FINAL TECHNICAL REPORT

DIGITAL COMPILATION OF DATA FOR THE CONTRA COSTA SHEAR ZONE FOR THE NORTHERN CALIFORNIA QUATERNARY FAULT MAP DATABASE: COLLABORATIVE RESEARCH WITH WILLIAM LETTIS & ASSOCIATES, INC. AND THE U.S. GEOLOGICAL SURVEY

Recipient:

Fugro William Lettis & Associates, Inc.
1777 Botelho Drive, Suite 262
Walnut Creek, California 94596

Principal Investigators:

Cooper Brossy, Keith Kelson, and Marco Ticci

Fugro William Lettis & Associates, Inc., 1777 Botelho Dr., Suite 262,
Walnut Creek, CA 94596
(tel: 925-256-6070; fax: 925-256-6076; email: k.kelson@fugro.com)

Program Element:

III: Research on earthquake occurrence, physics, and effects

U. S. Geological Survey
National Earthquake Hazards Reduction Program
Award Number 07HQGR0063

March 2010

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number 07HQGR0063. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

AWARD NUMBER 07HQGR0063

DIGITAL COMPILATION OF DATA FOR THE CONTRA COSTA SHEAR ZONE FOR THE NORTHERN CALIFORNIA QUATERNARY FAULT MAP DATABASE: COLLABORATIVE RESEARCH WITH WILLIAM LETTIS & ASSOCIATES, INC. AND THE U.S. GEOLOGICAL SURVEY

Cooper Brossy, Keith Kelson, and Marco Ticci
Fugro William Lettis & Associates, Inc., 1777 Botelho Dr., Suite 262,
Walnut Creek, CA 94596
(tel: 925-256-6070; fax: 925-256-6076; email: k.kelson@fugro.com)

ABSTRACT

This report summarizes the development of a digital database for the Contra Costa Shear Zone (CCSZ) as part of the construction of the Quaternary fault database in the San Francisco Bay region. The report describes our effort to compile and digitize existing data and conduct original geomorphic mapping via analysis of aerial photography and completion of field reconnaissance on this potentially active structure located between the Northern Calaveras fault and the West Napa fault. The database consists of digital line data in GIS format, as well as text descriptions in an electronic format similar to the USGS National Fault and Fold database and the SCEC Fault Activity database, for input into the Northern California Quaternary Fault Map database (NCQFMD). The project deliverable is the GIS database and associated metadata on the CCSZ, which will be transferred to U.S. Geological Survey personnel in Menlo Park.

This report bridges a critical data gap between two previous digital fault database compilations and provides additional new interpretations on the locations of potentially active faults between the West Napa fault and the Northern Calaveras fault. This report provides documentation of the structural connection between the two faults via the CCSZ. New findings in the Vallejo area include refinement of the southern end of the West Napa fault south of the Napa-Solano county line, and documentation of a step-over between the West Napa and Southampton faults. This analysis provides documentation for an alternative model to the previously favored interpretation that slip from the Northern Calaveras fault is transferred onto the Concord fault.

TABLE OF CONTENTS

Abstract i
Table of Contents ii
1.0 Introduction 1
2.0 Geologic Background-The Contra Costa Shear Zone 2
3.0 Methods of database construction 4
3.1 Database metadata 5
4.0 Interpretation of relationship between northern CCSZ and West Napa fault 7
5.0 Summary 10
6.0 References 11

LIST OF TABLES

Table 1: Aerial photography reviewed for this study
Table 2: Abbreviations used for attributing types of lineaments

LIST OF FIGURES

Figure 1: Regional map of the Contra Costa Shear Zone (CCSZ) in the Northern San Francisco Bay area
Figure 2: Regional tectonic map of the northern East Bay hills
Figure 3: Map of Vallejo area showing lineaments interpreted from 1937 aerial photography
Figure 4: Potential models for step-over between the West Napa and Southampton faults

1.0 INTRODUCTION

The youthful East Bay hills structural domain contains a series of left-stepping, *en echelon* dextral faults and lineaments, collectively termed the "Contra Costa Shear Zone" (CCSZ), that extend about 50 km from the Northern Calaveras fault to the West Napa fault (Unruh and Kelson, 2002a, 2002b; Kelson et al., 2004, 2005) (Figure 1). The CCSZ includes NNW-striking sections of the Reliez Valley, Lafayette, Southampton and other faults, and intervening sections of NW-trending folds (Figure 2). The CCSZ is associated with prominent geomorphic features in the East Bay hills that are suggestive of late Quaternary activity, including truncated bedding, scarps, linear drainages, vegetation alignments, springs, and tonal lineaments. The 1977 "Briones swarm," a NNW-trending alignment of small ($M_L < 4.3$) earthquakes with dextral focal mechanisms (Oppenheimer and MacGregor-Scott, 1992), is spatially associated with one of the lineaments of the CCSZ (Figure 2).

Analysis of regional geodetic data by d'Alessio et al. (2005) supports the interpretation that a substantial percentage of regional dextral deformation is accommodated by the CCSZ. Graymer et al. (2006) also acknowledge the CCSZ as a possible significant zone of deformation in the East Bay hills between the Calaveras and West Napa faults. However, despite *prima facie* evidence for tectonic and seismic activity (Unruh and Kelson, 2002a, 2002b; Kelson et al., 2005), direct evidence for Holocene surface rupture within the CCSZ has not been conclusively documented, and the shear zone is not formally recognized as a Holocene active seismic source by the USGS or the California Geological Survey (CGS).

The purpose of this technical report is to provide a digital database of the primary components of the Contra Costa Shear Zone between the town of Alamo on the south and the Napa County line on the north. Completion of this digital database fills a critical data gap within a major zone of deformation in the eastern Bay region. This report and digital database compliment similar efforts for the West Napa (Wesling and Hanson, 2008), Northern Calaveras fault (Kelson and Sundermann, 2007), Central Calaveras (Sundermann and Kelson, 2009), and Southern Calaveras (Rosenberg, in prep.) faults. Together, these datasets can now be integrated into the NCQFMD to produce a consistent and complete depiction of the active or potentially active components of the entire Calaveras fault in the eastern San Francisco Bay region. The GIS database described herein is the project deliverable and will be transmitted to Russ Graymer (lead U.S. Geological Survey complier for the NCQFMD) for incorporation into the master database.

2.0 GEOLOGIC BACKGROUND-THE CONTRA COSTA SHEAR ZONE

The East Bay hills in the San Francisco Bay region are bordered by the strike-slip Northern Calaveras fault on the east and the Hayward fault on the west (Figure 1). Prior to detailed geomorphic mapping of fault-related features by Kelson and Sundermann (2007) and this investigation, the northward extension of slip along the Northern Calaveras fault was postulated to occur in a right-step-over onto the active Concord fault (Wills and Hart, 1992; Smith 1992; Oppenheimer and Macgregor-Scott, 1992). Near the town of Danville, right-lateral strike slip on the Northern Calaveras fault is transferred to the interior of the East Bay Hills by a complex system of poorly integrated strike-slip faults and shear zones, collectively referred to as the "Contra Costa Shear Zone" (CCSZ, Figures 1 and 2). Slip is actively transferred onto previously mapped faults and folds, such as the Lafayette and Reliez Valley faults and the Las Trampas anticline (Dibblee, 1980; Graymer et al., 1994; Crane, 1995), as well as onto NNW-striking shear zones identified by Unruh and Kelson (2002a; 2002b). The shear zones are identified based on the presence of numerous geomorphic features suggestive of young fault movement that occur within distinct, NNW-trending bands (Unruh and Kelson, 2002a; Kelson et al., 2004). The features include topographic scarps, saddles and side-hill benches, linear valleys and valley margins, and tonal and vegetation lineaments. Some of these zones coincide with the Lafayette, Reliez Valley, and Cull Canyon strike-slip faults (Dibblee, 1980), whereas others (including the Larkey, Russell Peak, Briones, McEwen Road-Dillon Point, and Ozol-Columbus Parkway lineament zones; Figure 2) coincide with, and extend beyond, northerly striking parts of the Franklin and Southampton reverse faults. For example, the Dillon Point lineament coincides with a north-striking section of the Southampton fault along the western margin of Southampton Bay (Figure 2), and the Larkey lineament lies, in part, along the Saklan fault mapped by Dibblee (1980) and Woodward-Clyde (1975).

The lineament zones defining the CCSZ are interpreted as faults because they coincide with truncations of northwest-striking bedding and northwest-striking reverse faults and folds and with instrumental microseismicity (Unruh and Kelson, 2002a). For example, the Briones lineament is associated with the 1977 "Briones swarm," a cluster of small ($M_L < 4.3$) earthquakes that formed a NNW-trending alignment and exhibited dextral slip on NNW-striking nodal planes (Oppenheimer and MacGregor-Scott, 1992). Several small earthquakes (**M**3.2 to **M**3.7) with NNW-striking, dextral slip planes have occurred since 2003 and also are spatially associated with the CCSZ (Figure 2). The presence of this microseismicity provides evidence that the NNW-trending CCSZ lineaments in the northeastern East Bay hills are associated with active and potentially seismogenic strike-slip faults. In addition, the occurrence of the **M**5.2 Yountville earthquake in 2000 on the West Napa fault (Langenheim et al., 2003) provides evidence of some similarities between the CCSZ and the West Napa fault.

At its southern end, the CCSZ appears to be connected with the Northern Calaveras fault via the Las Trampas anticline (and its inferred blind reverse fault) (Figure 2). This transpressional structure appears to transfer dextral slip from the Northern Calaveras fault onto the dextral Reliez Valley and Lafayette faults. Similarly, the left-stepping, *en*

echelon pattern of the lineament zones suggest that strain is transferred northwestward collectively from the Reliez Valley and Lafayette faults into the interior of the northeastern East Bay Hills along the Russell Peak, Briones, and McEwen Road lineaments (Figure 2). In addition, some dextral slip may continue north-northwest from the Las Trampas anticline onto the Larkey lineament in Walnut Creek, onto sections of the Southampton fault, and then westward onto the Ozol, Columbus Parkway, and Dillon Point lineaments within the East Bay hills. Collectively, these relations suggest that NW-directed dextral shear strain in the East Bay Hills northwest of the northern Calaveras fault is accommodated through complex deformation along discontinuous, north-striking dextral slip faults, northwest-striking reverse faults and folds, and possibly blind faults. The pattern of mixed strike-slip faulting and reverse-oblique shortening is consistent with a braided strike-slip duplex within an overall transpressional tectonic setting (Twiss and Moores, 1992), as also observed in analog sandbox models (McClay and Bonora, 2001).

Total post-Miocene dextral shear (ca. 11 to 13 km) in the northern East Bay hills accommodated by shortening and distributed strike-slip faulting within the CCSZ is similar to the total post-Miocene offset on the Northern Calaveras fault, which suggests that most if not all of the motion on this fault steps northwestward into the East Bay hills in a restraining geometry, rather than eastward onto the dextral Concord fault through a releasing step-over (Unruh and Kelson, 2002a, 200b). As a whole, the NNW-striking interpreted faults within the CCSZ are arranged in a left-stepping, en echelon pattern that extends from the northern Calaveras fault on the south to the southern end of the West Napa fault (Figure 1). On this basis, the CCSZ is about 45 km long and has a regional orientation of about N28˚W.

Detailed field mapping of three emergent marine platforms along Carquinez Strait provides evidence that the CCSZ extends north of the East Bay hills into the Napa Valley region (WLA, 2003; Kelson et al., 2004, 2005). The 12-m-high and 18-m-high platforms in the Carquinez strait correlate with substage 5e (ca. 120 ka) and stage 9 (ca. 330 ka) sea-level high stands, respectively, and suggest that the East Bay hills west of the Southampton fault have undergone block uplift at a rate of 0.05 +/- 0.01 m/ka without substantial tilting (WLA, 2003; Kelson et al., 2004, 2005). With resolution of about 3m, the 120 ka and 330 ka shoreline angles are not displaced across the inactive Franklin fault, but exhibit substantial vertical displacement and gentle westward tilting across the NNW-striking Southampton fault. The pattern of deformation of the marine platforms indicates that the Southampton fault is the primary component of the CCSZ at the latitude of Carquinez Strait; these relationships indicate that the CCSZ extends northward toward the West Napa fault (WLA, 2003; Kelson et al., 2004, 2005). Our mapping conducted north of Carquinez Strait indicates the presence of geomorphic features and air-photo lineaments along the northwestward projection of the Southampton fault. These relations strongly suggest that the CCSZ extends northward through the city of Vallejo, and probably merges with the West Napa fault (Kelson et al., 2005). As noted by Bryant (2000), the southern end of the West Napa fault at Oat Hill is characterized by a left compressional step-over, which is comparable to other compressional step-overs within the CCSZ south of the Carquinez Strait.

3.0 METHODS OF DATABASE CONSTRUCTION

As indicated above, the primary goal of this constructing this database was to fill the gap in digital data between the compilation of fault data for the West Napa fault (Wesling and Hanson, 2008) on the north and the Northern Calaveras fault on the south (Kelson and Sundermann, 2007). In their investigation of the northern termination of the Calaveras fault, Unruh and Kelson (2002a) produced a detailed map of lineaments of the southern portion of the CCSZ via analysis of 1:20,000-scale, black and white, stereo-paired aerial photographs from 1937 and 1939 These data existed digitally in GIS format as ESRI shapefiles. We incorporated these existing data into the database and conducted additional geomorphic mapping north of approximately latitude 38° N, on both sides of the Carquinez Strait, and northward through the city of Vallejo to Oat Hill. This new effort employed the same approach to identification, interpretation, and compilation of potentially fault-related lineaments used by Unruh and Kelson (2002a). We used the same 1937 and 1939 aerial photography (Table 1) as the primary data set for interpreting potentially fault-related geomorphology, because these data sources are the oldest high-quality images that pre-date much of the urbanization and landscape alteration within the study area.

Table 1. Aerial photography reviewed for this study

Date flown	Frames*	Number of frames
8-20-1937	ABO-52-76 through 52-81	6
8-20-1937	ABO-52-102 through 52-107	6
10-9-1937	ABO-113-7 through 113-10	4
7-30-1939	BUU-283-66 through 283-72	7
7-25-1939	BUU-280-104 through 280-109	6
8-2-1939	BUU-289-28 through 289-34	7
8-2-1939	BUU-289-77 through 289-82	6
Note: All frames are black and white 1:20,000 scale. *Format of frame numbers is: three-letter county code followed by roll number followed by frame number.		

Digital Elevation Models (DEMs) derived from LiDAR data collected in 2008 available from Contra Costa County were used to confirm and refine the location of lineaments mapped via analysis of the historical aerial photography as well as identify potential fault-related geomorphic features not apparent in the historical imagery. In contrast, a 2003 LiDAR-derived elevation data set of the Vallejo area available from the National Center for Airborne Laser Mapping provided dramatically less information on original geomorphology because of the heavy urbanization of the Vallejo area compared to the much less developed central part of the East Bay Hills in the south.

Compilation of known and readily available previous fault-related investigations within the CCSZ primarily focused on the few unpublished consultant reports; as currently defined, the CCSZ contains no Alquist Priolo Act (AP) fault zones and therefore has had

no AP fault investigations. Wesling and Hanson (2008) provide a thorough review of investigations, including AP investigations, for the southern West Napa fault[1] and Kelson and Sundermann (2007) list relevant investigations for the Northern Calaveras fault. We made no attempt to duplicate these previously identified investigations in our database but did re-evaluate the locations of the southern West Napa fault presented by Wesling and Hanson (2008) using the available historical aerial photography (see section below).

Lineaments derived from analysis of aerial photography and data presented on original consultant's maps were compiled at a map scale of 1:20,000. Although the digital format of the CCSZ digital database permits viewing the data at a larger scale, the detail and accuracy of the compilation is compromised at any scale larger than 1:20,000. Viewing the data compilation at a larger scale will not generate any greater detail than that presented at the original scale and should not be used for investigations requiring greater detail.

3.1 Database metadata

The digital fault database constructed for the CCSZ contains two ArcGIS shapefiles: "CCSZ_investigations" and "CCSZ_lineaments." The CCSZ_investigations shapefile marks the location of known, readily available fault investigations within the CCSZ. Attributes of the shapefile include basic information such as the author, report title, year of completion, type of investigation (e.g., trenching, geophysics, etc.), and the name of the specific exploration (e.g., Trench 1 or T-1, etc). In addition, estimates of the location certainty of features (i.e. LOC_CER_TX field) and the confidence in the constraints on location (i.e. LOC_CER_CM field) are provided. The contents of the LOC_CER_TX field should address the question, "How is the fault expressed in this area?" while the LOC_CER_CM field addresses the question, "How confident are we that we have accurately located this trench from the data we have?" The relative location certainty was assigned based on the results presented in the investigation (exposures in trenches, interpretations of near-surface borehole data, expression of geomorphic features, etc.) but also our analysis of historical aerial photography. Uncertainties related to these previous investigations are based primarily on the accuracy of the original data sets; in other words, on the accuracy of registering trench locations as depicted in the original consulting reports, except where data locations were checked using detailed aerial photography, LiDAR data, or field reconnaissance. Additional attributes for features presented in this shapefile include any relevant notes on the investigation (i.e. the NOTES field), the name of the fault being investigated (FNAME), the particular section of the fault (or zone of lineaments), if any (FSEC_NAME), the relative offset or motion of the fault, if known (OFFSET), and the length of the feature in meters (LENGTH_MET).

---

[1] One investigation not included in Wesling and Hanson (2008) was conducted 1.7 km SSE of Oat Hill (-122.25047° 38.16685°). This investigation was done by Twining Laboratories, Inc., project no. A07259.01-02R; report date 7/19/2005, 23 p., 4 appendices (Written communication, Bill Bryant, Oct. 2009).

The attributes of features presented in the "CCSZ_lineaments" shapefile are similar, with a few additional fields. For example, the fault rank field (FRANK) presents our interpretation of whether the lineament represents a primary or secondary trace of a given fault section. DATE_UPDAT denotes the date the lineament was incorporated into the database. The TYPE field describes the geomorphic feature, or combination of features, that express the lineament. Table 2 explains the abbreviations used in the TYPE field. In the "CCSZ_lineaments" shapefile, the NOTES field contains relevant details of the lineament but also includes the datasets or activity from which the feature was interpreted (e.g., aerial photographs, field reconnaissance, LiDAR, trenching, etc.). The PROMINENCE field displays our observation of how well the lineament is expressed, where 1 = strongly pronounced, 2 = distinct, and 3 = weakly pronounced. The DESCRPT field combines the TYPE and PROMINENCE fields to create a complete attribute for the type of feature and its level of expression. In addition, where we interpreted that lineaments of this database represented portions of mapped faults presented in the USGS National Quaternary Fault and Fold Database, we assigned the lineaments the relevant fault code from the USGS database in the QFAULTID field.

Table 2. Abbreviations used for attributing types of lineaments

Symbol	Geomorphic feature
b	Break in slope
ld	Linear drainage
lf	Linear (hill) front
lt	Linear tonal signature
s	Saddle
sc	Scarp
f	Fault
t	Tonal signature
v	Vegetation lineament
rsd	Right stream deflection
sb	Side-hill bench

4.0 INTERPRETATION OF RELATIONSHIP BETWEEN NORTHERN CCSZ AND WEST NAPA FAULT

The compilation of data presented herein provides an opportunity to reevaluate the relationship of the CCSZ to the West Napa fault and synthesize the results of previous investigations. For example, Wesling and Hanson (2008) acknowledge that the reach of the West Napa fault south of Oat Hill (their "American Canyon-Carquinez Strait" reach) could be transitional between the CCSZ and the historically recognized Holocene-active portion of the West Napa fault. While Wesling and Hanson (2008) compiled and reviewed previous investigations of the West Napa fault to create a fault map, they acknowledge poor geomorphic expression of the West Napa fault in the Cities of American Canyon and Vallejo and a lack of investigations south of the Napa-Solano county line. In addition, Unruh and Kelson (2002a; 2002b) identify several north and northwest-trending lineament zones in the area (the Dillon Point and Columbus Parkway zones) that align with lineament zones on the south side of the Carquinez Strait (the McEwen Road and Ozol zones). In this same reach, previous bedrock mapping by Crane (1988) shows the presence of right-lateral strike slip faults and related reverse faults suggestive of a restraining bend or step-over connecting the West Napa fault with faults to the south. Review of 1937 aerial photography for this investigation provides data that fills the gap between analysis of post-urbanization imagery and bedrock mapping of the area.

As mentioned above, there are no AP fault investigations of the West Napa fault south of the Napa-Solano county line. The West Napa fault is not zoned as an Alquist Priolo fault south of this location, and previous investigations interpret the fault dies out (at least at the surface) in several splays in this area (Kleinfelder, 1992; Terrasearch, Inc., 1994; both in AP file no. 2950). However, our review of 1937 aerial photographs identified a zone of lineaments (the Lake Chabot zone; Figure 3) having roughly the same trend as the West Napa fault extending southward from the termination of the AP zone, along the eastern margin of Lake Chabot, and southward to the northeast of the City of Vallejo. These lineaments are manifested as linear streams, linear drainages, linear tonal signatures, breaks in slope (including truncated bedrock knobs), and aligned saddles. Several lineaments are particularly well-expressed, including several strikingly linear streams that align with a conspicuously linear break in slope that forms the eastern margin of the former (larger) Lake Chabot. In addition, several prominent linear drainages lie approximately along trend to the southeast. Taken together, these features probably represent the southeastward continuation of the West Napa fault and provide a link between the West Napa fault and the CCSZ.

Evaluation of lineaments observed in 1937 aerial photography (Figure 3) and synthesis with previous interpretation of potential fault locations in the Vallejo area suggests that the West Napa fault and CCSZ are connected. These lineaments generally coincide with the interpreted traces of the West Napa fault and other faults projecting northwestward from Southampton Bay shown by Crane (1988), providing geomorphic evidence for fault locations in this heavily modified and urbanized corridor. The geometry of these lineaments is consistent with a restraining bend or step-over connecting the right lateral

West Napa and faults of the northern CCSZ (Model A; Figure 4), similar to that shown by Crane (1988). The presence of the northwest-trending ridge of elevated terrain south of Blue Rock Springs Creek and Lake Chabot on both the east and west sides of I-80 is also consistent with compression and uplift associated with a restraining fault geometry. Wesling and Hanson (2008) identify several anticlines in this area, but these structures are not consistent with bedding orientations shown by Crane (1988), which are approximately N45W/40S. This bedding orientation is relatively constant across the elevated terrain and suggests the presence of south-dipping, bedding-parallel thrust faults on the north side of the elevated terrain along Blue Rock Springs Creek accommodate contraction in the area.

However, the distribution of lineaments supports another interpretation—that the West Napa fault and CCSZ faults are directly connected via a through-going fault strand (Model B; Figure 4). For example, several lineaments, including a weakly expressed break in slope, saddle, linear tonal signature, potentially right-deflected stream, and linear drainage, lie north of, and roughly along strike with, the Dillon Point and Columbus Parkway lineament zones (and interpreted locations of faults by Crane (1988)) (Figure 3). These lineaments may represent a fault link to the southern end of the West Napa fault, which would lie within a well-expressed linear drainage located directly north of and parallel to Blue Rock Springs Creek. This interpretation is somewhat tenuous because a significant change in strike, from north-northwest to more northwesterly occurs across the saddle and break in slope, weakening the support for a through-going fault in this area. However, this potential linkage via a through-going fault strand is consistent with previous the interpretation of the general structural style of the CCSZ proposed by Unruh and Kelson (2002a) where north-striking strike-slip faults displace or truncate northwest-trending reverse faults and folds.

A third possible fault geometry exists. In this case, the short, north-trending lineaments underlying Interstate 80 and those located about 2 km east represent overlapping sections of the southernmost West Napa and northernmost Southampton faults, respectively (Model C; Figure 4). The northwest-striking thrust faults located between the north-striking strike-slip faults would accommodate compression occurring across the step-over and, the potential northwest-trending thrust faults located outboard of the north-striking strike-slip faults may be less active. Regardless of the details, the simplest interpretation of the lineaments from the 1937 aerial photographs and their geometry is that they represent portions of a complex and possibly evolving restraining bend that connects the southern West Napa fault to the Southampton fault northeast of the city of Vallejo.

The CCSZ is now defined, on the basis of this and previous analyses, to extend from a simple intersection with the West Napa fault near Oat Hill on the north, through the City of Vallejo, across the Carquinez Strait, through the northern East Bay Hills, and to merge with the Northern Calaveras fault near the town of Alamo (Figure 2). Overall, the length of this structure is 45 km, and it has an overall orientation of N28˚W from the Napa-Solano county boundary to the town of Alamo (Figure 2). The CCSZ consists of several, left-stepping fault strands that have an *en echelon* pattern and are probably right-lateral strike-slip structures. The areas between these north-striking dextral faults contain either

northwest-trending folds or northwest-striking reverse faults, or both. The north-striking faults appear to be active structures that offset the reverse faults and associated folds, and (as shown by marine-terrace displacements on the northern side of Carquinez Strait (WLA, 2003; Kelson et al., 2004, 2005)) are associated with vertical uplift of crustal blocks. To our knowledge, none of these north-striking faults have been investigated sufficiently to conclusively determine the presence or absence of Holocene activity; however, the structural association with both the active Northern Calaveras and West Napa faults and with historical microseismicity provides strong evidence that the CCSZ is a Holocene seismic source. The presence and extent of the CCSZ demonstrates that right-lateral strain on the Northern Calaveras fault is transferred northward through the East Bay Hills, across the Carquinez Strait, and onto the West Napa fault, rather than via a right-step-over onto the active Concord fault.

5.0 SUMMARY

This report summarizes the construction of a digital database for the Contra Costa Shear Zone (CCSZ) for input into the Northern California Quaternary Fault Map database (NCQFMD). Importantly, this report bridges a critical data gap between existing digital fault database compilations for the West Napa fault (Wesling and Hanson, 2008) and Northern Calaveras fault (Kelson and Sundermann, 2007) and is the first documentation that the CCSZ is linked to the West Napa fault. The CCSZ is now defined, on the basis of this and previous analyses, to extend from a simple intersection with the West Napa fault near Oat Hill on the north, through the City of Vallejo, across the Carquinez Strait, through the northern East Bay Hills, and to a merge with the Northern Calaveras near the town of Alamo

We compiled and digitized existing data and conducted original geomorphic mapping via analysis of aerial photography and LiDAR and completed field reconnaissance on this potentially active structure. Few detailed fault investigations have been completed within the CCSZ; the bulk of the database consists of documented and potential fault locations presented in Unruh and Kelson (2002a) along with the other limited, site-specific data (e.g., Woodward Clyde, 1975, 1976, 1978, 1979a, 1979b; ESA, 1983; Geomatrix 1998; Kelson et al., 2006; WLA, 2006; Norcal Geophysical, 2010). Original geomorphic mapping conducted for this study utilized 1:20,000 scale, black and white, stereo aerial photography flown in 1937 and 1937 as well as LiDAR collected in 2003 and 2008 The resulting database consists of digital line data in ArcGIS format, as well as text descriptions in an electronic format describing potential and documented fault segments.

New findings in the Vallejo area from this study include refinement of the potential southern end of the West Napa fault as extending south of the Napa-Solano county line and documentation of a probable step-over between the West Napa and Southampton faults. Specifically, the CCSZ in Vallejo is a series of en echelon folds and fault strands that accommodate strain in a left step-over in the regional right-lateral strike-slip system. Several zones of lineaments define the 2-5 km wide step-over as extending through the northeast side of the City of Vallejo, from approximately Southampton Bay on the south to the Solano-Napa county line on the north. This step-over zone is similar to other left step-overs defined by lineaments located in other parts of the CCSZ to the south (i.e., the Lafayette zone to the Briones zone, to the McEwen Road zone, to the Ozol zone, to the Southampton zone, etc.) This database and analysis provide documentation for an alternative model presented by Unruh and Kelson (2002a) to the previously favored interpretation that slip on the Northern Calaveras fault is transferred onto the Concord fault (Wills and Hart, 1992; Smith 1992; Oppenheimer and Macgregor-Scott, 1992).

6.0 REFERENCES

Bryant W.A., compiler, 2000, Fault number 36b, West Napa fault, Napa Airport section, in Quaternary fault and fold database of the United States, U.S.G.S. website http://earthquakes.usgs.gov/qfaults

Crane, R., 1988, Geologic maps of the Las Trampas Ridge, Walnut Creek, Briones Valley, Cordelia, and Benecia 7.5-minute quadrangles: unpublished maps available from H&L Hendry, Concord, CA; scale 1:24,000.

Crane, R., 1995, Geology of the Mt. Diablo region and East Bay hills, in Sangines, E.M., Andersen, D.W., and Buising, A.V., eds., Recent Geologic Studies in the San Francisco Bay Area: Society of Economic Paleontologists and Mineralogists, Pacific Section v. 76, pp. 87-114.

d'Alessio, M.A., Johanson, I.A., Burgmann, 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(b6): B06403, doi:10.1029/2004JB003496.

Dibblee, T.W., Jr., 1980, Preliminary geologic maps of the Briones, Walnut Creek, and Benicia quadrangles, Alameda and Contra Costa Counties, California: U.S. Geologic Survey Open-File Report, scale 1:24,000.

Earth Science Associates, Inc., (ESA), 1983, Seismicity study of Martinez dam site, unpublished consultants: report prepared for the U.S. Bureau of Reclamation.

Geomatrix Consultants, Inc., (Geomatrix), 1998, Final Report, Walnut Creek Water Treatment Plant expansion, seismic study – Phase II: unpublished consultant's report to East Bay Municipal Utility District, Oakland, California; 57 p. and Appendices, dated October 1998.

Graymer, R., 2006, New Quaternary fault map database for the San Francisco Bay region, California: Abstracts of the Centennial Meeting of the Seismological Society of America, April 18-22, 2006, San Francisco, California, Abstract No. 114.

Graymer, R.W., Jones, D.L., and Brabb, E.E., 1994, Preliminary geologic map emphasizing bedrock formations in Contra Costa County, California: U.S. Geological Survey Open-File Report 94-622.

Kelson, K.I., Baldwin, J.N., Unruh, J.R., and Lettis, W.R., 2004, Coastal marine terraces define Late Quaternary fault activity and deformation within northern East Bay hills, San Francisco Bay region: Eos Trans. AGU, 85(47), Fall Meeting Supplement, Abstract T13C-1396.

Kelson, K.I., and Sundermann, S.T., 2007, Digital compilation of Northern Calaveras fault data for the Northern California Quaternary Fault Map Database: Final Technical Report submitted to the U.S. Geological Survey NEHRP, Award No. 05HQGR0023

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 <http://gsa.confex.com/gsa/2005CD/finalprogram/abstract_85559.htm>

Kelson, K.I., Thompson, S.C., and Matsuda, E., 2006, Expected fault displacements along the BART Concord-Bay Point Line, Alameda and Contra Costa Counties, California [abs.]: Seismological Society of America Annual Meeting, v. 37, no. 4.

Kleinfelder, 1992, Fault investigation report Eagle Crest Subdivision: Unpublished consultingreport prepared for American Canyon Associates, May 28. (AP report no. 2950).

Langenheim, V.E., Graymer, R.W., Jachens, R.C., McPhee, D.K., and Schmidt, K.M., 2003, The West Napa fault as defined by gravity and magnetic data, northern California: EOS Trans. AGU v. 84, no. 46, Abstract T11D-0429 <http://wrgis.wr.usgs.gov/wgmt/gu/agu_abstract_2003.htm>

McClay, K., and Bonora, M., 2001, Analog models of restraining stopovers in strike-slip fault systems: American Association of Petroleum Geologist Bulletin, v. 85, pp. 233-260.

NORCAL Geophyscial Consultants, Inc., 2010, DFSP Ozol geophysical investigation, Unpublished consultants report provided to Shaw Environmental for Defense Fuel Supply Point Environmental Response Contract SP0600-08-D-5812.

Oppenheimer, D.H., and Macgregor-Scott, N., 1992, The seismotectonics of the eastern San Francisco Bay region: Calif. Div. Mines Geol. Spec. Pub. 113, p. 11-16.

Rosenberg, L., In prep., Southern Calaveras and Related Faults: Collaborative Research with the U.S. Geological Survey Northern California Quaternary Fault Map Database Task, U.S. Geological Survey NEHRP, Award No. 06HQGR0017.

Sundermann, S.T., and Kelson, K.I., 2009, Digital compilation of Central Calaveras fault data for the Northern California Map Database: Collaborative Research with William Lettis & Associates, Inc., and the U.S. Geological Survey, Final Technical Report submitted to the U.S. Geological Survey NEHRP, Award No. 06HQGR0154.

Smith, G.A., 1992, The Ygnacio segment and the southern terminus of the Concord fault, in Borchardt, G., et al., eds., Proceedings of the Second Conference on Earthquake Hazards in the Eastern San Francisco Bay Area: California Division of Mines and Geology Special Publication 113, p. 319-323.

Terrasearch, Inc., 1994, Fault hazard investigation on Eagle Crest Property, American Canyon, California: Unpublished consulting report, October 6. (AP report no. 2950).

Twiss, R.J., and Moores, E.M., 1992, Structural Geology: W.H. Freeman Company, New York, 532 p.

Unruh, J.R., and Kelson, K.I., 2002a, Critical evaluation of the northern termination of the Calaveras fault, eastern San Francisco Bay area, California: unpublished Final Technical Report submitted to the U.S. Geological Survey National Earthquake

Hazard Reduction Program, Award Number 00-HQ-GR-0082; dated July, 2002; 28 p.

Unruh, J.R., and Kelson, K.I., 2002b, Critical evaluation of the northern termination of the Calaveras fault, eastern San Francisco Bay area, California [abs.]: Eos Trans. Fall Meeting Supplement, Abstract T62F-04, p. 1300.

Wesling, J.R., and Hanson, K.L., 2008, Digital compilation of West Napa fault data for the Northern California Quaternary Fault Map Database: Final Technical Report submitted to the U.S. Geological Survey NEHRP, Award no. 05HQAG0002.

Wills, C.J., and Hart, E.W., 1992, Progress in understanding the Concord fault through site specific studies, in Borchardt, G., and others, (editors), Proceedings of the second conference on earthquake hazards in the eastern San Francisco Bay area: California Division of Mines and Geology Special Publication 113, p. 311-317.

William Lettis & Associates, Inc., (WLA), 2003, Surface Investigations of the potential for earthquake-related surface deformation at proposed LNG and power plant facilities, Mare Island, Vallejo, California: Unpublished consultant’s report submitted to Bechtel Enterprises/Shell, dated January 13, 79 p.

William Lettis & Associates, Inc., (WLA), 2006, Expected fault displacements along the BART Concord-Bay Point Line, Alameda and Contra Costa Counties, California: Unpublished consultant’s report submitted to Bay Area Rapid Transit District, Oakland, CA; dated February 9, 2006, 77 p.

Witter, R.C., K.I. Kelson, A.D. Barron, and S.T. Sundermann, 2003, Map of active fault traces, geomorphic features and Quaternary surficial deposits along the central Calaveras fault, Santa Clara County, California: U.S. Geological Survey, National Earthquake Hazards Reduction Program Final Technical Report, Award No. 01HQGR0212, 32 p.

Woodward-Clyde Consultants, 1975, Assessment of geologic and seismic hazards, Rossmoor Leisure World, Walnut Creek, California: unpublished consultant's report dated July 9, 1975.

Woodward-Clyde Consultants, 1976, Assessment of geologic and seismic hazards for Neighborhood Five, Rossmoor Leisure World, Walnut Creek, California: unpublished consultant's report dated February 26, 1976.

Woodward-Clyde Consultants, 1978, Fault study, proposed Clubhouse No. 5, Neighborhood Nine, Rossmoor Leisure World, Walnut Creek, California: unpublished consultant's report dated October 13, 1978.

Woodward-Clyde Consultants, 1979a, Fault study, Saklan Indian Drive Extension, Neighborhood Nine, Rossmoor Leisure World, Walnut Creek California: unpublished consultant's report for Terra California, Walnut Creek, 25 p. + Appendix and figures.

Woodward-Clyde Consultants, 1979b, Fault study, Subdivision 5239, Mutual 50, Subdivision 5240, Mutual 51, Neighborhood Four, Rossmoor Leisure World, Walnut Creek, California: unpublished consultant's report for Terra California, Walnut Creek, California, 11 p.

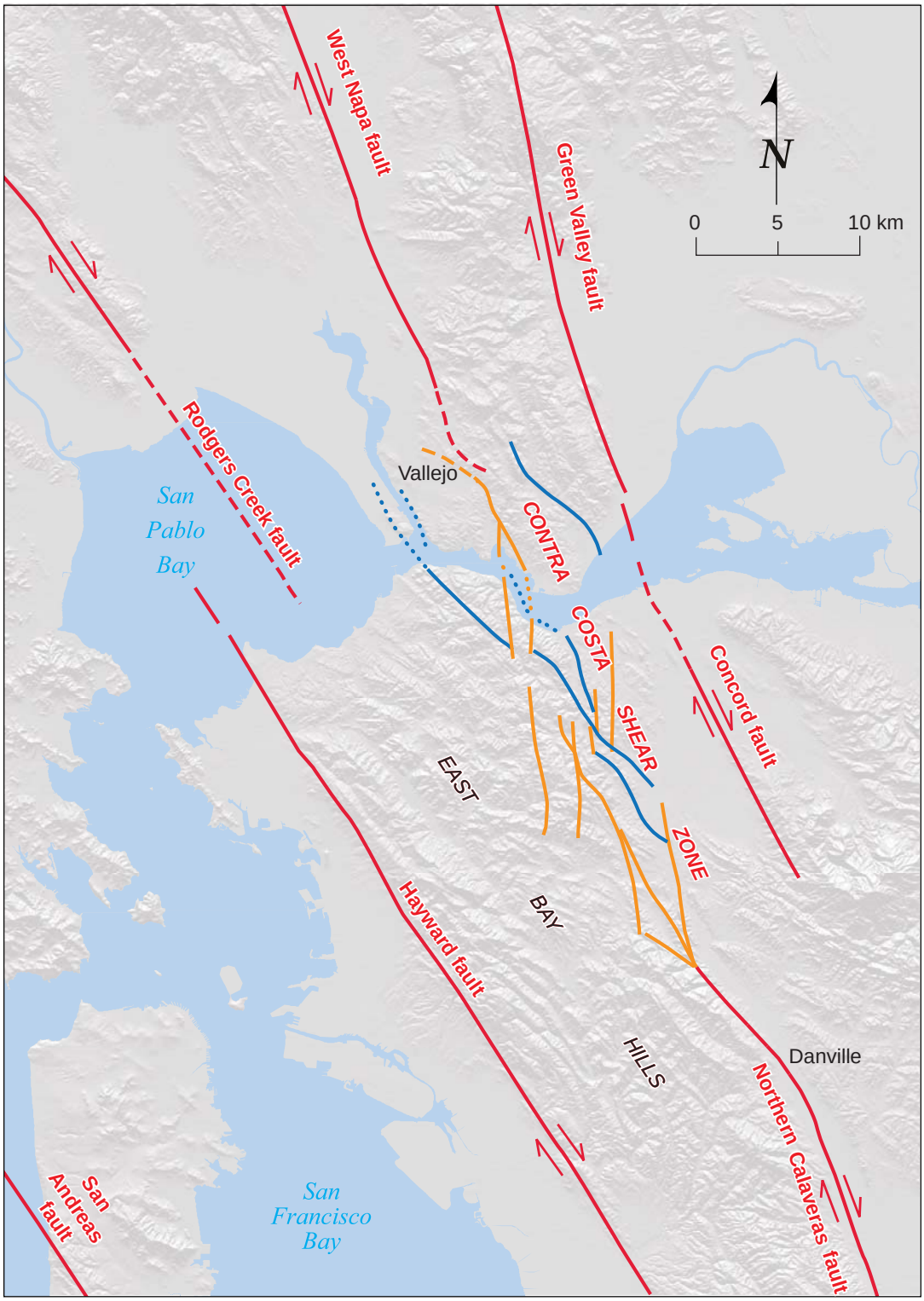


Figure 1. Regional map of the Contra Costa Shear Zone in the northern San Francisco Bay area, showing major active faults (red), potentially active faults (orange), and inactive faults (blue).

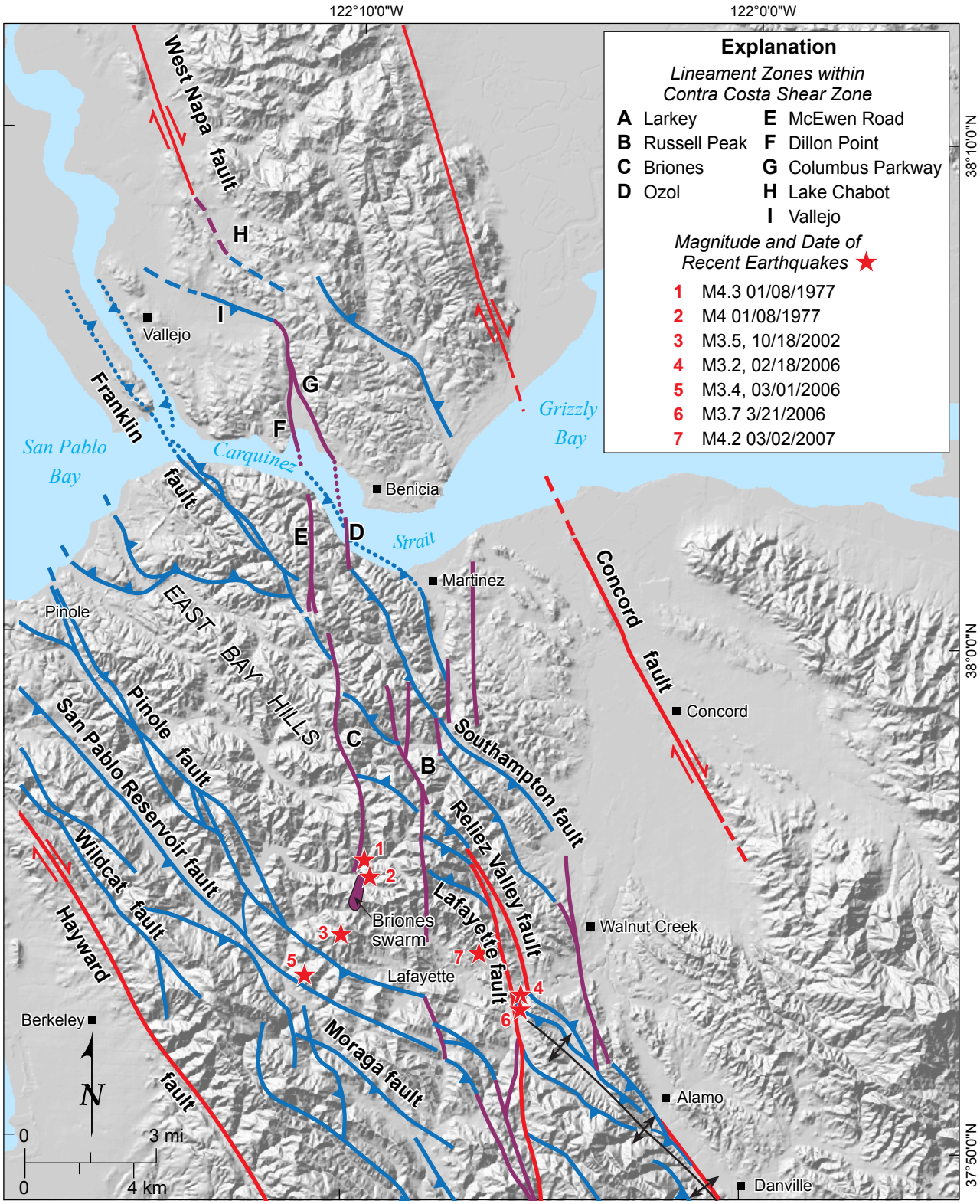
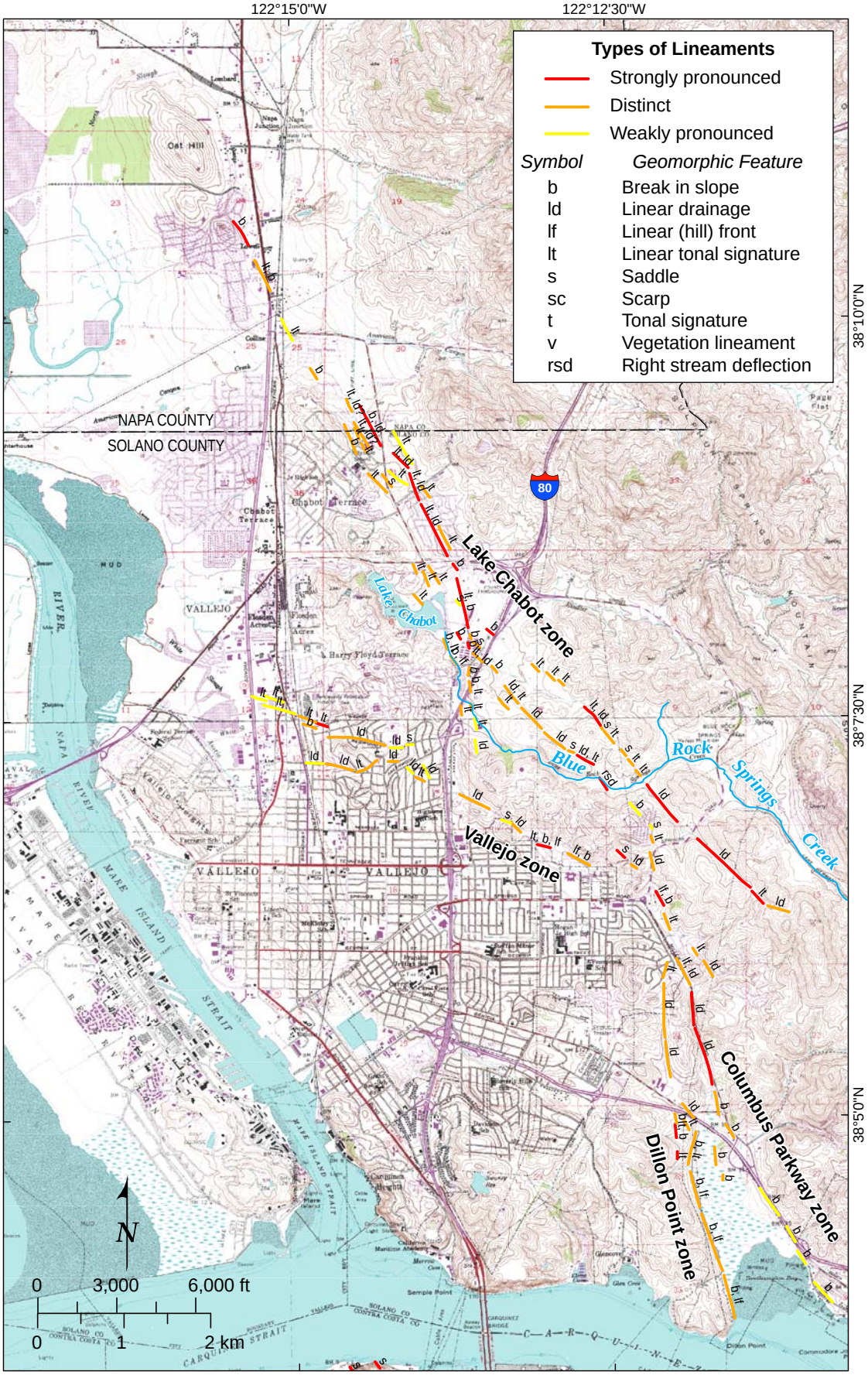


Figure 2. Regional tectonic map of the northern East Bay Hills, showing traces of major faults and inferred fault sections. Blue lines show mapped faults with reverse or oblique movement, red lines show previously mapped strike-slip faults, and purple lines show inferred dextral faults along lineament zones.



Topographic base USGS 7.5' quadrangles:
Cuttings Wharf, Cordelia, Mare Island, Benicia

Figure 3. Map of Vallejo showing lineaments interpreted from 1937 aerial photography.

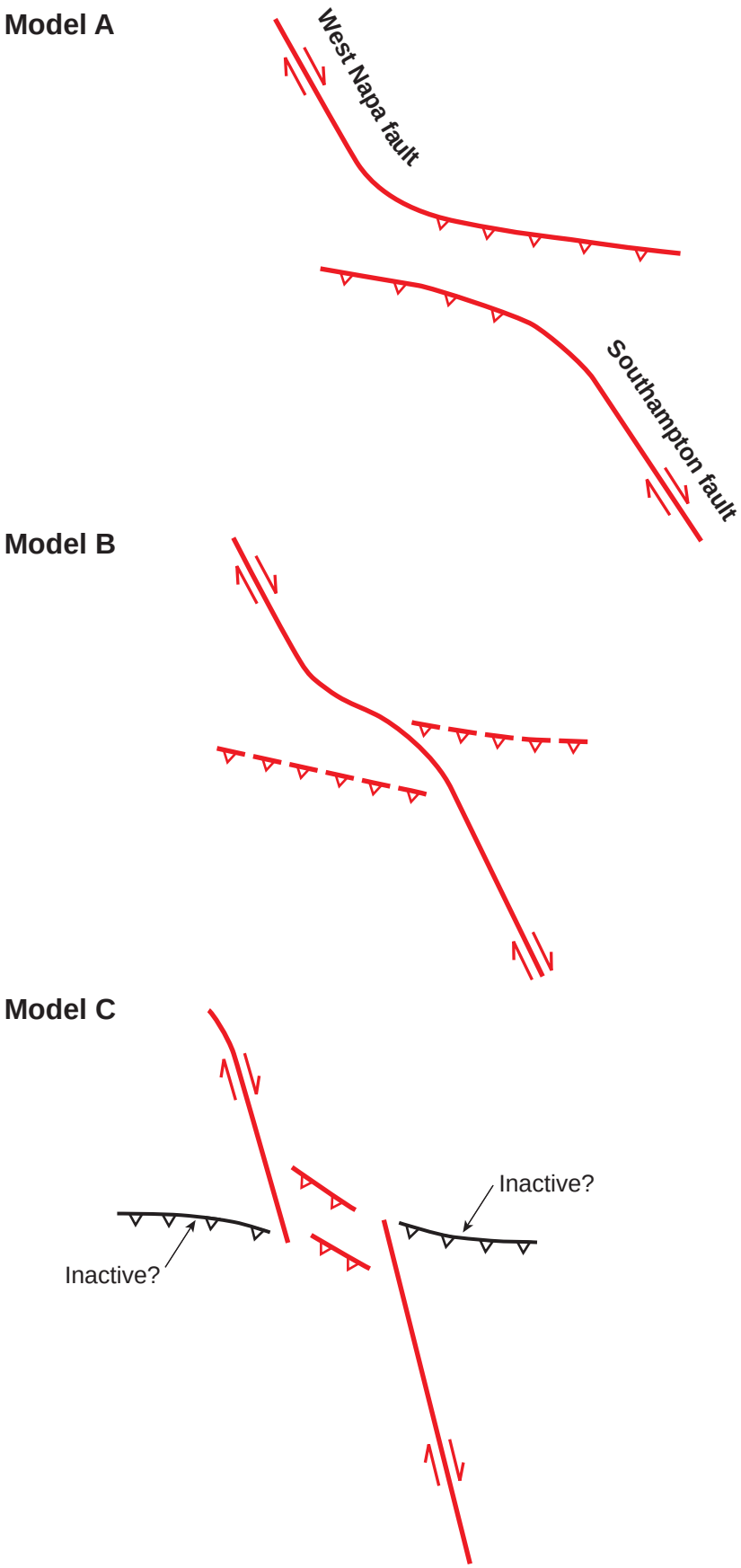


Figure 4. Potential stepover models between the West Napa and Southampton faults.