates that scarp heights are higher on older surfaces and progressively lower on younger terraces (Figure 6). For example, scarps developed on the Q1 terrace (oldest) are 30 to 35 m high and are 6 to 9 m high on the Q4 terrace (younger). No previous detailed studies of the scarp were found in the available literature; however, the prominent, broad Q2 terrace with an 18- to 22-m-high scarp was noted by Helley and Herd (1977), who describe a 24-m-high fault scarp in the vicinity of Redwood Creek. The topographic profiles also appear to document progressive tilting toward the Napa Valley on successively older terraces. Field observations indicate that there is little incision and erosion of the younger terrace treads and successively older terraces are progressively more incised and eroded. Only discontinuous remnants of the oldest terrace surface are preserved. Additionally, older scarps appear more eroded than younger scarps; however, agricultural practices locally have modified the scarp, and the relation between incision and erosion of the scarp may not entirely relate to fault activity.

Relatively discontinuous fault-related geomorphic features occur in the southern part of the reach where larger tributary drainages are absent and extensive urban development obscures likely fault traces along the western margin of the valley. Previous and current mapping indicates that multiple traces may exist in this area; however, the linearity of the hill front indicates that the main trace of the fault likely follows the western margin of Napa Valley. Some possible east-facing scarps are apparent near Old Sonoma Road; however, they have been heavily modified by grading activities for residential developments, and their location and origin is somewhat questionable.

Further south where the fault trends across the floodplain and active salt marshes, the fault is not readily apparent. The floodplain of the river and marshes are subjected to diurnal tides that may fluctuate two meters or more. Active erosional and depositional processes on floodplains and tidal marshes can easily obscure active fault features even on highly active faults. Similarly, it is important to note that fault mapping on the southern Rodgers Creek fault indicates that geomorphic expression of faulting dies out/ends where it projects into the salt marshes on the northern margin of San Pablo Bay (Randolph Loar, 2002). It is not surprising that the expression of the West Napa fault, which undoubtedly has a lower slip rate than the Rodgers Creek fault, dies out where it crosses the floodplain and marshes associated with the river.

Available data indicate that the West Napa fault borders the western side of a relatively deep Tertiary and Quaternary basin through this reach. Langenheim et al. (2006a, b) show an asymmetric isostatic gravity low that extends along the Napa Valley and areas to the east along this reach. This gravity low appears to delineate a basin containing Tsv and younger alluvial sediments. The asymmetry of the gravity low indicates the deepest portion of the basin occurs beneath the Napa Valley directly east of the West Napa fault. Water well data in Kunkel and Upson (1960) and Helley and Herd (1977) indicates that a relatively deep Plio-Pleistocene basin occurs beneath the valley along this reach. Unconsolidated sediments on the downthrown (east) side of the fault are more than 145 m thick (i.e., basal contact of unconsolidated alluvium deeper than elevation –115 m mean sea level [MSL]) along the northern part of the reach. Further south in central Napa, water well data indicate that unconsolidated alluvial deposits reach depths of more than 260 m (i.e., basal contact of unconsolidated alluvium deeper than elevation –250 m MSL). Water wells drilled within a few feet of sea level along the southern part of the reach report the basal contact of the alluvium with Tsv at depths of about 230 m to 240 m (i.e., elevation –230 to –240 m MSL). The presence of a deep Plio-Pleistocene basin indicates a relatively high rate of tectonic activity on the West Napa fault.

3.4 NAPA RIVER – AMERICAN CANYON

The Napa River – American Canyon reach trends approximately N 20°W and obliquely crosses the Napa River floodplain, salt marshes and low-relief alluvial terrain adjacent to the Sulphur Spring Mountains on the east and the Napa River and North Bay salt marshes on the west (Plate 1). A strong geomorphic expression of young faulting has long been recognized along this reach of the fault, and as a consequence, it is designated as an Alquist-Priolo Earthquake Fault Zone (Bryant, 1982; Hart, 1990).

Geologic units that underlie this reach include isolated, low hills underlain by Tertiary marine or terrestrial sediments that have been mapped as Domingene Sandstone (Sims et al., 1973) or Huichica Formation (Bezore et al., 2002). These low hills provide a small amount of relief to an otherwise gently west-sloping marine and alluvial plain. Although published geologic maps show alluvial deposits underlying this area, data from this study indicates that this area is underlain by older estuarine deposits that may be associated with a sequence of one or more uplifted marine terraces overlain by thin to moderately thick alluvial fan and fluvial deposits derived from Fagan Creek (Plate 1).

Southwest- and northeast-facing scarps, right-deflected drainages, tonal contrasts, and linear drainage segments are diagnostic landforms that identify the location of recently active fault traces along this reach (Plate 1; Figures 7 and 8). Many of these features have been noted in various previous reports and studies, and our mapping confirms the youthful geomorphic expression of young faulting along this reach. Fault-related geomorphic features are very distinct from aerial reconnaissance, aerial photographic interpretation, and ground reconnaissance mapping. The scarps are relatively broad features that range in width from about 40 m to more than 100 m and are continuous through much of the reach. Topographic profiles A-A′ and B-B′′ (Figures 9A and 9B, respectively) illustrate the scarps associated with the major traces of the fault directly south of the airport. The southwest-facing scarp near the trench site coincident with the main trace of the fault is about 1¾-m-high with a maximum slope angle of 3 to 4 degrees. The surface offset across the scarp is about 1½ m (Profile A-A′; Figure 9A). Smaller slope inflections to the east of the main scarp may represent secondary fault traces. Seeps and an apparent ground water barrier are associated with the scarp as indicated by the sharp tonal contrasts near the trench locality on Figure 7. The fault acting as a ground water barrier was confirmed during trenching of this study and Darwin Meyers Associates (DMA, 1983). Topographic profile B-B′ (Figure 9B) shows the approximately 5½-m-high northeast-facing scarp further south of the trench site. This scarp has a maximum slope angle of about 5 to 6 degrees. The surface offset across the scarp is about 3¾ m. This scarp profile appears to have two to three facets that may support the interpretation of multiple movements.

The scarps along this reach align with right-deflected ephemeral drainages that flow northeast to southwest across the fault (Figure 7). A relatively prominent ephemeral drainage directly south of the Napa County Airport trench locality appears to be deflected about 245 m in a right-lateral sense across the main trace of the fault and nearly 70 m across a secondary fault trace. Similar small deflected drainages occur locally along this reach of the fault. Although the trace of the fault is poorly expressed in the active floodplain and salt marshes along the river, it is important to note that the Napa River makes a broad right swing of nearly 2,000 m across the projection of the fault (Plate 1).

In addition to the presence of abundant fault-related geomorphic features, several trenches have exposed Holocene-active fault traces along this reach of the fault (Plate 1; Table 2). DMA (1983; AP2929) identified probable Holocene-active fault traces in two 2- to 3-m-deep trenches excavated across the southwest-facing scarp near the southern side of the Napa County Airport (Figures 7 and 8). These trenches exposed shear planes that truncated a sandy clay unit with a 45-cm-thick B horizon developed in it. The shear planes appear to project into the topsoil and are coincident with moisture content changes in the sediments and an inflection in the topography. The sandy clay unit on the east is juxtaposed against less weathered greenish gray clay on the west. The trend of the fault between the two trenches is about N28°W. The youngest unit exposed in the DMA trenches is dark grayish brown silty clay containing large shrink-swell cracks. Shear planes oriented N14°W, 60°SW were mapped in this unit above the fault zone; however, shrink-swell processes in the soil may have produced these features. A Holocene age was assigned to the faulted sediments, but no basis for this age was presented. The GC-1 trench excavated for this study is located near the DMA (1983) trench as described below.

Several studies to locate active traces of the fault have been completed to the south of the DMA (1983) study for commercial real-estate development between Green Island Road and extending on to the northern part of Oat Hill (Plate 1). The studies included subsurface investigations that locally constrain the presence of active fault traces along this reach as shown on Plate 1 and summarized on Table 2. Some noteworthy studies that located active fault traces include J.H. Kleinfelder (1983; 1984a, b, c), Earthtech (1989), and Bailey Scientific (1991). Additional, newly acquired studies have identified active fault traces on the flanks of Oat Hill (i.e., Giblin Associates, 2005; Raney Geotechnical, 2003a, 2007). The recent studies demonstrate the presence of active traces along the strongly expressed lineament on the northeast flank of the hill as mapped in Bryant (1982) and this study. The studies by Giblin Associates (2005) and Raney Geotechnical (2003a, b; 2007) also demonstrates the presence of an active fault trace approximately coincident with weakly expressed lineaments and questionable fault traces identified by J.H Kleinfelder (1984b, c) on the southwest side of Oat Hill. None of the studies along this reach were detailed enough to assess the recurrence and slip rate of the fault.

3.5 AMERICAN CANYON – CARQUINEZ STRAIT

The trend of the fault changes at Oat Hill about ten degrees from the previous reach to N 30° W. along the American Canyon – Carquinez Strait reach. This left/westerly bend in the fault is an apparent restraining bend in the fault, although a left step across Oat Hill cannot be ruled out based on the available mapping and subsurface data. The American Canyon – Carquinez Strait reach lies along the western margin of the Sulphur Spring Mountains adjacent to the low relief terrain that borders the river and North Bay salt marshes on the west (Plate 1; Figure 2).

Kgv underlies the entire reach from Oat Hill at the northern end to the Carquinez Strait on the south. Late Quaternary alluvial deposits are mapped in small valleys and low lying areas between hills. Bedrock underlying the mountains and low-relief terrain primarily consists of Kgv (Sims et al., 1973). West-northwest-trending, en echelon bedrock ridges are present along the central part of this reach of the fault.

Overall, the American Canyon – Carquinez Strait reach has relatively poor geomorphic expression because the natural terrain has been highly modified or masked by urban development associated with the cities of Vallejo and American Canyon. Localized parts of this reach have relatively strong geomorphic expression where there is less urban development. This reach of the fault appears to be transitional between the East Contra Costa shear zone as defined by Kelson et al. (2005) and the historically recognized Holocene-active portion of the West Napa fault. The fault has a relatively strong geomorphic expression in Southampton Bay, where the Southampton fault has been historically mapped. The northwestern margin of the bay is very linear, and is interpreted to be the expression of young fault activity, although no paleoseismic data are available to confirm this interpretation.

Evidence of active fault traces associated with mapped lineaments was identified in trenching studies along the northernmost part of this reach (Kleinfelder, 1983, 1984a, b, c; 1992; DHA, 1988a, 1989) (Table 2; Plate 1). These studies help constrain the active faulting on the northern part of the reach, but to our knowledge, no studies are available for the southern part of the reach. The fault is generally obscured by urban development between the trenching studies south of Oat Hill and Southampton Bay. The presence of en echelon, northwest-trending bedrock ridges through this part of the reach may indicate complex step-over zone between the Southampton and West Napa faults. The reach follows the isostatic gravity anomaly described for the previous reach.

4.0 PALEOSEISMIC SITES

4.1 NAPA COUNTY AIRPORT TRENCH SITE

As previously described, strong geomorphic expression of recent fault activity is present in the vicinity of the Napa County Airport, where the fault traverses a plain underlain by Holocene and late Pleistocene alluvial and estuarine sediments (Figures 4 and 7). Evidence of recent faulting includes alignments of northeast- and southwest-facing scarps, closed depressions, seeps and springs, and right-deflected of drainages. Paleoseismic investigations, including detailed mapping of the surficial geology, profiling of fault scarps, and interpreting the stratigraphy, soils, and structural features exposed in natural cuts, test pits and a trench were conducted at this site.

Trench GC-1 was excavated on the southernmost side of the Napa County Airport (Figure 7), where a southwest-facing scarp in alluvium, a right-deflected drainage, and displaced geomorphic surfaces are readily apparent on aerial photographs and in the field. The trench was excavated about 80 m southeast of the DMA (1983) trenches across a very sharp linear tonal contrast that is coincident with a 1- to 1.5-m-high west-facing scarp that traverses a broad terrace (elevation 20 ft.) on the south side of the Napa County Airport (Figures 7 and 8). The lineament trends N16°W. The lineament and scarp, which are evident on 1988 aerial photographs (Figure 7), are now obscured by up to 1 m of fill that was placed by the County to smooth the surface across the scarp (Plate 2). The trench was 50 m long and 2.4 to 2.6 m deep along most of its length. Groundwater was encountered at a depth of 1.5 m to 2 m and was pumped out repeatedly during the day while the trench walls were being cleaned and mapped.

Figure 10 is a map of the north wall of trench GC-1 and descriptions of the stratigraphic units. In addition to the man-made fill, four principle stratigraphic units were identified in the trench exposure. From oldest to youngest these are as follows:

- Unit 1—Late Pleistocene estuarine or alluvial sediments having a strongly developed calcic soil (Unit 1B).
- Unit 2—Late Pleistocene (?) alluvium in cut-and-fill channels inset into Unit 1B.
- Unit 3—Holocene (?) colluvium and/or bioturbated sediments that unconformably overlie units 1 and 2.
- Unit 5—A black vertisol developed on Holocene overbank sediments.

In addition to these sedimentary deposits, two tectonically derived units were mapped. Unit 4 consists of a wedge of sediment at the base of the fault scarp that formed either as scarp-derived colluvium or, more likely, as a pressure ridge adjacent to the fault. Unit 3-5 is a tectonically mixed zone in the fault zone that contains materials from units 3, 4 and 5.

Unit 1. This unit consists of massive fine sandy clay and clayey fine sand deposits that were probably deposited in a fluvial-deltaic environment similar to the floodplain of the modern Napa River. There is well-developed calcic paleosol (Bk horizon having stage II to II+ carbonate morphology; 20- to 40-mm carbonate nodules are common) in the uppermost meter of Unit 1, which is mapped as Unit 1B on Figure 10. The upper part of the paleosol has been eroded, particularly on the upthrown side of the fault, and the base of the Bk horizon was not exposed on the downthrown side of the fault. Therefore, the maximum thickness of the Bk horizon is not known.

At the trench site the deposits upslope of the main fault are associated with a broad, gently west-sloping geomorphic surface that is at an elevation of approximately 6 m (20 ft.). Apparent fan-shaped topographic contours to the east of the site suggest the trench is near the distal end of alluvial fans that grade out onto this surface.

Based on the present elevation of the terrace at this site and the sedimentologic characteristics of the associated deposits exposed in the trench, we interpret the Unit 1 deposits to have been deposited during a sea level highstand. Estuarine deposits and wave-cut platforms associated with the marine oxygen isotope stage (MIS) 5e highstand have been inferred at several locations in the northern San Francisco Bay at altitudes of 6 to 8 m (20 to 25 ft.) above mean sea level (Atwater et al., 1977; Helley et al., 1993; Borchardt, 1994a, b; Dwyer and Borchardt, 1994. Correlation of Unit 1 with the MIS 5e sea-level highstand indicates an age of about 120 to 125 ka for these deposits. However, recent mapping of emergent marine terraces about 15 km to the south along Carquinez Strait indicate that these deposits may be younger. Kelson et al. (2005) identified three emergent marine terraces with shoreline-angle altitudes of 4 m (~13 ft.), 12 m (~40 ft.) and 18 m (~60 ft.) on the east side of the Southampton fault. The 12 m and 18 m terraces are correlated with MIS 5e and MIS 9, respectively. Given the similar altitudes of the 4 m terrace along Carquinez Strait and the 6 m terrace at the trench site, both on the east side of the West Napa fault, a correlation of the estuarine deposits in the trench to oxygen MIS 5a (i.e., 80 ka) appears to be more likely. If so, the data suggests that uplift rates probably are similar between these two areas. The stage II carbonate morphology of the calcic soil on Unit 1 began forming at least several tens of thousands of years ago sometime after the bay receded.

Both the estuarine/alluvial deposits (Unit 1A) and the paleosol developed on them (Unit 1B) are displaced by the fault. No distinctive marker beds were observed in Unit 1A and the total amount of displacement of this unit could not be determined. The paleosol (Unit 1B) is displaced vertically at least 1.2 m down-on-the-southwest. The amount of lateral slip cannot be determined from the trench exposure.

Unit 2. This unit consists of clayey, silty fine sand alluvium that fills channels incised into Unit 1. Unit 2 is distinguished from Unit 1 by its redder color, sandier texture and the absence of the well-developed calcic soil.

Unit 2 does not intersect the fault in this exposure so the timing or amount of faulting relative to this unit cannot be determined directly. The fact that Unit 2 truncates the Bk horizon on Unit 1 and the relatively small amount of carbonate buildup in the soil profile subsequent to the deposition of Unit 2 suggests these alluvial deposits are much (several thousands to tens-of-thousands of years) younger than Unit 1.

Unit 3. This unit consists of a layer of material derived from Unit 1 (mostly Unit 1A) mixed with black silty clay loam similar to Unit 5A. The unit contains numerous krotovina and vertical fissures. The deposit mantles a buried scarp and is generally parallel to the natural ground surface (i.e., the surface prior to placement of the man-made fill). Unit 3 contains angular pieces of carbonate eroded from Unit 1B. On the west side of the fault Unit 3 also contains pedogenic carbonate (stage II carbonate morphology; 2- to 3-mm carbonate nodules are common). This upper Bk soil horizon, which is shown on Figure 10 by the diagonal hachure pattern, diverges from Unit 3 as it crosses the scarp and it occurs in the overlying unit (Unit 5A) on the downthrown side of the fault.

Unit 3 is disrupted by the fault zone. The layer is discontinuous across the fault and material similar to Unit 3 occurs within Unit 4 and Unit 3-5. The vertical separation across the fault on the base of Unit 3 is 55 to 60 cm down-on-the-west.

Unit 4. This unit consists of a mixture of materials similar to units 3 and 5A. The upper and lower contacts of the unit are indistinct and the origin of the unit is uncertain. It was initially interpreted to represent a wedge of scarp-derived colluvium deposited during a single event after Unit 3 formed. This would suggest single-event displacements having a vertical throw of more than 30 to 35 cm (i.e., the thickness of the wedge). This would suggest that the scarp in the Pleistocene terrace could have been produced by as few as five surface faulting events.

Alternatively, Unit 4 may represent a buried pressure ridge. Given the predominant strike-slip sense of displacement on the West Napa fault and the flower-structure-like pattern of the faulting, it is more likely that Unit 4 is a bulge of material that was tectonically pushed up during faulting. In this scenario, Unit 4 could have been produced during a single event or by a number of smaller events.

Unit 5. This unit consists of black silty clay loam. Fissures extend through the entire thickness of the unit, which is characteristic of vertisols having high clay content that shrinks and swells during repeated drying and wetting. This shrinking and swelling mixes the soil and can destroy evidence of faulting.

Unit 5 represents a cumulative A horizon that has built up over time as repeated flooding along the Napa River and its tributaries deposited fine-grained overbank sediments on the terrace surface. Two obsidian flakes that appear to have been worked were observed in Unit 5. Although it could be argued that these flakes fell down fissures or were introduced by burrowing animals, their occurrence at the same stratigraphic level near the base of Unit 5 suggests the deposits post date human occupation, which would indicate the deposits are probably middle to late Holocene in age.

The plow layer (Unit 5B) associated with the ground surface prior to placement of the fill is preserved on the downthrown (west) side of the fault. This plow layer was not observed on the northeast side of the fault and the top part of Unit 5 may be missing. Based on the available exposure, it appears that Unit 5 is 20 to 30 cm thicker on the downthrown side of the fault.

The basal part of Unit 5A is disrupted by the fault. Post-Unit 5 faulting is indicated by shears that extend into and appear to displace the base of the unit (Figure 10, Station 25 m).

Conclusions. The stratigraphic and structural relations exposed in trench GC-1 clearly indicate that late Pleistocene and Holocene alluvial deposits are displaced by the West Napa fault zone. The cumulative late Pleistocene vertical displacement (during approximately the past 120 to 125 thousand years [kyr] or 80 kyr) is more than 1.2 m down on the west. Both the tectonic setting of the fault and geomorphic evidence suggest the fault is predominantly a right-lateral strike-slip fault; the total net slip could not be determined based on the trench exposure. The middle- to late-Holocene vertical displacement (i.e., the base of Unit 5) is less than 0.5 m, which indicates there have been multiple surface-faulting events during the late Quaternary. The number and timing of individual surface faulting events has been obscured by shrinking and swelling of the clayey soil in the upper part of the trench.

4.2 NAPA CREEK EXPOSURE OF FAULT

Evidence of late Holocene faulting has been identified in a natural outcrop of the West Napa fault along the right (south) bank Napa Creek (Wesling et al., 2000, 2001; Figures 4 and 11). Preliminary mapping of the lower part of the exposure and radiocarbon dating indicates that there has been at least one surface-faulting event during the past 600 years.

At this exposure Napa Creek is incised into the Holocene alluvium and Tertiary Sonoma Volcanic bedrock, resulting in an approximately 3- to 4-meter-high exposure of the fault zone. Figure 12 is a schematic log of the lower two meters of the exposure. The upper one to two meters of the exposure are covered with young colluvium and minor household debris (i.e., cans and bottles). The base of the log approximately corresponds with the bottom of the creek. Aerial photographic interpretation and ground reconnaissance indicate that a low fault scarp is present on the alluvial terrace above (southeast) the exposure (Figure 11; Plate 1).

Sandy and gravelly alluvial deposits are exposed in the stream cut (Figure 12). The basal clayey sand is clearly faulted across a 20-cm-wide zone of sheared alluvium and gouge that juxtaposes the clayey sand against sheared Sonoma Volcanic bedrock. The overall orientation of the fault zone, as measured in the outcrop, is about N 30° W, 85° SW. Detrital charcoal from the clayey sand has been radiocarbon dated as approximately 600 years before present, as shown on Figure 12 and listed in Table 4.

A younger alluvial unit composed of sand and gravel overlies and is inset into the clayey sand. One radiocarbon date on detrital charcoal from the overlying sand and gravel sequence is about 800 years before present. Faulting in this unit is poorly expressed; however, the presence of a steeply dipping (i.e., upturned) alluvial beds and occasional rotated clasts above the well-expressed portion of the fault zone indicates the upper unit also has been faulted. The apparent older date for the younger unit is somewhat problematic; however, both dates indicate that the faulting event or events is very young. A trench by Western Geological Consultants (1980) (reported in the Bryant's Fault Evaluation Report [1982]) to the south (Figure 11) supports the conclusion of young faulting in the area of the site. In their trench, they describe faulted topsoil but do not provide numerical age estimation of that soil. The upper one to two meters of sediment at the Napa Creek exposure was not exposed during our reconnaissance investigation.

5.0 SLIP RATE

The slip rate for the West Napa fault is not well constrained, but for a long time has been considered to be on the order of 1 mm/yr (e.g., 1 ± 1 mm/yr; Cao et al., 2003) based on the fault's perceived poor geomorphic expression. The results of this study, as well as recent geodetic, geophysical, and geologic studies and observations suggest the slip rate likely is higher. The detailed mapping of the fault zone as described above shows that the fault is better expressed geomorphically than had been recognized previously, and there is a growing body of evidence for recent (less than 600 to 700 years B.P.) surface faulting displacements along parts of the fault where evidence of Holocene faulting previously had not been recognized. Supporting these observations and studies, geophysical (Langenheim et al., 2006a, b) and water-well (Kunkel and Upson, 1960) data indicate that the Napa Valley has developed into a relatively deep, young tectonic depression since deposition of the Sonoma Volcanics in the latter part of the Tertiary Period. The association of relatively deep Quaternary basins of probable tectonic origin with the West Napa fault likely reflects a higher long-term vertical rate of displacement and thus a higher total slip rate than previously thought.

Comparison of slip budgets between the regions north and south of Carquinez Strait also suggests that a significant amount of slip is being transferred from the North Calaveras fault to the West Napa fault via the Cull Canyon/Lafayette/Reliez Valley fault zone (Unruh et al., 2002). A recent analysis of GPS data also indicates a rate of 4 ± 3 mm/yr for the preferred model (d'Alessio et al., 2005). In light of these more recent studies, estimated slip rates used in a Phase 1 seismic hazard analysis as part of the Delta Risk Management Study (DRMS) conducted for the California Department of Water Resources (DWR) ranged from 0.5 to 4 mm/yr with preferred values in the range of 1 to 3 mm/yr (URS/Jack Benjamin Associates, 2007).

6.0 CONCLUSIONS

The West Napa fault is associated with an approximately 57-km-long zone of late Quaternary deformation that trends along the western margin of the Napa Valley from near the City of St. Helena on the north to Carquinez Strait on the south. The fault has an overall better geomorphic expression than previously thought, and additional evidence of young fault activity has been observed as part of this study and other studies of the fault. Locally, poor geomorphic expression of parts of the fault appears to reflect urbanization and other cultural modifications. Additional factors that influence the geomorphic expression of the West Napa fault include its relative geomorphic position, nontectonic geomorphic processes, structural complexities, and fault behavioral characteristics. The mapping for this study indicates the fault can be divided into five reaches based on differences in geomorphic position and expression of the fault, distinctive terrain traversed by the fault, and/or the type and availability of mapping data. From north to south, the reaches include St. Helena – Dry Creek, Yountville – North Napa, North Napa – Napa River, Napa River – American Canyon, and American Canyon – Carquinez Strait.

The St. Helena – Dry Creek reach is parallel to the western margin of Napa Valley for about 23.5 km from in the hills directly west of St. Helena to the prominent westerly bend in the fault in north Napa (Plate 1). Historically, this reach has not been included as part of the West Napa fault; however, fault-related geomorphic features are aligned along a previously identified bedrock fault that parallels the western margin of the Napa Valley. The bedrock fault and associated geomorphic features align with the mapped trace of the West Napa fault to the south. Linear valleys and topographic escarpments first observed during the aerial reconnaissance appear to be coincident with the bedrock fault separating Kgv and Tsv as mapped by Fox (1983). The majority of geomorphic features that define the overall geomorphic expression of this reach include larger-scale features, such as linear drainages, alignment of saddles, topographic escarpments, and breaks in slope; however, the occurrence right-deflected drainages, east-facing scarps, side-hill benches, and right-deflected ridges strongly indicate young fault activity.

The Yountville – North Napa reach trends along the base of the hills forming the western margin of the Napa Valley for about 9 km from Yountville to the prominent westerly bend in the fault that also defines the southern extent of the St. Helena – Dry Creek reach. These two reaches overlap, but the Yountville – North Napa reach trends in a more northerly direction and lies along the edge of the Napa Valley near the bedrock-alluvium contact. This part of the fault appears to juxtapose Tsv on both sides. Previous studies traditionally have considered the Yountville – North Napa reach to be the northernmost part of the West Napa fault with features indicative of late Quaternary activity, based on the presence of photolineaments, a groundwater barrier and geophysical anomalies. No trenching or other paleoseismic studies have been completed along this section of the fault. Indistinct tonal lineaments/contrasts, topographic escarpments, and possible east-facing scarps were observed during the aerial reconnaissance investigation. Most readily identifiable fault-related features along this reach include linear tonal contrasts and topographic escarpments; however, geomorphic features that strongly indicate the presence of young fault activity include east-facing scarps, right-deflected drainages, and a possible closed depression that are discontinuously expresssed along the middle to northern part of the reach. It is unclear if several right-deflected drainages along the southern part of the reach are fault related or represent channel modifications for agriculture. The discontinuous nature of the features in the south appears to be a result of young fluvial deposition and erosion, and agricultural activities that may obscure some subtle geomorphic features.

The North Napa – Napa River reach is somewhat obscured by cultural development and generally has an overall moderate to poor geomorphic expression. Along this reach, the fault appears to bifurcate into two or more traces: one trace along the base of the east-facing linear hill front at the margin of the Napa Valley, and one or more poorly expressed traces within the hills to the west. Discontinuous fault-related geomorphic features include linear hill fronts, breaks in slope, and subtle scarps occur along the central to southern part of the reach where larger tributary drainages are absent and extensive urban development obscures likely fault traces along the western margin of the valley. The linearity of the hill front and the presence of a deep Quaternary basin beneath the valley indicate that the main trace of the fault likely follows the western margin of Napa Valley. Faulted late Holocene deposits along Napa Creek confirm the presence of young faulting along the base of the hill front, and fault traces within the upland area are on trend with an east-facing fault scarp that displaces a sequence of at least four late Quaternary fluvial terraces along Redwood Creek. The larger apparent vertical separations and progressively increased eastward tilting of older terraces indicates recurrent late Quaternary faulting along the central part of the fault. At the southernmost end of the reach, the fault has little to no geomorphic expression for about 1 to 2 km where it crosses salt marshes and the floodplain of the Napa River.

The Napa River – American Canyon reach of the fault traverses the low, flat terrain south of the Napa River and consists of a narrow zone of well-expressed scarps, deflected drainages, and linear drainages. Quaternary to Tertiary sedimentary deposit underlie the reach. Numerous trenches excavated across this part of the fault, including a trench excavated for this study, confirms that late Pleistocene and Holocene alluvial deposits are displaced. The stratigraphic and structural relations exposed in our trench indicate there have been multiple surface-faulting events during the late Quaternary; however, the number and timing of individual surface-faulting events has been obscured by shrinking and swelling of the clayey soil in the upper part of the trench.

The American Canyon – Carquinez Strait reach lies along the western margin of the Sulphur Spring Mountains adjacent to the low relief terrain that borders the river and North Bay salt marshlands on the west. Kgv underlies the entire reach from Oat Hill at the northern end to the Carquinez Strait on the south. West-northwest-trending, en echelon bedrock ridges are present along the central part of this reach of the fault. Overall, this reach has relatively poor geomorphic expression because the natural terrain has been highly modified or masked by urban development associated with the cities of Vallejo and American Canyon. This reach of the fault appears to be transitional between the East Contra Costa shear zone as defined by Kelson et al. (2005) and the historically recognized Holocene-active portion of the fault. The fault has a relatively strong geomorphic expression in Southampton Bay, where the Southampton fault has been historically mapped. Evidence of active fault traces associated with mapped lineaments was identified in trenching studies along the northernmost part of this reach. These studies help constrain the active faulting on the northern part of the reach, but to our knowledge, no studies are available for the southern part of the reach. The presence of en echelon, northwest-trending bedrock ridges through this part of the reach may indicate complex step-over zone between the Southampton and West Napa faults.

7.0 REFERENCES

Applied Earth Sciences, 1978, Site trenching, boreholes, research and aerial photographic interpretation in American Canyon referenced in Kleinfelder (1992) and Terrasearch (1994).

Atwater, B.F., Hedel, C.W., and Helley, E.J., 1977, Late Quaternary depositional history, Holocene sea-level changes, and vertical crustal movement, Southern San Francisco Bay, California: U.S. Geological Survey, Professional Paper 1014, 15 pp.

Bailey Scientific, 1989, Geologic hazards investigation, Green Island Industrial Park, Napa County, California: Unpublished consulting report prepared for Panattoni Development Company, September 22. (AP-2328)

Bailey Scientific, 1990, Geologic hazards investigation, Green Island Industrial Park No. 3, Napa County, California, Price Property: Unpublished consulting report prepared for Mr. Harry Price, August 28. (AP-2451)

Bailey Scientific, 1991, Geologic hazards investigation, Struble Property, Parcel "B," Green Island Road, Napa County, California: Unpublished consulting report prepared for Mr. Lester Struble, August 9. (AP-2614)

Balbi & Chang Associates (BCA), 1983a, Geotechnical investigation report, Tribotech Manufacturing Facility, Oat Hill, Napa, California: Unpublished consulting report prepared for Mr. Bud Cain of Tribotech, September 6. (AP-1668)

Balbi & Chang Associates (BCA), 1983b, Geologic study, proposed Tribotech Facilities, Oat Hill, Napa, California: Unpublished consulting report prepared for Ward Maher and Sons, Inc., September 27. (AP-1668)

Balbi & Chang Associates (BCA), 1984, Alquist-Priolo requirements, geologic study, proposed Tribotech facilities, Oat Hill, Napa County, California: Unpublished consulting report prepared for Ward Maher and Sons, Inc., February 1. (AP-1668)

Bezore, S., Randolph-Loar, C.E., and Witter, R.C., 2002, Geologic map of the Cuttings Wharf 7.5′ Quadrangle, Napa and Solano counties, California: A digital database: California Geological Survey, scale 1:24,000.

Bezore, S., Clahan, K.B., Sowers, J.M., and Witter, R.C., 2005, Geologic map of the Yountville 7.5′ Quadrangle, Napa County, California: A digital database: California Geological Survey, scale 1:24,000.

Borchardt, G., 1994a, Holocene slip rate of the northern Hayward fault at Point Pinole, California (abs.), *in* Jacobson, M. L., ed., National Earthquake Hazards Reduction Program, Summaries of technical reports Volume XXXV, U.S. Geological Survey, Open-File Report 94-176, pp. 243-245.

Borchardt, G., 1994b, The Sangamon strandline in northern San Francisco Bay and its significance for paleoseismic studies (abs.), *in* Prentice, C.S., Schwartz, D.P., and Yeats, R.S., eds., Proceedings of the Workshop on Paleoseismology, U.S. Geological Survey, Open-File Report 94-0568, pp. 24-25.

Bay Soils, Inc., 1978, Geological and soil reconnaissance for a site near the Eagle Crest Property in American Canyon referenced in Kleinfelder (1992) and Terrasearch (1994).

Bryant, W.A., 1982, West Napa fault zone; Soda Creek fault (East Napa fault): California Division of Mines and Geology Fault Evaluation Report FER-129, 9 pp.

Bryant, W.A. (compiler), 2005, Digital database of quaternary and younger faults from the Fault Activity Map of California, Version 2.0: California Geological Survey, http://www.conservation.ca.gov/cgs/information/publications/Pages/QuaternaryFaults_ver2.aspx.

Cao, T., Bryant, W.A, Rowshandel, B., Branum, D., and Wills, C.J., 2003, The revised 2002 California probabilistic seismic hazard maps, June 2003: California Geological Survey, http://www.consrv.ca.gov/CGS/rghm/psha/fault_parameters/pdf/2002_CA_Hazard_Maps.pdf.

Clahan, K.B., Wagner, D.L., Bezore, S.P., Sowers, J.M., and Witter, R.C., 2005, Geologic map of the Rutherford 7.5′ Quadrangle, Sonoma and Napa counties, California: A digital database: California Geological Survey, scale 1:24,000.

Clahan, K.B., Wagner, D.L., Saucedo, G.J., Randolph-Loar, C.E., and Sowers, J.M., 2004, Geologic map of the Napa 7.5′ Quadrangle, Napa County, California: A digital database: California Geological Survey, scale 1:24,000.

d'Alessio, M.A., Johanson, I.A., Bürgmann, R., Schmidt, D.A., and Murray, M.H., 2005, Slicing up the San Francisco Bay Area: Block kinematics and fault slip rates from GPS-derived surface velocities: Journal of Geophysical Research 110, doi:10.1029/2004JB003496, 19 pp.

Darwin Myers Associates (DMA), 1981, Geologic reconnaissance investigation, 250 Broadway (south of American Canyon Road), Vallejo, California: Unpublished consulting report.

Darwin Myers Associates (DMA), 1982, Geologic reconnaissance for a portion of Eagle Crest Property in American Canyon referenced in Kleinfelder (1992) and Terrasearch (1994).

Darwin Myers Associates (DMA), 1983, Geologic and Seismic Hazards Reconnaissance, Napa Airport Study Area, Napa County: Unpublished consulting report, August 10, 1 plate, 1 appendix, 31 pp.

Darwin Meyers Associates (DMA), 1984, Technical review of Alquist-Priolo report and addendum prepared for Tentative Parcel Map #2359-PM (Medeiros); report and map prepared by Kleinfelder & Associates (report dated 11-18-83; addendum dated 9-6-84):

Unpublished consulting report prepared for Napa County Planning and Development Department, September 12. (AP-1669)

Donald Herzog & Associates, Inc. (DHA), 1984, Soil investigation Murdock Property, 1133 Larkin Way, Napa, California: Unpublished consulting report, May 5, 6 plates, 26 pp. (C-569)

Donald Herzog & Associates, Inc. (DHA), 1988a, Report geologic hazard investigation, 37-Acre Residential Subdivision AP #85-040-21, south of Eucalyptus Drive, American Canyon, California: Unpublished consulting report prepared for Mr. David Strunk, April 13. (AP-2233)

Donald Herzog & Associates, Inc. (DHA), 1988b, Geologic investigation for a portion of Eagle Crest Property in American Canyon referenced in Kleinfelder (1992) and Terrasearch (1994).

Donald Herzog & Associates, Inc. (DHA), 1989, Report addendum, 37-Acre Residential Subdivision AP #85-040-21, south of Eucalyptus Drive, American Canyon, California: Unpublished consulting report prepared for Mr. David Strunk, February 10. (AP-2233)

Dwyer, M.J., and Borchardt, G., 1994, Paleoseismicity and liquefaction potential of a Sangamon marine terrace near the San Andreas fault, Sonoma County, California (abs.), *in* Prentice, C.S., Schwartz, D.P., and Yeats, R.S., eds., Proceedings of the Workshop on Paleoseismology: U.S. Geological Survey, Open-File Report 94-0568, pp. 59-61.

Earthtec Ltd., 1989, Preliminary geotechnical/geological study, Struble Industrial Park, Green Island Road, Napa County, California: Unpublished consulting report prepared for Mr. Lester Struble, February 24. (AP-2614)

ENGEO, 1977, Geologic Investigation for Mead Property, Napa County, California: Unpublished consulting report prepared for Ward-Ryder Company, March 21, 30 pp. (C-352)

Environmental Management & Research, Inc. (EMRI), 1979, Fault hazard investigation, preliminary soils data, Green Island Industrial Park, Napa County, California: Unpublished consulting report, August 1, 24 pp. (AP-2328)

Figuers, S., 1991, The tectonics of western Solano County, *in* Figuers, S., Prince, R., Eppink, J., Erskine, M., Baldwin, R., Crane, R., Halliday, J., and Crane, K., eds., Field Trip Guide to the Geology of Solano County: Northern California Geological Society and Association of Engineering Geologists Field Trip, October 12, Pleasanton, California, pp. 160-171.

Fox, K.F., Jr., 1983, Tectonic setting of late Miocene, Pliocene, and Pleistocene rocks in part of the Coast Ranges north of San Francisco, California: U.S. Geological Survey, Professional Paper 1239.

Fox, K.F., Jr., Sims, J.D., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of eastern Sonoma County and western Napa County, California: U.S. Geological Survey, Miscellaneous Field Studies Map MF-483, scale 1:62,500.

Geomatrix Consultants, Inc. (Geomatrix), 1998, Final Report, Walnut Creek Water Treatment Plant Expansion, Seismic Study—Phase II: Unpublished consulting report prepared for East Bay Municipal Utility District, October 30, 5 tables, 9 figures, 2 appendices, 63 pp.

Geotechnical Engineering Inc. (GEI), 1996, Soil Investigation Including Geologic Hazard Evaluation, New Assembly Hall, Kingdom Hall & Bridge, American Canyon Assembly of Jehovah's Witnesses, Commerce & Hanna Drives, American Canyon, California: Unpublished consulting report, 32 pp. (AP-2328)

Giblin Associates, 2005, Geologic Hazards and Preliminary Geotechnical Investigation, Oat Hill Subdivision, American Canyon, CA: Unpublished consulting report prepared for Delco Builders and Developers, October 13.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 2002, Geologic map and map database of northeastern San Francisco Bay Region, California: U.S. Geological Survey, Miscellaneous Field Studies Map MF-2403, version 1.0, scale 1:100,000.

Harding Lawson Associates, 1987, Site reconnaissance south of Oat Hill in American Canyon referenced in Kleinfelder (1992) and Terrasearch (1994).

Hart, E.W., 1990, Fault-rupture hazard zones in California: California Division of Mines and Geology Special Publication 42, 24 pp.

Helley, E.J., and Herd, D.G., 1977, Map showing faults with Quaternary displacement, northeastern San Francisco Bay region, California: U.S. Geological Survey, Miscellaneous Field Studies Map MF-881, scale 1:125,000.

Helley, E.J., Lajoie, K.R., Spangle, W.E., and Blair, M.L., 1979, Flatland deposits of the San Francisco Bay Region, California—Their geology and engineering properties, and their importance to comprehensive planning: U.S. Geological Survey, Professional Paper 943, 88 pp.

Jayko, A.S., and Lewis, S.D., compilers, 1996, Toward assessing the seismic risk associated with blind faults, San Francisco Bay Region, California: U.S. Geological Survey, Open-File Report 96-267, 1 plate, scale 1:500,000, 188 pp.

Jennings, C.W., 1994, Fault activity map of California and adjacent areas with locations and ages of recent volcanic eruptions: Department of Conservation, California Geological Survey, Geologic Data Map No. 6, scale 1:750,000.

J.H. Kleinfelder & Associates (J.H. Kleinfelder), 1983, Fault Location Study, Medeiros Subdivision – Parcel 2, Napa County, California: Unpublished consulting report, November 18. (AP-1669)

J.H. Kleinfelder & Associates (J.H. Kleinfelder), 1984a, Addendum to fault location report, tentative parcel map #2359-PM, Mederios Subdivision: Unpublished consulting report, September 6. (AP-1669)

J.H. Kleinfelder & Associates (J.H. Kleinfelder), 1984b, Engineering geology evaluation report, Oat Hill Industrial Subdivision, TR Contract No. 84-2, Napa County, California: Unpublished consulting report, August 2. (AP-1668)

J.H. Kleinfelder & Associates (J.H. Kleinfelder), 1984c, Response to comments concerning engineering geology evaluation report, Oat Hill Industrial Subdivision, TR Contract No. 84-2, Napa County, California: Unpublished consulting report, August 31. (AP-1668)

Kelson, K.I., Unruh, J.R., and Baldwin, J.N., 2005, Late Quaternary deformation in the northeastern East Bay hills, San Francisco Bay region (abs.): Geological Society of America, Abstracts with Programs, v. 37, no. 4, p. 106.

Kisliuk, B., 2008, Browns Valley site rejected for fire station: Napa Valley Register newspaper article, April 26.

Kleinfelder, 1990a, Preliminary geological engineering evaluation, commercial development at the southwest corner of the intersection of Broadway Street and American Canyon Road, Napa County Assessor's Parcel No. 059-110-30 & 33, Napa County, California: Unpublished consulting report prepared for Elliott Real Estate, June 11. (AP-2483)

Kleinfelder, 1990b, Addendum to preliminary geological engineering evaluation dated June 11, 1990, for the proposed commercial development to be located on Napa County Tax Assessor's Parcel No. 059-110-30 and 33, Napa County, California: Unpublished consulting report prepared for Elliott Real Estate, September 18. (AP-2483)

Kleinfelder, 1990c, Second addendum to preliminary geological engineering evaluation dated June 11, 1990 and September 18, 1990, for the proposed commercial development to be located on Napa County Tax Assessor's Parcel No. 059-110-30 and 33, Napa County, California: Unpublished consulting report prepared for Elliott Real Estate, November 5. (AP-2483)

Kleinfelder, 1992, Fault investigation report Eagle Crest Subdivision: Unpublished consulting report prepared for American Canyon Associates, May 28. (AP-2950)

Kunkel, F., and Upson, J.E., 1960, Geology and ground water in Napa and Sonoma counties, California: U.S. Geological Survey, Water-Supply Paper 1459, U.S. Government Printing Office, Washington, D.C., 252 pp.

Langenheim, V.E., Graymer, R.W., and Jachens, R.C., 2006a, Geophysical setting of the M_L 5.2 Yountville, California, earthquake: Implications for seismic hazard in Napa Valley, California: Bulletin of the Seismological Society of America, v. 96, no. 3, pp. 1192-1198.

Langenheim, V.E., Roberts, C.W., McCabe, C.A., McPhee, D.K., Tilden, J.E., and Jachens, R.C., 2006b, Preliminary isostatic gravity map of the Sonoma Volcanic field and vicinity, Sonoma and Napa counties, California: U.S. Geological Survey, Open-File Report 2006-1056, scale 1:100,000.

Pampeyan, E.H., 1979, Preliminary map showing recency of faulting in coastal north-central California: U.S. Geological Survey, Miscellaneous Field Studies Map MF-1070, 13 pp. pamphlet, 3 sheets, scale 1:250,000.

Petersen, M.D., Frankel, A.D., Harmsen, S.C., Mueller, C.S., Haller, K.M., Wheeler, R.L., Wesson, R.L., Zeng, Y., Boyd, O.S., Perkins, D.M., Luco, N., Field, E.H., Wills, C.J., and Rukstales, K.S., 2008, Documentation for the 2008 Update of the United States National Seismic Hazard Maps: U.S. Geological Survey, Open-File Report 2008–1128, 61 pp.

Randolph Loar, C.E., 2002, Neotectonics of the Southern Rodgers Creek Fault, Sonoma County, California: San Francisco State M.S. thesis in applied geosciences Geology, 4 plates, 3 appendices, 54 pp.

Raney Geotechnical, 2003a, Fault Rupture Hazard Investigation, Green Island Industrial Park, Approximately 50-Acre Site, Hanna Drive South of North Slough, American Canyon, California: Unpublished consulting report prepared for Industrial & Commmercial Contractors, L.P., January 24.

Raney Geotechnical, 2003b, Geotechnical Investigation, Commerce 197 Building, Commerce Boulevard, American Canyon, California: Unpublished consulting report.

Raney Geotechnical, 2005, Geotechnical investigation top of the hill buildings, Hanna Drive east of Commerce Drive, American Canyon, California: Unpublished consulting report prepared for Colonel Projects, Inc., December 2.

Raney Geotechnical, 2007, Supplemental Fault Rupture Hazard Investigation, Green Island Industrial Park, Approximately 50-Acre Site, Hanna Drive South of North Slough, American Canyon, California: Unpublished consulting report.

Sims, J.D., Fox, K.F., Jr., Bartow, J.A., and Helley, E.J., 1973, Preliminary geologic map of Solano County and parts of Napa, Contra Costa, Marin, and Yolo counties, California: U.S. Geological Survey, Miscellaneous Field Studies Map MF-484, scale 1:62,500.

Soil Conservation Service, 1978, Soil Survey of Napa County, California: U.S. Department of Agriculture Soil Conservation Service in Cooperation with University of California Agricultural Experiment Station, U.S. Government Printing Office, 51 plates, scales 1:24,000 and 1:253,440, 104 pp.

Sowers, J.M., Noller, J.S., and Lettis, W.R., 1995, Maps showing Quaternary geology and liquefaction susceptibility in the Napa, California, 1:100,000 sheet: U.S. Geological Survey, Open-File Report 95-205, 2 plates, scale 1:100,000, 23 pp.

Stuiver, M., and Polach, H.A., 1977, Discussion: Reporting of ^{14}C data, Radiocarbon, v. 19, p. 355-363.

Terrasearch, Inc., 1994, Fault hazard investigation on Eagle Crest Property, American Canyon, California: Unpublished consulting report, October 6. (AP-2950)

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

Toppozada, T.R., Bennett, J.H., Hallstrom, C.L., and Youngs, L.G., 1992, 1898 "Mare Island" earthquake at the southern end of the Rodger Creek Fault, *in* Borchardt, G., et al., eds., Proceedings of the second conference on earthquake hazards in the eastern San Francisco Bay Area: California Department of Conservation, Division of Mines and Geology (California Geological Survey), Special Publication 113, pp. 385-392.

Unruh, J.R., Kelson, K.I., and Barron, A., 2002, Critical evaluation of the northern termination of the Calaveras fault, eastern San Francisco Bay area, California: Final Technical Report, U.S. Geological Survey, National Earthquake Hazards Reduction Program Award Number 00-HQ-GR-0082, July, 72 pp.

URS Corporation/Jack Benjamin & Associates, 2007, Technical Memorandum Delta Risk Management Study (DRMS) Phase 1, Topical Area Seismology: Report prepared for the California Department of Water Resources, February 1

Wagner, D.L., and Bortugno, E.J., 1982, Geologic map of California, Santa Rosa sheet: California Division of Mines and Geology, scale 1:250,000.

Wagner, D.L., Clahan, K.B., Saucedo, G.J., Randolph-Loar, C.E., and Sowers, J.M., 2004, Geologic map of the Sonoma 7.5′ quadrangle, Sonoma and Napa counties, California: A digital database: California Geological Survey, scale 1:24,000.

Wallace-Kuhl & Associates, Inc. (WKA), 1994, Geologic hazards report, American Canyon City Arts Center, 3751 Broadway (Highway 29), American Canyon, California: Unpublished consulting report, August 29. (AP-2798)

Weaver, C.E., 1949, Geology and mineral deposits of an area north of San Francisco Bay, California: California Division of Mines Bulletin 149, 135 pp.

Wentworth, C.M., 1997, General distribution of geologic materials in the San Francisco Bay region, California: A digital map database: U.S. Geological Survey, Open-File Report 97-774, database resolution 1:125,000.

Wesling, J.R., Hanson, K.L., and Swan, F.H., 2000, Paleoseismic investigation of the West Napa fault, San Francisco Bay Area, California (abs.): EOS, Transactions of the American Geophysical Union, v. 81, no. 48, p. F851.

Wesling, J.R., Hanson, K.L., and Swan, F.H., 2001, Investigation of the West Napa fault, San Francisco Bay Area, California (abs.): Seismological Research Letters, v. 72, no. 2, pp. 226-227.

Western Geological Consultants, 1980, Geologic Hazards Investigation, Brown's Valley Road and Robinson Lane, Napa, California: Unpublished consulting report (C-396).

Working Group on Northern California Earthquake Potential (WGNCEP), 1996, Database of potential sources for earthquakes larger than magnitude 6 in northern California, U.S. Geological Survey, Open-File Report 96-705, 53 pp.

TABLE 1

AERIAL PHOTOGRAPHY COVERAGE

Mapping of the West Napa Fault Zone
Napa County, California

Type	Date	Scale	Source
Stereo Pair, B&W	19-27-73	1:20,000	U.S. Geological Survey
Stereo Pair, B&W	3-1-58	1:36,000	Pacific Aerial Surveys
Stereo Pair, B&W	5-11-79	1:54,000	Pacific Aerial Surveys
Stereo Pair, B&W	11-2-81	1:54,000	Pacific Aerial Surveys
Stereo Pair, B&W	7-8-88	1:7,200	Pacific Aerial Surveys

TABLE 2

SUMMARY OF PREVIOUS FAULT EVALUATION STUDIES
Mapping of the West Napa Fault Zone
Napa County, California

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
ENGEO, 1977	C-352	Center of Sec. 5, T5N, R4W Mead Property	Study included review of available literature, interpretation of aerial photographs, field reconnaissance, trenching program, and geophysical surveys to aid in locating the fault. Trenching of a lineament (defined by either a break-in-slope or tonal contrast) that coincided with previously mapped traces of the WNF provided stratigraphic and structural evidence of recent faulting. Setbacks were recommended although the timing of most recent offset was not determined.	
DHA, 1984	C-569	SE ¼ Sec. 5, T5N, R4W 1133 Larkin Way Napa, California	Based on a surficial geotechnical reconnaissance and subsurface investigations (excavation and logging of four test pits), a trace of the WNF was identified and setbacks recommended. The fault zone is observed in bedrock (Great Valley Sequence) in two trenches and extends up to the colluvium/bedrock interface. Slickensided planes at the base of the colluvium indicate significant soil creep at the site, thus precluding a reliable assessment of recency.	
DMA,1983	AP 2929	Sec. 11, T4N, R4W Napa County Airport	Based on interpretation of aerial photographs, field mapping, and subsurface trenching investigations, this study concluded that Holocene deposits were displaced across the main trace of the West Napa fault at this locality. Shear planes in the topsoil, a geomorphic break in slope, and change in moisture content were cited as the primary evidence for recent faulting. It also was noted that minor, roughly fault traces and branching faults might occur within 200 to 300 feet of the main trace.	The two trenches of the DMA study were about 80 m north of the trench excavated for the present study.
Earthtec Ltd., 1989	AP 2614	NW¼ Sec.11, T4N, R4W Green Island Road (Struble Property)	Based on indications of faulting (jumbled and chaotic mixing of sandstone and mudstone) that were observed in a trench excavated across a photo-lineament (interpreted to be a branch of the WNF) that crosses the northeastern corner of the site; a setback was recommended.	

TABLE 2

SUMMARY OF PREVIOUS FAULT EVALUATION STUDIES

Mapping of the West Napa Fault Zone
Napa County, California

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
Bailey Scientific, 1991	AP 2614	NW¼ Sec.11, T4N, R4W Green Island Road (Struble Property)	Deformed units (Great Valley sequence and Huichica formation) observed in three trenches are interpreted as a tight fold (overturned anticline). Logs show steep contacts between Great Valley sequence and Huichica formation (Pliocene-Pleistocene) with older sediments overlying younger sediments. The Huichica Formation is flat lying on the southwest side of the tight fold and moderately to steeply dipping on the northeast side. The Great Valley Sequence overlies the Huichica Formation. Slickensides (described as sheared surfaces produced by the tight folding) are concentrated in Huichica clays along the overturned limb. A photolineament through the site is interpreted to represent the axis of the anticline.	Structural relationships depicted on logs are more likely due to faulting.
Bailey Scientific, 1990	AP 2451	SW¼ Sec. 13, T4N,R4W (Price Property)	Study included review of pertinent geologic literature, photogeologic interpretation, a geologic reconnaissance, and magnetic and seismic refraction surveys.	
Bailey Scientific, 1989	AP 2328	S. Sec 14 and SW¼ Sec 13, T4N, R4W (Panattoni property)	Study included an exploration trench, a ground-magnetic survey, site and local geologic reconnaissance, photogeologic interpretation, and a literature review. No evidence was found that was interpreted as being representative of a fault or related to a fault. The trench exposed a soil “B” horizon developed on older alluvium and colluvium estimated age of 10 ka. A stage II+ to III carbonate morphology has developed in the soil formed in the older alluvium exposed in the trench, suggesting these deposits are likely older than 20 ka.	Referenced in Bailey Scientific (1990) location of Trench “A” on Panattoni property shown on Darwin Myers map included as Appendix A to this report.
EMRI, 1979	AP 2328	S. Sec 14 and SW¼ Sec 13, T4N, R4W (Panattoni property)	Investigations included magnetic survey and excavation and logging of three trenches across each of the three WNF traces mapped by Helley and Herd (1977). No magnetic anomalies were detected across suspected fault trace (data not shown in report). Evidence of faulting was	Documentation of location of lineaments and trenches is inadequate to evaluate conclusions cited in report. There is no discussion of the ages of

TABLE 2

SUMMARY OF PREVIOUS FAULT EVALUATION STUDIES
Mapping of the West Napa Fault Zone
Napa County, California

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
			not observed in any of the trenches. The authors concluded that the air photo lineation observed towards the west side of the site coincides with a tonal variation in color due to change in lithology (presence of channel) and is not fault related.	Quaternary deposits exposed in trenches.
J.H. Kleinfelder, 1984b, c	AP 1668	SE¼ Sec 14, SW¼ Sec 13, NE¼ Sec 23, NW¼ Sec. 24, T4N, R4W Oat Hill	Study included excavation and logging of five trenches and six test pits, photogeologic interpretation, and literature review. The field investigation located several landslides, areas of active soil creep, a fault on the western slopes of Oat Hill and probable fault-related fracturing at the northeast corner of the project site. The study concluded that the main trace of the WNF likely occupies a saddle east of the site. Trenching on the western side of Oat Hill, across a photolineament, intercepted a fault that the report states is likely an active fault (associated with springs) but its recency was not determined.	
BCA, 1983a, b, 1984	AP 1668	SE¼ Sec 14, SW¼ Sec 13, NE¼ Sec 23, NW¼ Sec. 24, T4N, R4W Oat Hill	These reports chiefly describe geotechnical conditions and foundation investigation. Geologic investigations to assess geologic hazards included field reconnaissance, review of aerial photographs, and review of available data and sampled borings. The report states there is no evidence of (active) faults or fault-related structures on or directly adjacent to the building location.	The building site is located approximately 900 ft southwest of the concealed trace of the West Napa fault on the east side of Oat Hill. Documentation of the geologic investigations is insufficient to adequately review conclusions regarding potential faulting in the vicinity of the site.
GEI, 1996	AP 2328	North of Oak Hill C, SE¼ Sec.14, T4N, R4W Commerce & Hanna Drives	Seismic hazards- proposed site lies partly within the A-P Earthquake Fault zone for West Napa fault; recommended that building site be moved west to avoid zone or that detailed fault studies be conducted. Stratigraphy at site based on shallow borings consists of limited (~3 ft) of fill and topsoil, over stiff plastic (highly expansive) clay underlain by sandstone, shale and claystone.	Detailed fault studies were not conducted for this study.

TABLE 2

SUMMARY OF PREVIOUS FAULT EVALUATION STUDIES

Mapping of the West Napa Fault Zone
Napa County, California

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
J.H. Kleinfelder, 1983, 1984a	AP 1669	NW¼ Sec.24, T4N, R4W (Medeiros Property)	Study included review of published and unpublished literature and reports, interpretation of aerial photographs, site reconnaissance, and excavation and logging of two trenches. This study concluded that the surface trace of the West Napa fault, defined by an aerial photograph lineament and disruptions in stratigraphic units exposed in trenches, did cross the site	The lineament used to locate the fault across the site is not documented in the initial report or addendum as stated in review by DMA (1984). There is insufficient detail shown on log to evaluate the validity of the fault zone interpretation. The fault zone is shown as a 12.5 ft-wide zone of caliche seams that were added to the log in the addendum and appear to be diagrammatic rather than mapped.
DHA, 1988, 1989	AP 2233	SE¼ Sec. 23 and SW¼ Sec. 24, T4N, R4W	Seven trenches (total of 688 linear feet) were excavated across the northeast corner of the site to investigate the location of active traces of the WNF. Bedrock faults identified in four of the trenches were not observed to extend up into the topsoil layer. These fault traces were interpreted to be secondary traces of the WNF that are not well enough defined to be consider potentially active. A supplemental investigation was conducted to further assess the activity of faults identified on the site. Based on these studies, which included additional trenching, four fault traces (A, B, C, and D) are mapped in the site. Based on displacement of residual soils (of uncertain age) observed on traces A, C, and possibly D, these three faults are considered to be active and setbacks are recommended. Trace B does not displace the residual soil and is judged not active.	
WKA, 1994	AP 2798	SW¼ Sec. 24, T4N, R4W 3751 Broadway	No evidence of surface faulting was observed at the site. Investigations included excavation and logging of two trenches perpendicular to the trend of the WNF mapped	Older alluvium exposed in lower part of trenches (depth 6-7 ft to 10 ft) contains calcite/gypsum

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
		(State Hwy 29)	~250 ft west of the site.	nodules to 1-in diameter.
DMA, 1981		SE¼ Sec. 25, T4N, R4W	Based on research, review of other investigation reports and air photo analysis, this report concluded that there is no evidence of active fault traces on the property.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994) References fault investigations for the area including Applied Earth Sciences (1978) report for property to the southeast where trenching failed to disclose the presence of faulting.
DMA,1982		SE¼ Sec. 25, T4N, R4W and SW¼ Sec 30, T4N, R3W	(Portion of Eagle Crest Property) Based on research, review of other investigation reports and air photo analysis, this report concluded that there is no evidence of active fault traces on the property and that no further geologic study is warranted.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994)
Terrasearch, Inc., 1994	AP 2950	SE¼ Sec. 25, T4N, R4W American Canyon, Broadway Road at American Canyon Road	Study area marks southern terminus of West Napa fault; several splays present that die out and become discontinuous in the near surface. Trenching investigations (five trenches excavated at site) identified a limited portion of one trace as potentially active. Faulting and/or folding of older Pleistocene alluvium (Qpa-estimated to be 10 to 70 ka) was identified in four of the trenches.	Age of unfaulted alluvium exposed in trenches is not well constrained. Surface deposits are disrupted in central part of site area over portions of the fault that are identified as potentially active. Unfaulted older alluvium in trenches excavated in the northern part of the study area mapped as Qpa are described as weakly cemented near bottom of exposure.
Kleinfelder, 1992	AP 2950	Broadway Road American Canyon, SE¼ Sec 25, T4N, R4W	Based on trenching investigations, this study concluded that the active trace of the WNF terminates (at least at surface) in the north part of study area. The fault was identified in trench exposures as a near-vertical trace of fault gouge exhibiting evidence of right-lateral, strike-slip movement offsetting sediments possibly as young as	

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
			Holocene age. The subsurface exposures confirmed the presence of the fault as projected from a sharp lineal surface feature identified from inspection of aerial photographs in the region north of the site (north of American Canyon Road).	
Kleinfelder, 1990a, b, c	AP 2483	C, Sec. 25, T4N, R4W	Based on a field reconnaissance and photogeologic interpretations, it was concluded that eastern boundary of the subject property lies about 120 m (400 feet) west of sharp tonal lineament in alluvium that was used to define main trace of the WNF for the Fault Rupture Hazard Zone in this area.	
DHA, 1988b		NW¼ Sec.31, T4N, R4W Portion of Eagle Crest Property	Preliminary geotechnical investigation. Based on research, a site reconnaissance and air photo analysis, this study concluded that there are no indications of active faulting at the site and the risk of related ground rupture is considered low.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994)
Bay Soils, Inc., 1978		SW¼ Sec. 30, T4N, R3W	Based on geological and soil reconnaissance, this report concluded that no faults or lineations are present.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994) No subsurface investigations were performed.
Harding Lawson Associates, 1987		NW¼ Sec 31, T4N, R4W	Concluded that there is no conclusive evidence of faulting south of Oat Hill based on a site reconnaissance, photo interpretation and technical report research.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994)
Applied Earth Sciences, 1978		NW¼ Sec. 31, T4N, R3W	Exploration including trenching, boring, research and interpretation of aerial photographs failed to disclose evidence of faulting.	(referenced in Kleinfelder, 1992, and Terrasearch, 1994)
Raney Geotechnical, 2003a, b, 2005, 2007	N/A	SW¼ Sec. 13, SE¼ Sec. 14, T4N, R4W	Exploration included literature review, review and interpretation of aerial photographs, excavation and study trenches, drilling and logging of three borings to depth of 19 feet, and descriptions of soil profile development. Initial	The fault on the northeast side of Oat Hill is coincident with the main trace of the West Napa fault as defined by Bryant (1982). The

TABLE 2

SUMMARY OF PREVIOUS FAULT EVALUATION STUDIES

Mapping of the West Napa Fault Zone
Napa County, California

STUDY[1]	AP NO.[2]	LOCATION[3]	OBSERVATIONS/RESULTS[4]	COMMENTS[5]
			trenching reported in 2003a identified a well-defined active fault on the southwest side of Oat Hill. Additional trenching in 2007 documented the presence of an active fault on the northeast side of the hill. The estimated ages of late Quaternary surficial deposits along the fault on the northeast side of the hill were based on the degree of soil profile development and were used to assess the recency of activity.	fault is coincident with a strong lineament (Bryant, 1982; this study). The main trace juxtaposes Cretaceous Great Valley Sequence on the southwest against Plio-Pleistocene Huichica Formation on the northeast. The fault on the southwest side of the hill juxtaposes Cretaceous Great Valley Sequence on both sides. Both fault traces align with faults/lineaments to the south and north.
Giblin Associates, 2005	N/A	SW¼ Sec. 13, SE¼ Sec. 14, NE¼ Sec. 23, NW¼ Sec. 24 T4N, R4W	Exploration included literature review, review and interpretation of aerial photographs, excavation and study of 30 test pits and 20 trenches, drilling and logging of three borings to depth of 51 feet, and descriptions of soil profile development. Two well-defined, active fault zones were intercepted in several trenches, with one zone occurring on the northeast side of Oat Hill and one zone on the southwest side of the hill. The faulting on the northeast side of the hill is interpreted to be the main trace of the West Napa fault, and the faulting on the southwest side is a series of parallel fault planes that dip steeply to the northeast. The ages late Quaternary surficial deposits based on the degree of soil profile development were used to assess activity on fault traces exposed in the trenches.	The fault on the northeast side of Oat Hill aligns with the fault exposed by Raney Geotechnical (2007) to the north. The fault on the southwest side of the hill aligns with the fault exposed by Raney Geotechnical (2003a) to the north and DHA (1988, 1989).

[1] See References for complete citation.
[2] Refers to Alquist-Priolo study number assigned by the California Geological Survey.
[3] Approximate location with respect to section, township, and range, and/or street address. See Plate 1 for detailed locations of studies.
[4] Description of the data, results and conclusions described in the study report.
[5] Comments based on critical evaluation of each study.

TABLE 3
SUMMARY CHARACTERISTICS OF WEST NAPA FAULT REACHES
Mapping of the West Napa Fault Zone
Napa County, California

Fault Reach	Bedrock Geologic Relationships*	Pattern of Faulting	Geomorphic Position of Fault Trace	Geomorphic Expression of Fault Trace	Primary Evidence Indicating Geologically Recent Fault	Cultural Modifications Along Reach	Mapping Techniques
St. Helena - Dry Creek	Kgv and KJf on west juxtaposed against Tsv on east	Relatively simple pattern of faulting	Fault is near western margin of valley.	Right-deflected drainages, linear drainages, linear break-in-slope, and east-facing scarps.	Presence of fault-related geomorphic features indicative of young faulting	Little, forested terrain and agricultural land	Interpretation of aerial photographs with limited ground reconnaissance mapping; aerial reconnaissance
Yountville - North Napa	Tsv comprises hills with Veterans Peak on west side of fault, and isolated hills/knobs underlain by Tsv on the east.	Relatively simple pattern of faulting	Fault along western valley margin	Arcuate alignment of east-facing scarps, tonal contrasts, topographic escarpments, and possible right-deflected drainages.	Presence of fault-related geomorphic features indicative of young faulting	Little but locally moderate, agricultural land	Interpretation of aerial photographs with ground reconnaissance along roads; aerial reconnaissance
North Napa - Napa River	Kgv on southwest juxtaposed against Tsv on northeast and faulting along valley margin juxtaposes Tsv against Qal, Qoa, and QTh(?).	Complex pattern of anastamosing fault traces	Fault traces trend along the western margin of the valley and within the low hills directly to the west.	East-facing scarps, linear drainage segments, break-in-slope, and possible right-deflected drainages along the northern part of section; linear range front, tonal contrasts, and linear drainage segments to south. The number and continuity of lineaments.	Trenches and natural exposures documenting late Pleistocene and Holocene activity	Considerable urbanization masks trace of fault.	Aerial reconnaissance, field reconnaissance, interpretation of aerial photographs; Compilation of available trenching data
Napa River - American Canyon	Isolated knobs/hills underlain by Kgv and Tertiary marine sediments	Relatively simple trace	Fault traces traverse Napa River floodplain, salt marshes, and low-relief terrain marginal to the river and north bay salt marshes.	East- and west-facing scarps, right-deflected drainages, and tonal contrasts; Napa River makes a broad swing to the west and then changes course to the south where river crosses fault.	Trenches document late Pleistocene and Holocene fault activity	Urbanization locally separated by agricultural and bay margin land	Compilation of available mapping and trenching data; Aerial reconnaissance; Field reconnaissance, interpretation of aerial photographs, paleoseismic trenching
American Canyon - Carquinez Strait	Kgv on both sides of fault	No through-going/continuous trace of fault observed in mapping or in previous mapping.	Fault traverses medium to low-relief terrain.	Alignment of fault-related geomorphic features separated by NW-trending ridges mapped as anticlines. Linear drainage segments, tonal contrasts and scarps along northern part of reach. Linear drainage segments and Southampton Bay linear to south.	Trenches document late Pleistocene and Holocene fault activity along northern part of reach. Kelson and others (2005) document activity based on mapping of marine terraces along Carquinez Strait indicate Pleistocene.	Considerable urbanization along trace of fault	Mapping based on aerial reconnaissance, interpretation of aerial photography and limited field reconnaissance; Trenching data available for northern part of reach.

* KJF = Cretaceous to Jurassic Franciscan Formation; Kgv = Cretaceous Great Valley Formation; Tsv = Tertiary Sonoma Volcanics; QTh = Plio-Pleistocene Huichica Formation; Qoa = Pleistocene older alluvium; Qal = Holocene alluvium.

TABLE 4

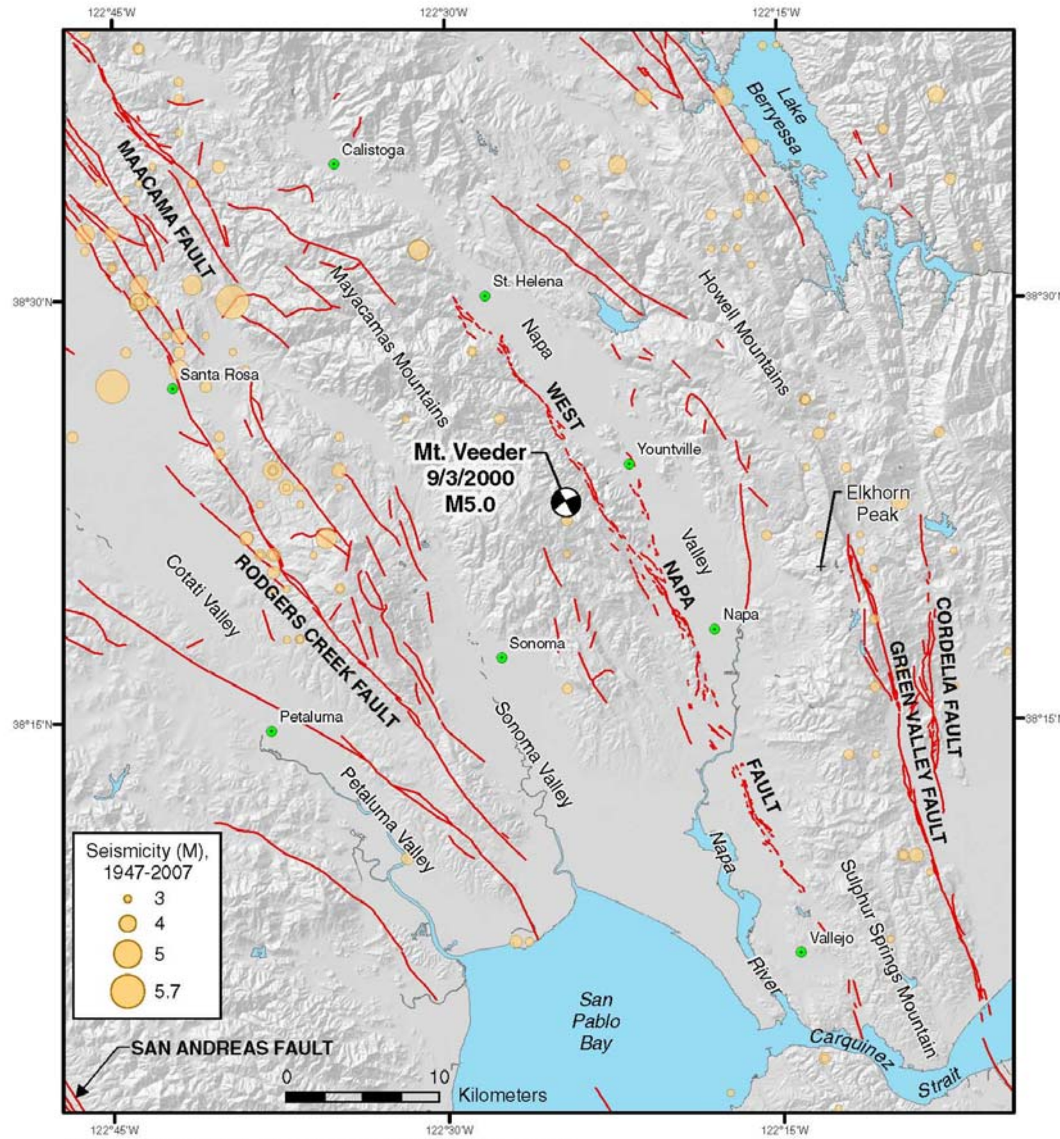
RADIOCARBON RESULTS FOR THE NAPA CREEK EXPOSURE

Mapping of the West Napa Fault Zone
Napa County, California

Laboratory Number	Sample Name	$\delta^{13}C$	Fraction Modern	±	$D^{14}C$	±	^{14}C Age	±
75747	Napa Creek 1	-25	0.9023	0.0040	-97.7	4.0	830	40
75748	Napa Creek 2	-25	0.9272	0.0041	-72.8	4.1	610	40
75749	Napa Creek 3	-25	0.9256	0.0041	-74.4	4.1	620	40

1. Radiocarbon analyses were completed at the Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory on May 21, 2001.
2. Delta ^{13}C values are the assumed values, according to Stuiver and Polach (1977), when given without decimal places. Values measured for the material itself are given with a single decimal place.
3. The quoted age is in radiocarbon years using the Libby half-life of 5,568 years and following the conventions of Stuiver and Polach (1977).
4. Radiocarbon concentration is given as fraction Modern, $D^{14}C$, and conventional radiocarbon age.
5. Sample preparation backgrounds have been subtracted, based on measurements of samples of ^{14}C-free coal. Backgrounds were scaled relative to sample size.
6. Comment: The material dated was acid-base-acid treated charcoal.

File path: S:\10300\10377\10377.000\07_1206_fr_fig_01.mxd



Source: Bryant (2005); West Napa fault modified (this study)

Figure 1 Shaded relief map showing Quaternary-active faults in the northern San Francisco Bay area

File path: S:\10300\10377\10377.000\07_1206_fr_fig_02.mxd

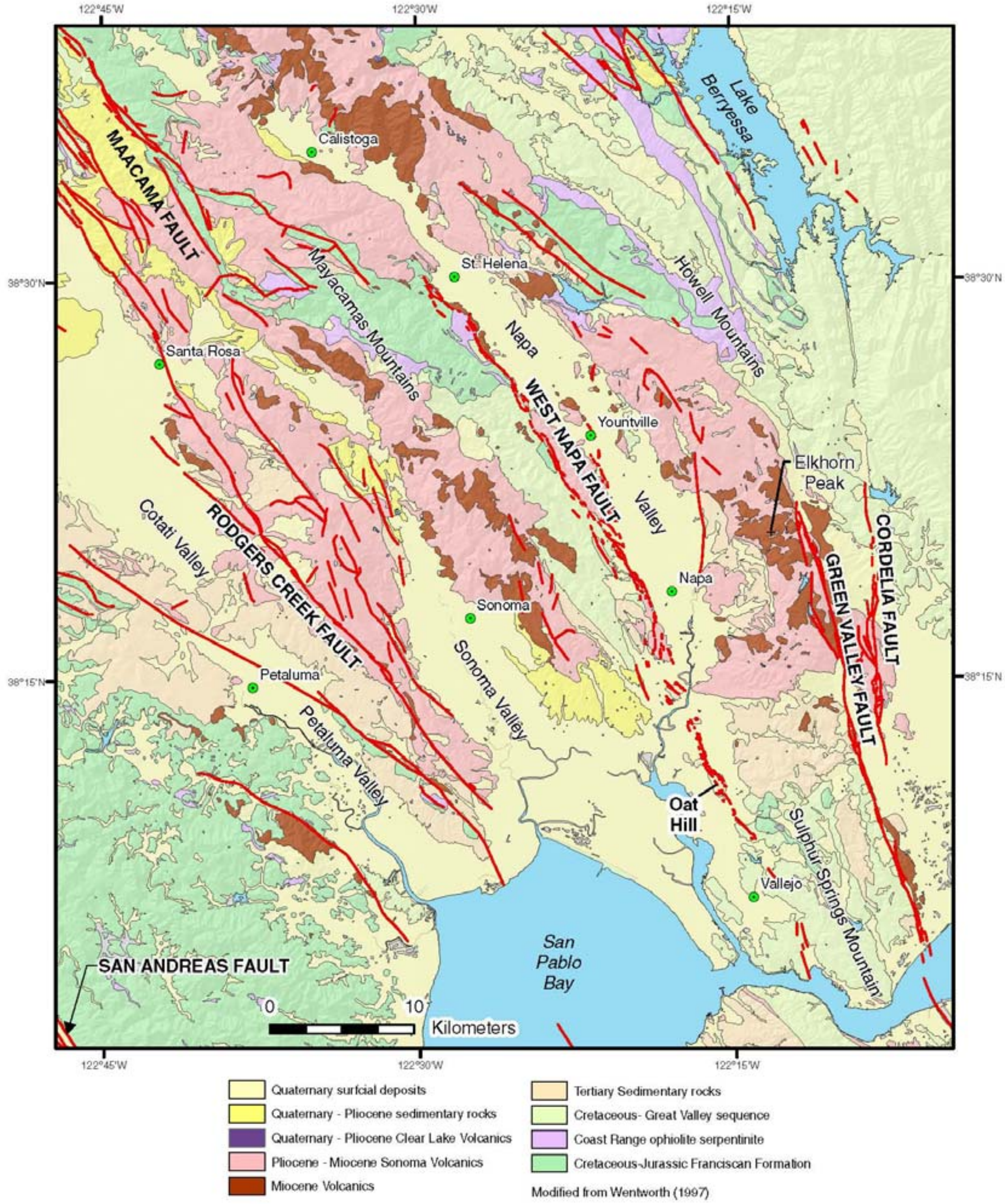


Figure 2 Geologic map of study region

File path: S:\10300\10377\10377.000\07_1206_fr_fig_03.mxd

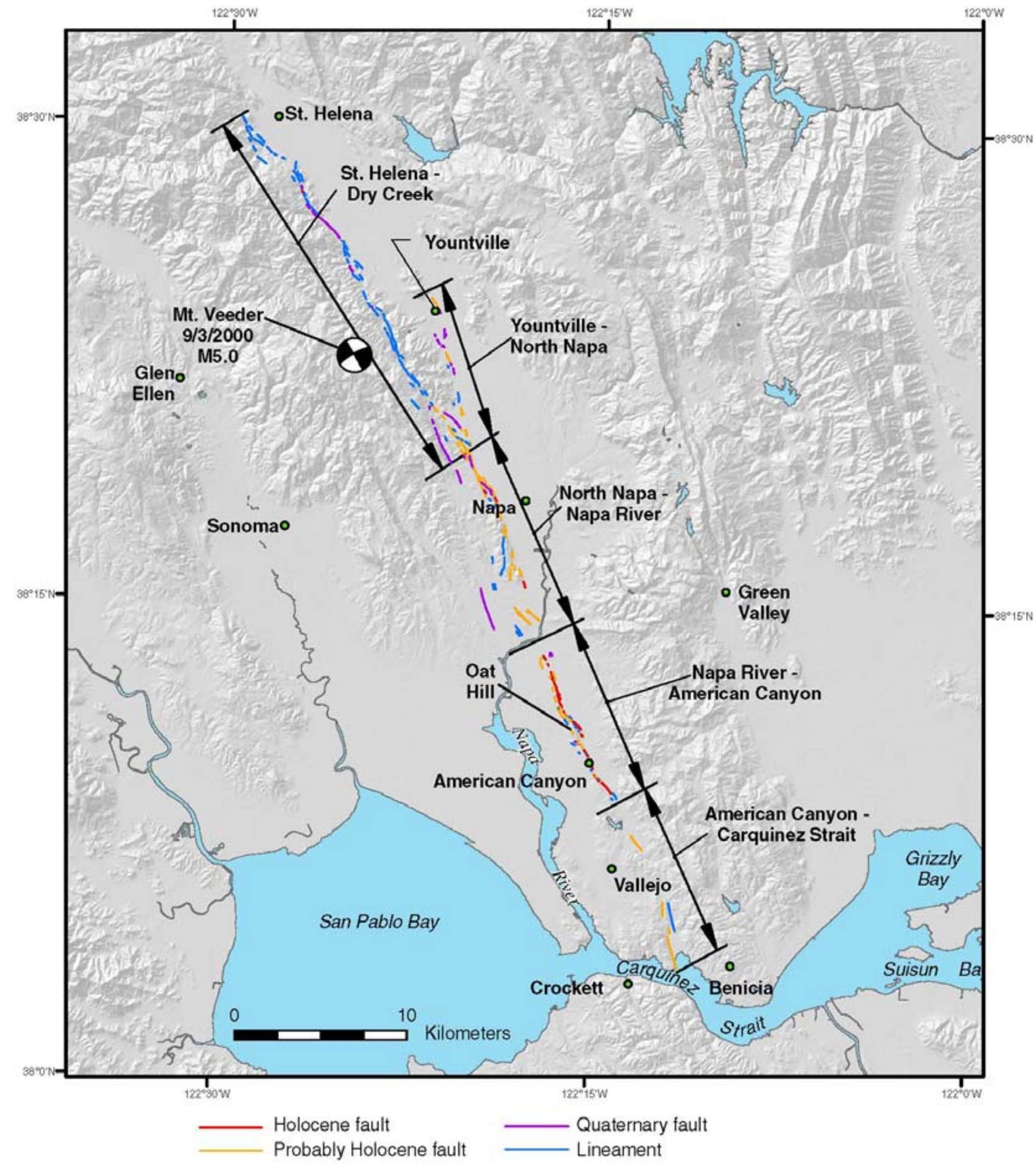


Figure 3 Map showing Quaternary-active faulting and reaches along the West Napa fault zone

File path: S:\10300\10377\10377.000\07_1206_fr_fig_04.mxd

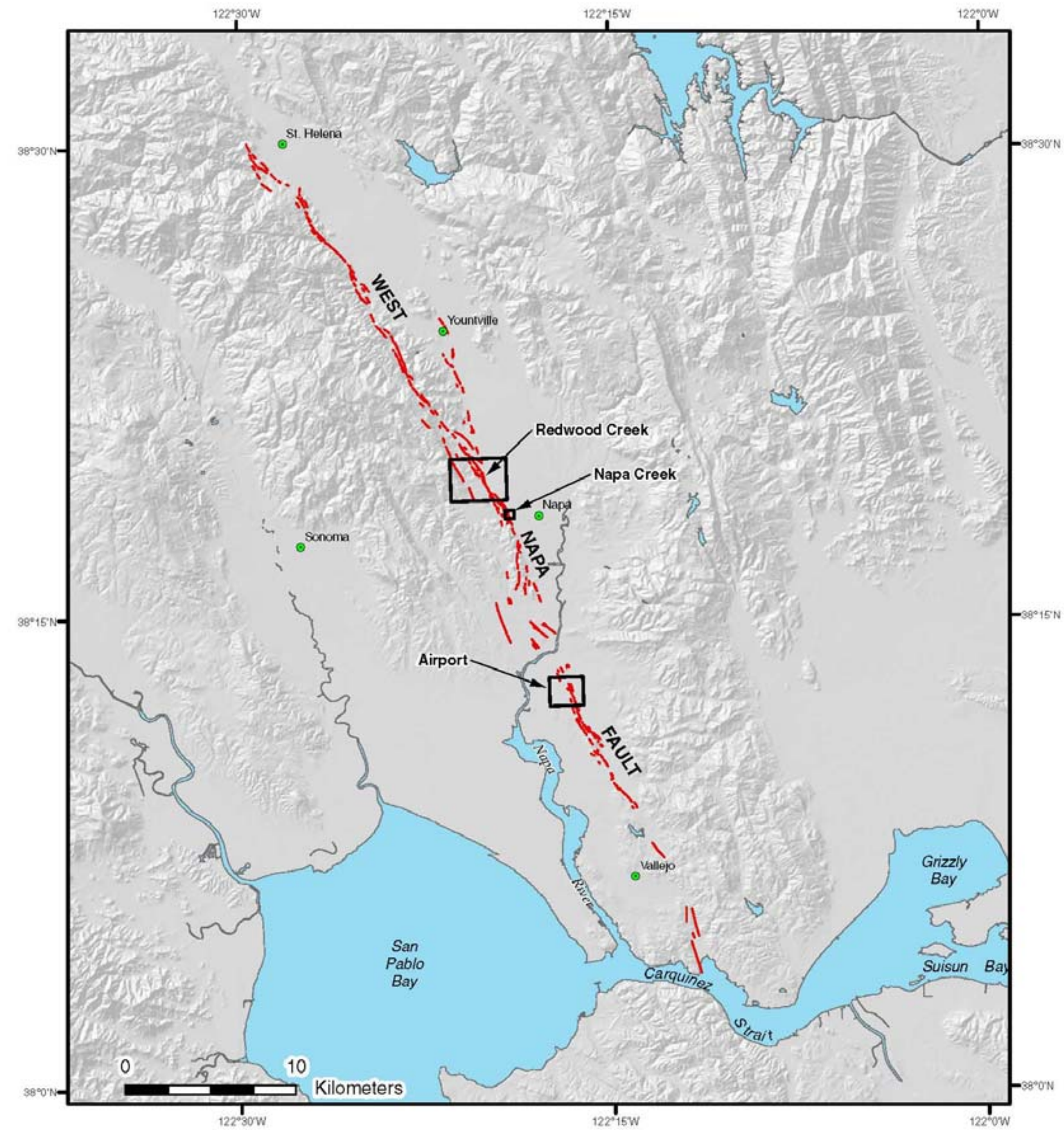


Figure 4 Map showing locations of detailed paleoseismic investigations

S:\10300\10377\10377.000\07_1206_fr_fig_05.ai

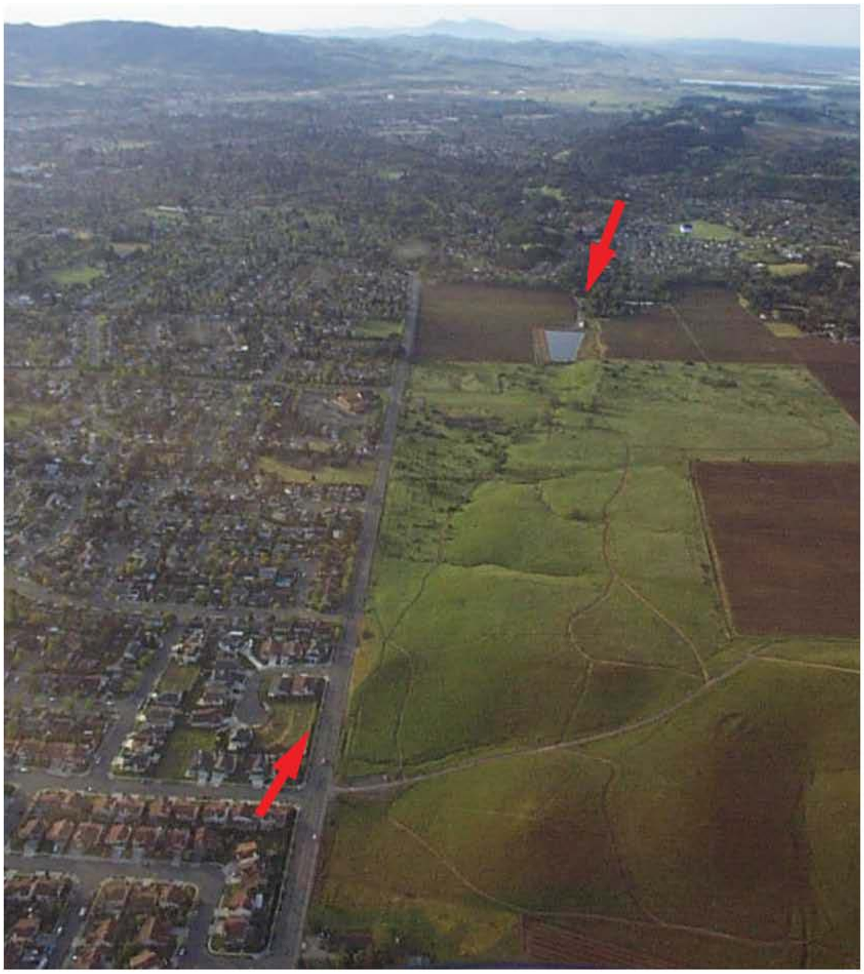


Figure 5 Oblique aerial photograph looking south along the West Napa fault at the Alston Park – Redwood Creek locality. The flight of uplifted Pleistocene and Holocene stream terraces that are preserved in the undeveloped area to the west (right) of the fault scarp (arrows) indicates recurrent down-on-the-east component of movement

S:\10300\10377\10377.000\07_1206_fr_fig_06.ai

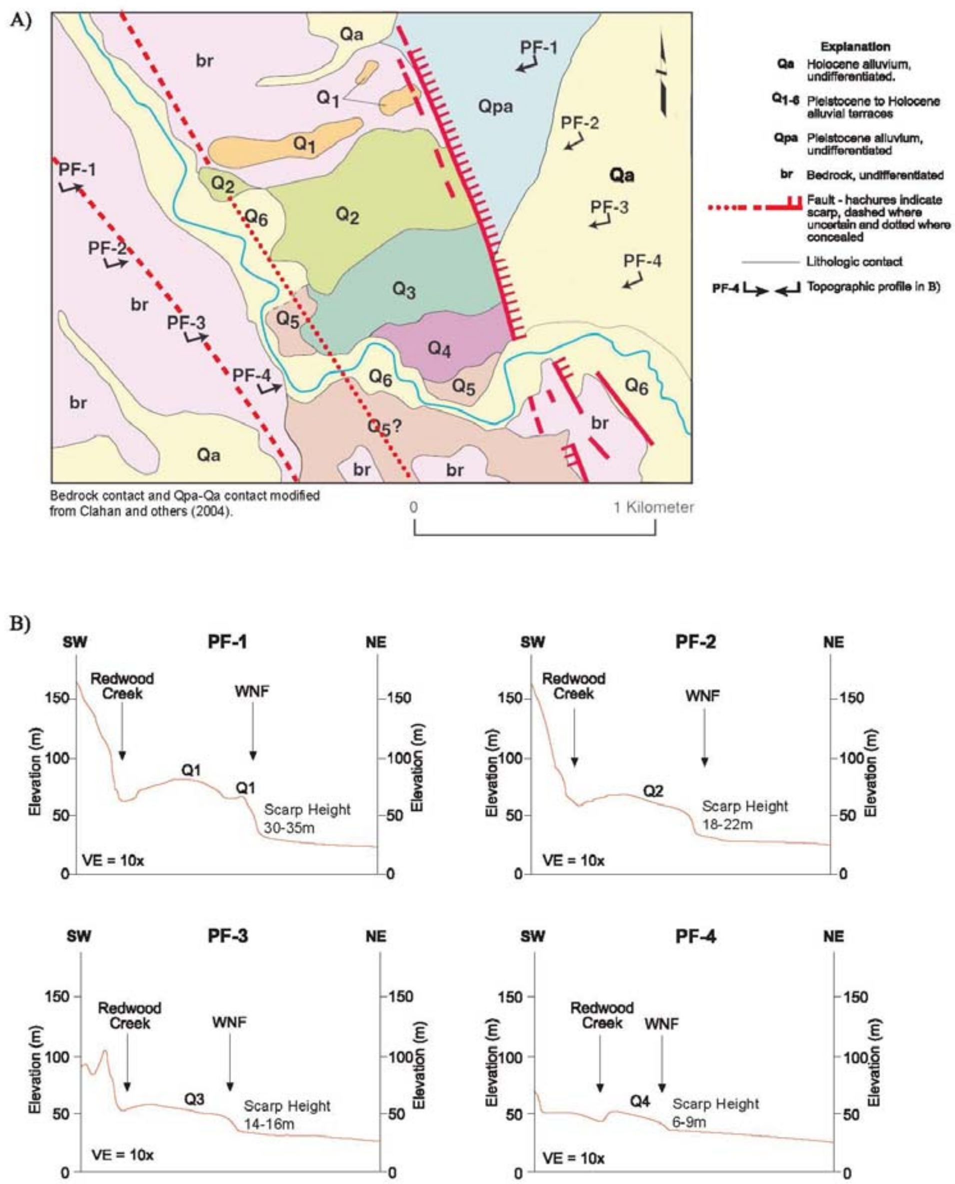


Figure 6 (a) Geologic map and (b) topographic profiles of fluvial terraces along Redwood Creek in the Alston Park area

File path: S:\10300\10377\10377.000\07_1206_fr_fig_07.mxd

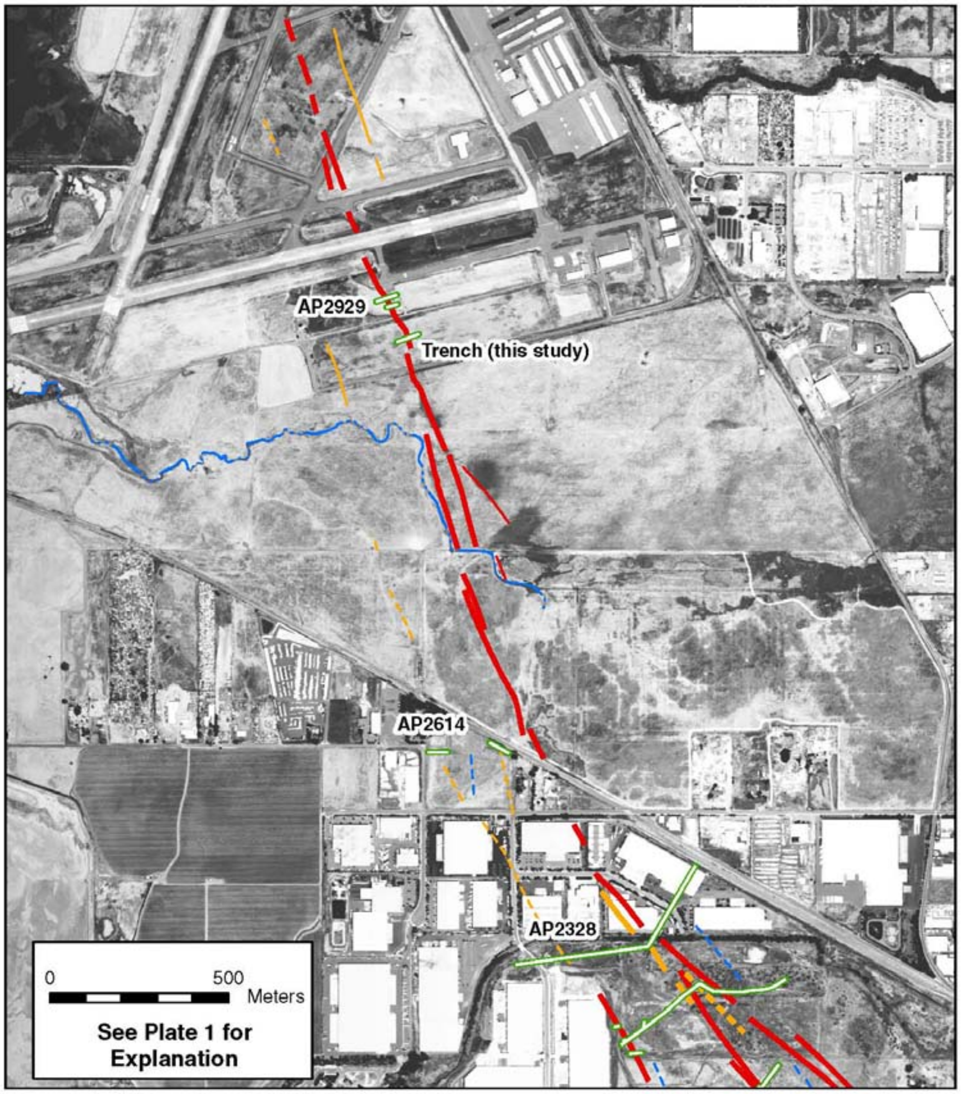


Figure 7 Photogeologic map of fault traces at the Napa County Airport trench locality

S:\10300\10377\10377.000\07_1206_fr_fig_08.ai

Figure 8 Oblique aerial photograph of the West Napa fault zone, Napa County Airport trench locality

S:\10300\10377\10377.000\07_1206_fr_fig_09.ai

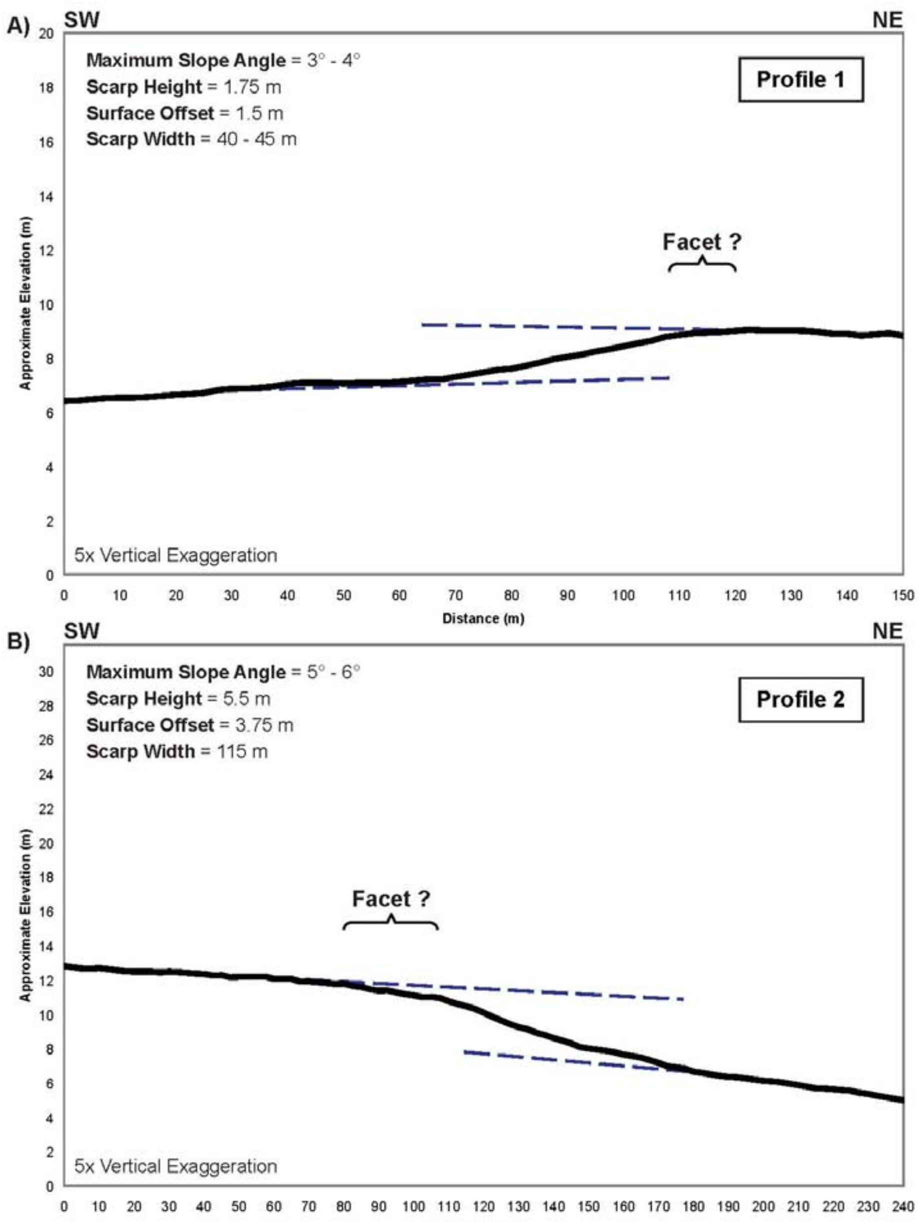


Figure 9 Topographic profiles across scarps directly south of the Napa County Airport trench locality

S:\10300\10377\10377.000\07_1206_fr_fig_10.ai

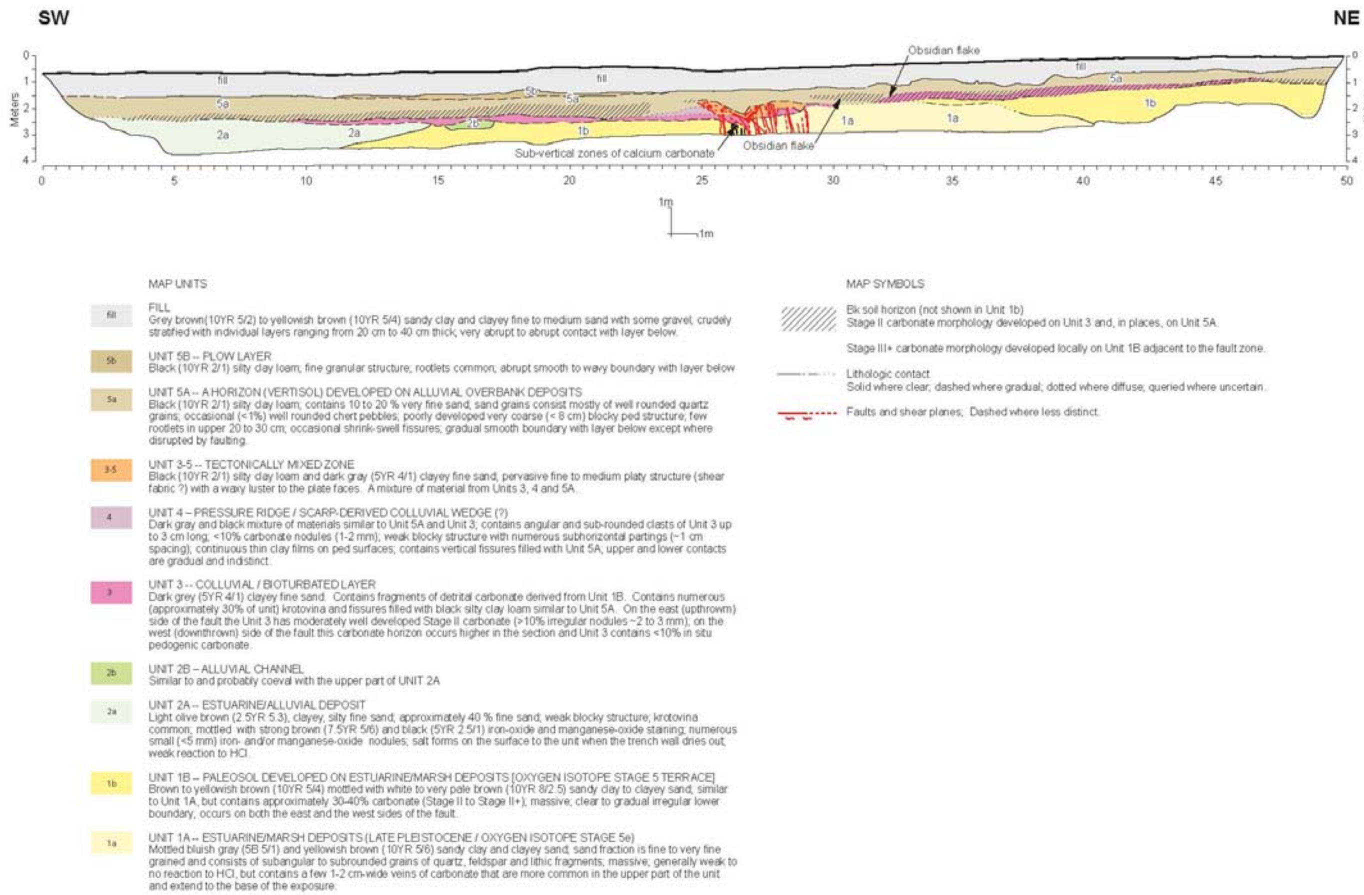


Figure 10 (a) Map of north wall of trench 1, Napa County Airport trench locality, and (b) explanation

S:\10300\10377\10377.000\07_1206_fr_fig_11.ai

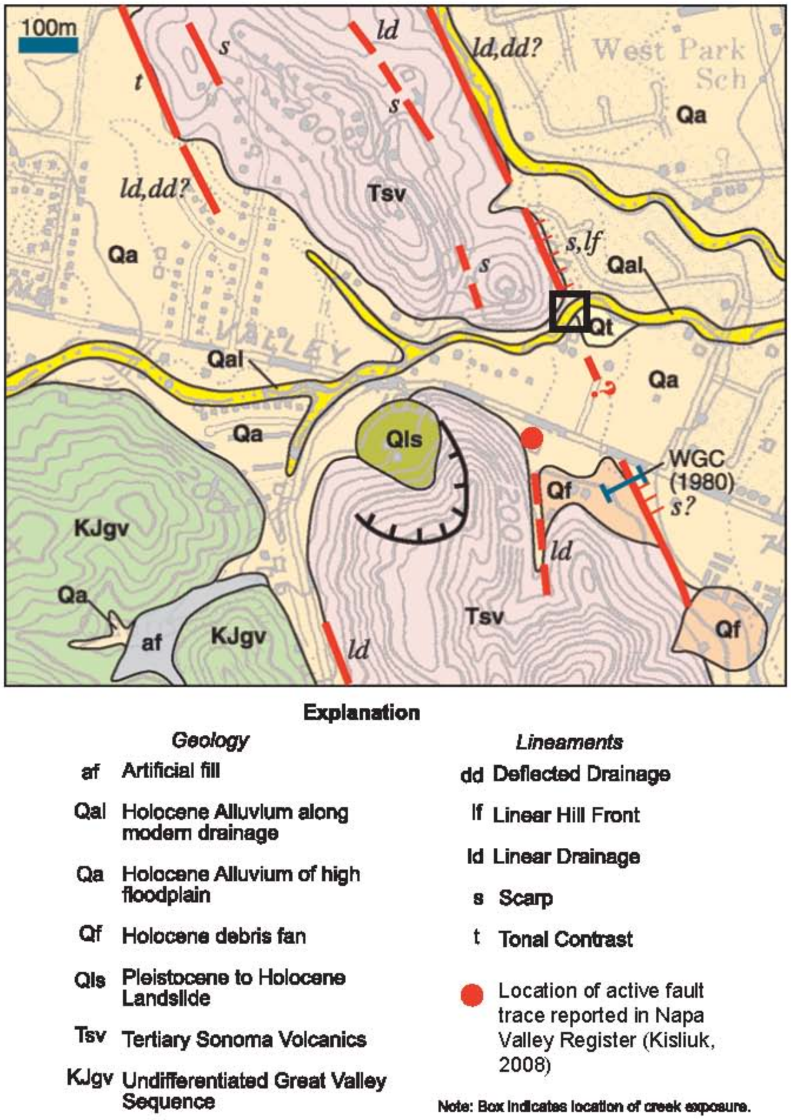


Figure 11 Geologic map of Napa Creek locality, Napa County, California

S:\10300\10377\10377.000\07_1206_fr_fig_12.ai

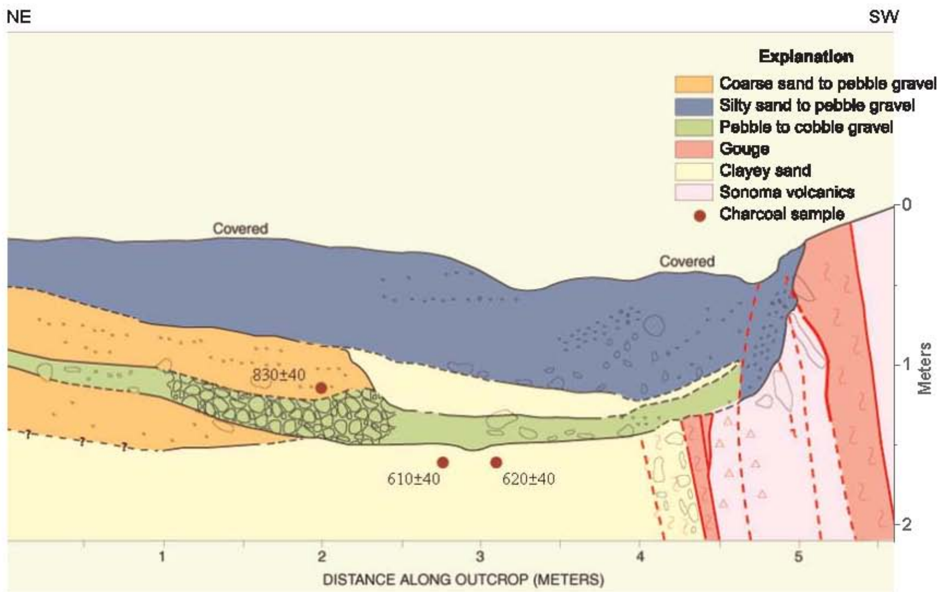
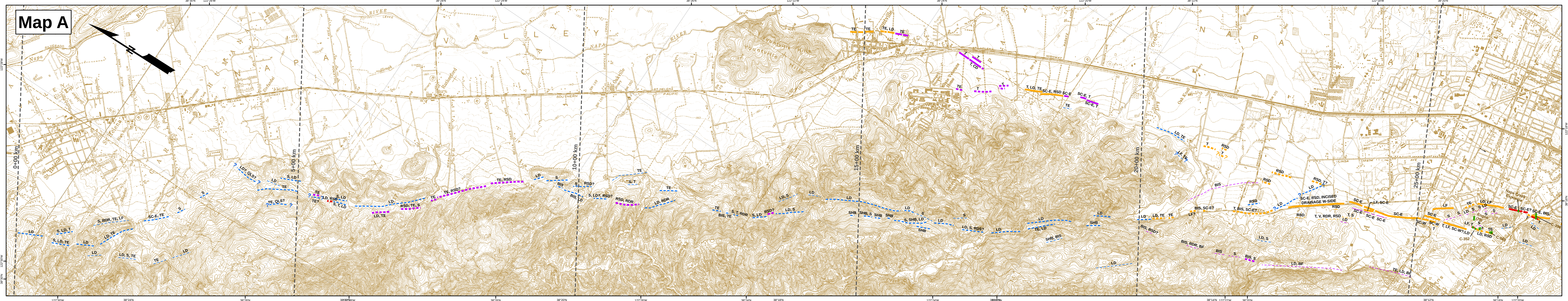
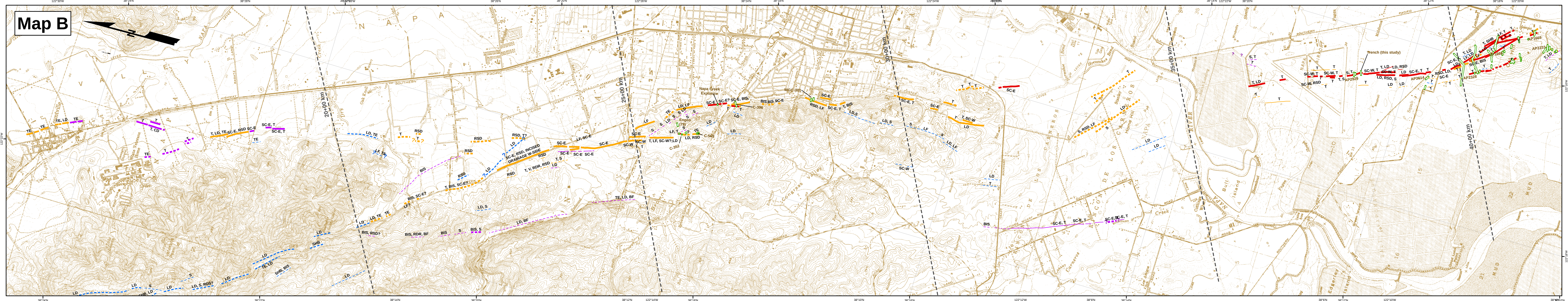
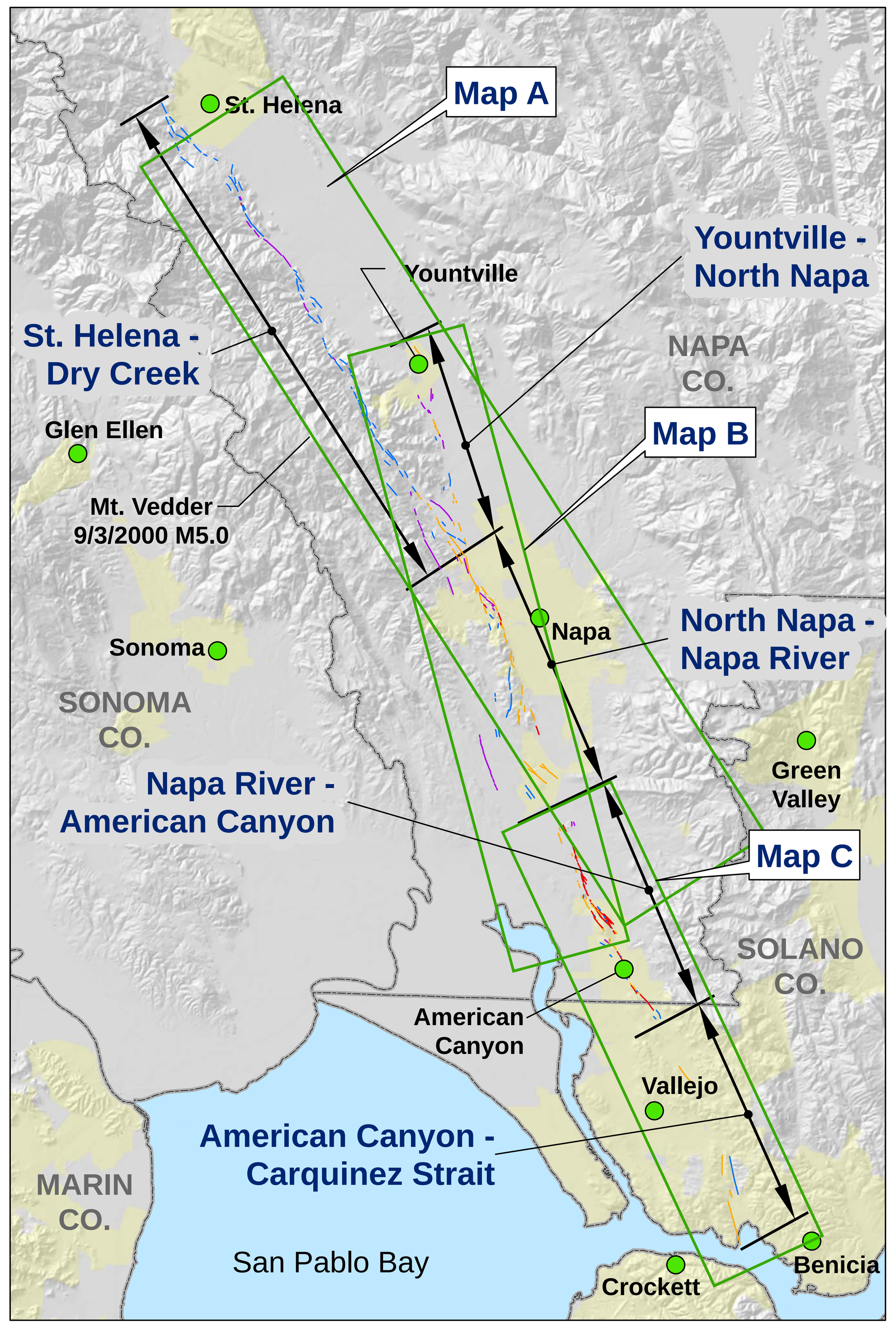


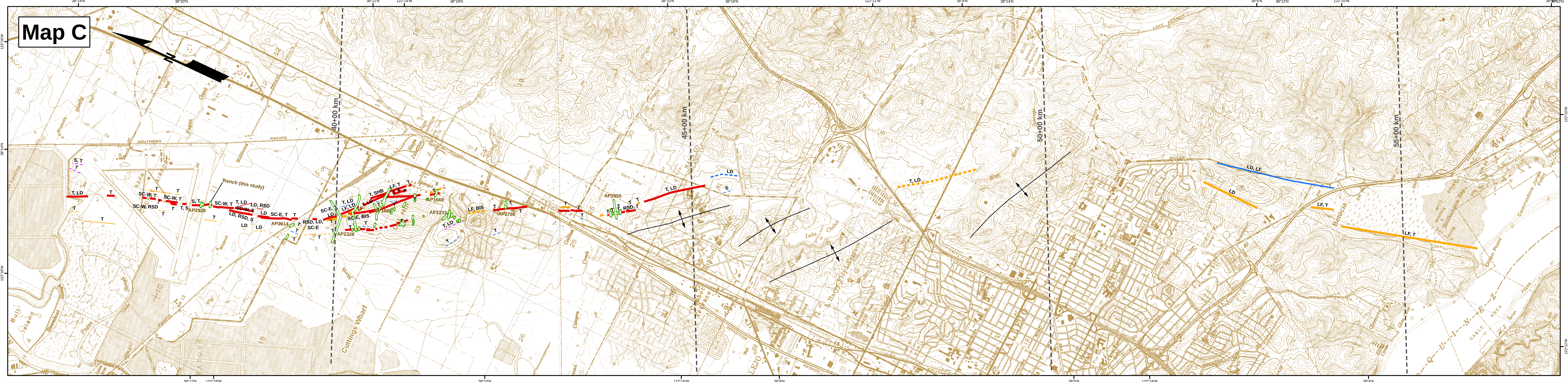
Figure 12 Sketch map of the natural outcrop of the West Napa fault along Napa Creek, Napa County, California

Hanson and Wesling (2008)
USGS NEHRP 05HQAG0002









Explanation

Fault; solid where certain or obvious, dashed where approximately located or inferred, queried where uncertain.

Primary Trace
- Holocene
- Probably Holocene
- Quaternary

Secondary Trace
- Holocene
- Probably Holocene
- Quaternary

Lineament; solid where strongly expressed; dashed where less strongly expressed; and queried where weakly expressed. Lineaments along the St. Helena – Dry Creek reach are associated with a mapped bedrock fault (Sims et al., 1973; Fox, 1983)
- Primary
- Secondary

Axis of anticline

AP2328 Trench locality, Study number assigned by the California Geological Survey for Alquist-Priolo and other fault investigations. See Table 2 for summary of results. Additional data and individual trench numbers are provided in the digital database.

Geomorphic and geologic features

BF	Bedrock fault
BIS	Break in slope
CD	Closed depression
LD	Linear drainage
LF	Linear hill/range front
QLS	Quaternary landslide
RDR	Right-deflected ridge
RSD	Right-deflected stream
S	Saddle
SC-E	Scarp (east facing)
SC-W	Scarp (west facing)
SHB	Side hill bench
T	Tonal contrast
TE	Topographic escarpment
V	Vegetation lineament

0 1 2 Kilometers

0 1 2 Miles

1:34,075

Map Showing Active Traces and Lineaments Associated with the West Napa Fault

J.R. Wesling and K.L. Hanson (2008)

Appendix 1
Lineament Analysis
Mapping of the West Napa Fault Zone
Napa County, California

St. Helena - Dry Creek 0+00 to 23+50 km		23.5	Yountville - North Napa 14+70 to 23+50 km		8.8	North Napa - Napa River 23+50 to 35+00 km		11.5
Feature*	Number	Percentage	Feature*	Number	Percentage	Feature*	Number	Percentage
BF	2	1%	BF	0	0%	BF	0	0%
BIS	11	8%	BIS	0	0%	BIS	5	5%
CD	0	0%	CD	1	3%	CD	0	0%
LD	38	28%	LD	3	9%	LD	18	19%
LF	2	1%	LF	1	3%	LF	9	10%
RDR	6	4%	RDR	0	0%	RDR	0	0%
RSD	13	9%	RSD	5	14%	RSD	3	3%
S	25	18%	S	0	0%	S	14	15%
SC-E	4	3%	SC-E	4	11%	SC-E	15	16%
SC-W	0	0%	SC-W	0	0%	SC-W	6	6%
SHB	8	6%	SHB	0	0%	SHB	0	0%
T	6	4%	T	12	34%	T	21	23%
TE	21	15%	TE	9	26%	TE	2	2%
V	1	1%	V	0	0%	V	0	0%
Total	**137**	**100%**		**35**	**100%**		**93**	**100%**
Lineament Density Lineamants /km =		**6**	**Lineament Density Lineamants /km =**		**4**	**Lineament Density Lineamants /km =**		**8**

Napa River - American Canyon 35+00 to 43+50 km		8.5	American Canyon - Carquinez Strait 43+50 to 56+00 km		12.5
Feature*	Number	Percentage	Feature*	Number	Percentage
BF	0	0%	BF	0	0%
BIS	2	3%	BIS	0	0%
CD	0	0%	CD	0	0%
LD	13	16%	LD	4	20%
LF	3	4%	LF	3	15%
RDR	0	0%	RDR	0	0%
RSD	3	4%	RSD	1	5%
S	4	5%	S	1	5%
SC-E	4	5%	SC-E	0	0%
SC-W	3	4%	SC-W	0	0%
SHB	1	1%	SHB	0	0%
T	46	58%	T	11	55%
TE	0	0%	TE	0	0%
V	0	0%	V	0	0%
	79	**100%**		**20**	**100%**
Lineament Density Lineamants /km =		**9**	**Lineament Density Lineamants /km =**		**2**

* BF = bedrock fault; BIS = break in slope; CD = closed depression; LD = linear drainage; LF = linear hill/range front; RDR = right-deflected ridge; RSD = right-deflected stream; S = saddle; SC-E = scarp (east facing); SC-W = scarp (west facing); SHB = side hill bench; T = tonal contast; TE = topographic escarpment; and V = vegetation lineament.