FINAL TECHNICAL REPORT

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

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ABSTRACT

This study presents a new digital map compilation of fault traces along the Central Calaveras fault in the eastern San Francisco Bay region. The work described herein is part of a collaborative effort between private and academic geologists and the U.S. Geological Survey (USGS) to construct a Quaternary fault map and database for the San Francisco Bay area. The goal of this study is to compile geologic data on the active Central Calaveras fault in a digital format for the Northern California Quaternary Fault Map Database (NCQFMD). This new compilation of fault traces revises and builds upon previous work between Calaveras Reservoir on the north and the San Felipe Lake on the south. The digital database of fault characteristics developed in this work helps define fault-related hazards along the Central Calaveras fault. Development of this fault database is important for adequately documenting the current understanding of the fault, and is key to the current USGS effort to develop digital, up-to-date geologic maps of the Bay area. The Central Calaveras fault database resulting from this effort was submitted to the U.S. Geological Survey in conjunction with this report (01/2009).

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1.0 INTRODUCTION

The 123-km-long Calaveras fault is a major right-lateral strike-slip fault in the San Francisco Bay region, and an important component of the San Andreas fault system that forms the boundary between the Pacific and North American tectonic plates. The Calaveras fault splays from the San Andreas fault near the town of Hollister and extends northwest to the northern San Ramon Valley, near Danville (Figure 1) with a total dextral offset of as much as 200 km (Jones et al., 1994). The Calaveras fault inherits slip from the San Andreas fault between 17±4 mm/yr (Kelson et al., 1999; Kelson, 2001; Lienkaemper et al., 1991) and 15±3 mm/yr (WGCEP, 2003). Based on present-day creep rates, structural relations with adjacent faults, contemporary seismicity and geomorphic expression, the Calaveras fault is interpreted to consist of three primary sections (Kelson et al., 1999; Kelson, 2001; WGCEP, 2003), including the Northern, Central, and Southern sections (Figure 1). These three sections may or may not reflect surface-rupture segments.

The Central Calaveras fault traverses obliquely through the steep terrain of the Diablo Range, which has undergone extensive regional urban growth in the past two decades since the inception of the Alquist-Priolo maps. The Central Calaveras fault is well characterized by microseismicity and moderate earthquakes, but lacks a well documented paleoseismic record. The digital database of fault characteristics developed in this work helps define fault-related hazards, in particular the locations and distribution of surface rupture. This database builds upon our recent mapping of fault-related features and late Quaternary surficial deposits along the Central Calaveras fault (Witter et al., 2003). Development of this fault database is important for adequately documenting the current understanding of active fault strand locations, and is critical for USGS efforts to develop digital, up-to-date geologic maps of the San Francisco Bay area.

The goal of this study is to compile geologic and geomorphic data on the Central Calaveras fault in a digital format for the Northern California Quaternary Fault Map Database (NCQFMD). This study is a collaborative effort with other researchers, and was coordinated by Dr. Russell Graymer of the U.S. Geological Survey (Menlo Park). The research priorities for the NCQFMD project, as outlined by Dr. Graymer, are:

1. Provide “fault traces in GIS”;
2. Evaluate “fault strand rank”;
3. Evaluate “location uncertainty:’
4. Characterize “geomorphic expression”; and
5. Compile “site-specific point data”.

This effort addresses the first three of these datasets, and includes a database of interpreted fault traces according to fault strand location, rank, and uncertainty. The geomorphic expression of each strand is included as part of the subjective assessment of fault strand rank. In addition, the database is a compilation of several site-specific point datasets relevant to characterizing individual fault strands, including (1) locations of selected trenches, and (2) locations of fault strands identified via geomorphic features, active creep, or trench exposures.

The Central Calaveras fault database resulting from this effort is being submitted to the U.S. Geological Survey in conjunction with this Final Technical Report. Preliminary results were summarized by Sundermann and Kelson (2007). This map and database of the Central Calaveras fault compliments and extends a digital database of Northern Calaveras fault data by Kelson and Sundermann (2006) and develops further the potential fault-related lineaments database developed for the Central Calaveras fault by Witter et al. (2003). The lineament map product shows fault-related lineaments and existing sites of detailed investigation, but does not interpret the location and continuity of primary and secondary fault traces. Synthesizing the existing digital lineament map, and incorporating the recent subsurface investigations along the Central Calaveras fault into the digital database, will provide an up-to-date database for the Central Calaveras fault.

2.0 OVERVIEW OF THE CENTRAL CALAVERAS FAULT

The 59±10 km-long (37 ± 6 mi) (WGCEP, 2003) Central Calaveras fault traverses through the western Diablo Range between Calaveras Reservoir on the north and San Felipe Lake on the south (Figure 2). Based on the complex architecture of active surficial traces and the distributed nature of surface deformation depicted on the map, the Central Calaveras fault is a multi-segmented fault zone that partitions slip from the San Andreas fault onto the southern Hayward fault and Northern Calaveras fault near Calaveras Reservoir. The slip appears to be accommodated on the Southern and Central Calaveras faults by aseismic creep and moderate-magnitude earthquakes. The Central Calaveras fault is differentiated from fault sections to the north and south on the basis of aseismic creep and geologic slip rates, overall strike, geomorphic expression, microseismicity, and historical seismicity (Kelson, 2001; WGCEP, 2003, 2007).

2.1 Aseismic Creep and Geologic Slip Rates

The Central Calaveras aseismic creep rate of 14 to 17 mm/year is significantly higher than that along the Northern (3 to 4 mm/year) Calaveras fault (Galehouse and Lienkaemper, 2003). Repeated measurements at multiple U.S.G.S. alignment arrays and trilateral networks (Figure 3) portray an aseismic creep rate that varies along the length of the fault segment and over time. The Central Calaveras creep rate appears to be slowing to 14 mm/year based on measurements taken after the Loma Prieta 1989 event at the Coyote Ranch alignment array. However, the U.S.G.S. monitoring program 33-year average remains 17 mm/year.

According to the 2003 Working Group, the Calaveras fault inherits 15 ± 3 mm/yr from the San Andreas fault onto the southern segment. This long term slip rate carries more or less through the Southern and Central segments. Paleoseismic studies at the San Ysidro Creek site, located approximately 4.8-km northwest of San Felipe Lake fault-segment boundary, provides a preliminary late Holocene slip rate on the central Calaveras fault of 14 ± 5 mm/yr (Kelson et al., 1998; Baldwin et al., 2002). Within the uncertainty of the geologic data, this long-term slip rate is consistent with the short-term rate based on aseismic creep and geodetic modeling.

To the north within the Calaveras Reservoir step-over, and segment boundary, the Central Calaveras fault partitions slip at a rate of 8 to 10 mm/yr onto the southern Hayward fault (Lienkaemper et al., 1991; Manaker, 2005) and 4 to 7 mm/yr onto the Northern Calaveras fault (Kelson et al., 1992; 1996; Simpson et al., 1999).

2.2 Overall strike

The Central Calaveras fault strikes more westerly (N30°W to N35°W) in comparison to the Northern and Southern Calaveras faults, which strike approximately N23°W (Kelson et al., 2001). This change in the overall strike is apparent and partially defines the segment boundary between the Southern and Central Calaveras. A transition to a more northerly trending Northern Calaveras is evident within the Calaveras Reservoir right-releasing bend as slip transferred to the Northern Calaveras and the Mission seismic trend, which regionally maintains a similar trend to the Central Calaveras.

2.3 Geomorphic Expression

The rugged terrain of the Diablo Range has not undergone significant urban development, providing geomorphic expression as a primary data source for evaluation of the anastomosing fault pattern. At a detailed scale (greater than 1:24,000 map scale), the Central Calaveras fault is a zone of extensional fault bound basins, braided secondary fault splays, restraining stepovers, and *en echelon* fault patterns, and is more complex than the Southern and Northern Calaveras faults. Prominent fault-related landforms define the Central Calaveras fault in late Quaternary surficial deposits, including distinct topographic scarps, right-laterally offset streams, sag ponds, linear drainages, and other fault-related features (Bryant, 1981a, 1981b; Smith 1981; Witter et al., 2003) (Figures 4a to 4h). Considering the sparsity of paleoseismic information along the Central Calaveras, the geomorphic expression of the fault (as illustrated by detailed, LiDAR [Light Detection And Ranging] topographic data) is a valid indicator of fault location and character (Figures 5a to 5h). The previous lineament map along the Central Calaveras fault (Witter et al., 2003) provided the basis for the map developed herein, and contains individual fault lines attributed with specific geomorphic feature codes (following Clark, 1973; Armstrong and Wagner, 1978; and Smith, 1981).

2.4 Microseismicity and Historical Seismicity

In contrast to the Northern and Southern Calaveras fault segments, the Central Calaveras fault is characterized by abundant instrumentally recorded microseismicity (Oppenheimer et al., 1990). Instrumental seismicity associated with the Central Calaveras fault appears to continue northwestward on a more westerly trend onto the Mission seismic trend rather than continue north onto the Northern Calaveras through the Calaveras Reservoir step-over. A second prominent trend of instrumentally recorded seismicity diverges northwest from the Central Calaveras fault toward the southern extent of the Hayward fault at Halls Valley (Manaker, 2005). Analysis of the spatial distribution of microseismicity

before and after historic moderate earthquakes shows that fault deformation occurs through aseismic creep above 5 km depth, and a combination of aseismic creep and microearthquakes between depths of 5 and 10 km, with **M**≥5 earthquakes at depths between 8 and 10 km (Oppenheimer et al., 1990; 2008b). Several historic, moderate-magnitude earthquakes (Table 1) are a part of strain release on the fault. Currently the Central Calaveras fault is experiencing a northward proceeding earthquake cycle (Oppenheimer et al., 1990; 2008b) of five **M**≥5 earthquakes (Figure 3). The cycle was initiated by the 1949 Gilroy earthquake triggering a northward progression over 60 years to the 2007 **M**5.5 Alum Rock event near the southern end of Calaveras Reservoir (Oppenheimer et al., 2008a). Uncertainty remains regarding the maximum earthquake magnitude possible along the Central Calaveras fault (WGCEP, 2003, 2007).

Table 1. Historical seismicity along the Central Calaveras fault (greater than M 5.0).

Date	Magnitude	Longitude	Latitude	Depth	Name	Reference
6-Jul-1899	5.8	-121.5000	37.2000	n.d.	Unnamed	Toppozada et al., 1981
26-Oct-1943	5.1	-121.7432	37.3870	8.55	Alum Rock	Oppenheimer et al., 1990
9-Mar-1949	5.2	-121.4800	37.0200	n.d.	Gilroy	Bolt and Miller, 1975
5-Sep-1955	5.5	-121.7800	37.3700	n.d.	Unnamed	Bolt and Miller, 1975
6-Aug-1979	5.9	-121.5178	37.1040	8.95	Coyote Lake	Oppenheimer et al., 1990
24-Apr-1984	6.2	-121.6780	37.3093	8.42	Morgan Hill	Oppenheimer et al., 1990
31-Mar-1986	5.7	-121.6938	37.4695	8.54	Mt. Lewis	Oppenheimer et al., 1990
13-Jun-1988	5.1	-121.7432	37.3870	8.55	Alum Rock	Oppenheimer et al., 1990
20-Jun-1987	6.2	-121.5000	37.0000	n.d.	Unnamed	Toppozada et al., 1981
1-Jul-1911	6.5	-121.6861	37.3139	~8.5	Morgan Hill	Oppenheimer et al., 1990
31-Oct-2007	5.5	-121.7743	37.4337	10.04	Alum Rock	Oppenheimer et al., 2008a

3.0 MAP DEPICTION OF NORTHERN CALAVERAS FAULT TRACES

Previous digital compilations of data on the Calaveras fault includes the National Quaternary Fault and Fold database, which provides a detailed digital compilation of the characteristics of the primary sections of the Calaveras fault, extending from the town of Danville on the north to the Paicines fault on the south, near the town of Hollister (Bryant and Cluett, 1999a, 1999b, and 1999c). Also, the California Geological Survey (CGS) has developed over the past several decades a complementary digital GIS database of Holocene-active Alquist-Priolo ("A-P") fault traces. The CGS developed digital files depicting the areas of investigations conducted prior to 2001 for regulatory compliance with the A-P Act, although individual trenches or other relevant subsurface data are not identified in this database. Prior to the U.S. Geological Survey's collaborative effort described in this report, these data were not linked into a consistent, comprehensive database that could be accessed for scientific research, engineering-driven seismic hazard analyses, or public outreach. A primary goal of this proposed collaborative effort is to compile these digital databases into a consistent map-based digital product for use in scientific research, consulting, and public outreach activities.

The digital database presented with this report is a continuation on several facets of our previous analysis of the Central Calaveras fault (Witter et al., 2003), which generated a strip-map of potential fault related lineaments along the segment. First, the database refines the locations of individual strands at a 1:12,000 scale using recently acquired, sophisticated datasets, including LiDAR-derived topography collected as part of the GeoEarthscope Northern California LiDAR Project. The database used herein also includes additional fault investigations conducted since the publication of the lineament database in 2003. Second, lineaments without supporting evidence of being fault related or a strand of the Central Calaveras fault were eliminated. Third, fault strands were attributed in the GIS database according to location certainty (e.g., certain, approximate, concealed) and confidence in the constraints on location (e.g., well, moderately, poorly constrained). Fault rank (e.g., primary, secondary) was assigned to individual strands based on supporting evidence of activity and a regional depiction of the segment. Lastly, the database was formatted to reflect preset requirements for assimilation into the Northern California Fault Map Database (NCQFMD).

The primary and secondary fault traces were mapped in ArcGIS 9.2 and attributed using the NCQFMD format for incorporation into the USGS regional database. Fault strands attributes specific to NCQFMD were added, including location certainty and confidence, fault rank, geographic constraints and general fault categorization. The relative location certainty was assigned on the basis of exposures in cross-fault

trenches, interpretations of near-surface borehole data, geomorphic features, and analysis of aerial photographs. Uncertainties related to these data sets are based primarily on the accuracy of the original data sets; in other words, on the accuracy of registering trench and borehole locations as depicted in the original consulting reports, except where data locations were verified in the field or checked using detailed aerial photography. Because active strands of the Central Calaveras fault commonly are associated with geomorphic expression (ranging from strong to subtle), the accuracy of fault strands in this data base is better than if the mapping were based only on trench exposures.

3.1 Metadata for the Northern Calaveras Fault Database

The database was compiled using ArcGIS 9.2, a Geographic Information System created by Environmental Systems Research Institute (ESRI, Redlands, California). The comprehensive database consists of the Central Calaveras fault compilation database, supporting metadata, and this report. The compilation consists of geologic and fault data from unpublished consultant's reports and academic investigations, appended with revisions by the authors to complete continuity amongst the datasets at this large geographic scale. Geologic mapping of the Central Calaveras fault was compiled at the most detailed scale available.

The fault map database consists of four ARC shapefiles, created and attributed within the NCQFMD format for incorporation into the USGS regional database. The primary shapefile, CenCalaveras_fault, presents our final interpretation of the fault, at fault strand resolution, as a polyline file. Three additional shapefiles, Trenches, CenCalaveras_Creep and CenCalaveras_locales, present digitization of the compiled datasets used in our interpretation. The trenches polyline shapefile is a digitization of paleoseismic trench locations from Alquist-Priolo studies and research investigations performed along the Central Calaveras fault or within about 1 km of the primary fault zone. The CenCalaveras_locales point shapefile depicts the exact locations of fault exposures within individual trenches, as interpreted from trench logs in publications or consulting A-P reports, boring arrays, high-resolution creep monitoring arrays, or the locations of fault strands based on prominent geomorphic expression.

Fault-related lineaments, geomorphic expressions and topographic features were mapped using stereo-paired, historic air photos taken along all or parts of the fault in 1939 and 1999. Lineament maps were compiled and scanned using a large format color scanner with a resolution of 1200 dots per inch. The scanned maps and air photos were georectified into the working coordinate system for vectorization using the Georeferencing extension in ArcGIS 9.2. Georeferencing was accomplished with control points linked to map edge tics and cultural features in a heads-up digitization process. The link table was

intentionally saturated to facilitate sub-meter root mean square horizontal error. Fault-related features were vectorized using the rectified aerial photographs compared to digital ortho-photoquads via a heads-up digitization process, and were drawn as accurately as possible at the map scale of 1:12,000. Fault-related features were overlain onto digital topographic quadrangle maps. Site-specific trenches, boreholes or other features constraining the fault locations were compiled digitally on these topographic maps. Attribute tables were completed within the GIS and follow the NCQFMD format.

Pre-processed 0.5 meter LiDAR digital elevation models (DEM) were used to further constrain the resolution of the digitized fault-related features. The LiDAR datasets were provided through the Geo Earthscope Northern California LiDAR project from their website data portal: https://portal.geongrid.org/gridsphere/gridsphere?gs_action=lidarNCAL&cid=geonlidarframeportlet. The DEM tiles were acquired as bare-earth, 1 square-kilometer tiles and stitched together using the ArcToolbox Mosaic tool in 5 kilometer sections along trend. These 5-km-long sections were processed to create shaded relief using the Spatial Analyst Hillshade tool.

Mapped fault locations were also compared with previously mapped traces of CGS Official Maps of Alquist-Priolo Earthquake Fault Zones; the "Fault Traces of California Map" (1994) by Charles Jennings; "Preliminary Geologic Map of the San Jose 30 x 60 Minute Quadrangle" (1999) by Wentworth et al.; and "Geology of the Southernmost Part of Santa Clara County" (1997) by R. Graymer.

Vectorized maps and the acquired digital files were compiled at a map scale of 1:12,000. Although the digital format of the dataset permits viewing the data at a larger scale, the detail and accuracy of the drawing is compromised at any scale larger than 1:12,000. Viewing the data 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.

4.0 PHYSICAL SUB-SECTIONS OF THE NORTHERN CALAVERAS FAULT

This section provides additional explanation of the characterization of Central Calaveras fault strands and their attribution in the GIS database. Figures 4a to 4h illustrate the pattern of fault strands comprising the Central Calaveras fault, as compiled in the digital database. This map compilation provides a basis for interpreting eight sub-sections of the fault, as suggested by fault strike, different widths of the deformation zone, geomorphic expression, fault-trace map pattern, and other fault characteristics (Figure 2; Table 2). The sub-sections are not likely to represent individual fault-rupture segments during large-magnitude earthquakes on the Central Calaveras fault, although the style and pattern of surface deformation is expected to vary amongst the sub-sections. The sub-sections are refined from the previous lineament map (Witter et al., 2003) to include actual boundaries of the sections, and refined attributes based on our interpretation for this stripmap. Detailed descriptions of the fault-related features and geometries of each sub-section are presented by Witter et al. (2003).

Table 2. Central Calaveras fault sub-section boundaries, lengths, and orientations.

Fault Sub-section	*Approximate Geographic Boundary*	*Latitude (N)*	*Longitude (W)*	**Length (km)**	**Average Trend**
	Marsh Road	*37.444*	*-121.804*		
Alum Rock				**11.1**	**317˚**
	Arroyo Aguague	*37.362*	*-121.727*		
Halls Valley				**7.8**	**324˚**
	Panochita Hill	*37.300*	*-121.684*		
San Felipe Valley				**5.1**	**347˚**
	Metcalf Road	*37.255*	*-121.673*		
Animas Creek				**8.1**	**320˚**
	Lone Lake	*37.194*	*-121.623*		
Anderson Reservoir				**9.6**	**315˚**
	Coyote Creek	*37.126*	*-121.556*		
Coyote Reservoir				**7.9**	**332˚**
	Roop Road	*37.060*	*-121.520*		
San Ysidro				**6.4**	**326˚**
	Canada Road	*37.010*	*-121.486*		
San Felipe				**3.7**	**324˚**
	Millers Canal	*36.981*	*-121.464*		

5.0 CONCLUSIONS

This report provides an explanation of the compilation of geologic data on active strands of the Central Calaveras fault in a digital format for the Northern California Quaternary Fault Map Database (NCQFMD). The digital database of fault characteristics developed in this work helps define fault-related hazards, in particular the locations and distribution of surface fault-strands and possible locations of surface rupture. This database builds upon and extends substantial previous compilation efforts (Witter et al., 2003), and provides a consistent, comprehensive database that can be accessed for scientific research, engineering-driven seismic hazard analyses, and public outreach. The database was constructed to be completely seamless with the USGS-driven format for the Northern California Quaternary Fault Map Database (NCQFMD), and was compiled using ArcGIS v9.2. This detailed analysis provides a consistent database for interpreting eight sub-sections of the Central Calaveras fault, as suggested by fault strike, sense-of-slip, geomorphic expression, fault-trace map pattern, and other fault characteristics. These sub-sections are not likely to represent individual fault-rupture segments during large-magnitude earthquakes on the Central Calaveras fault.

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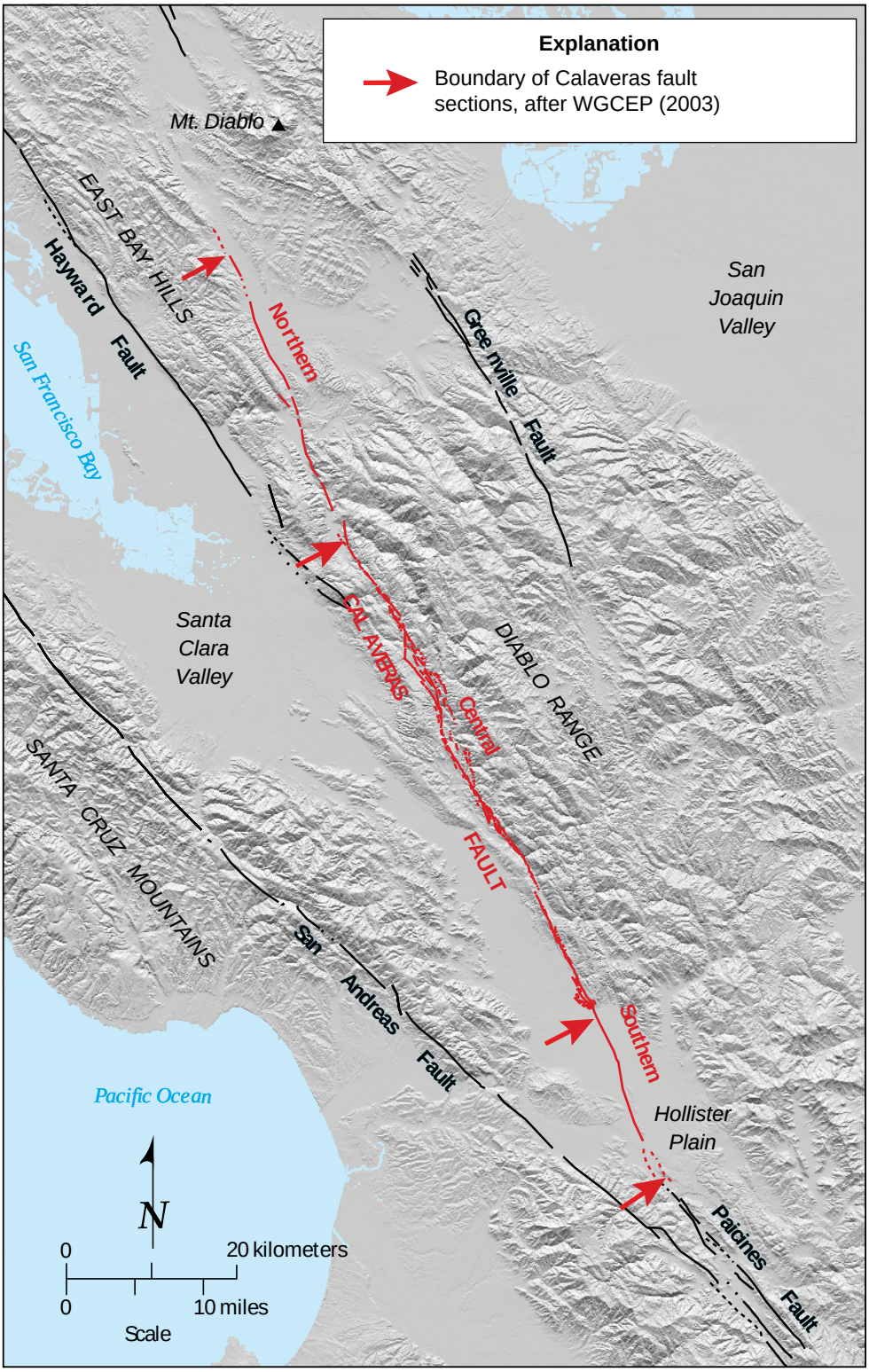
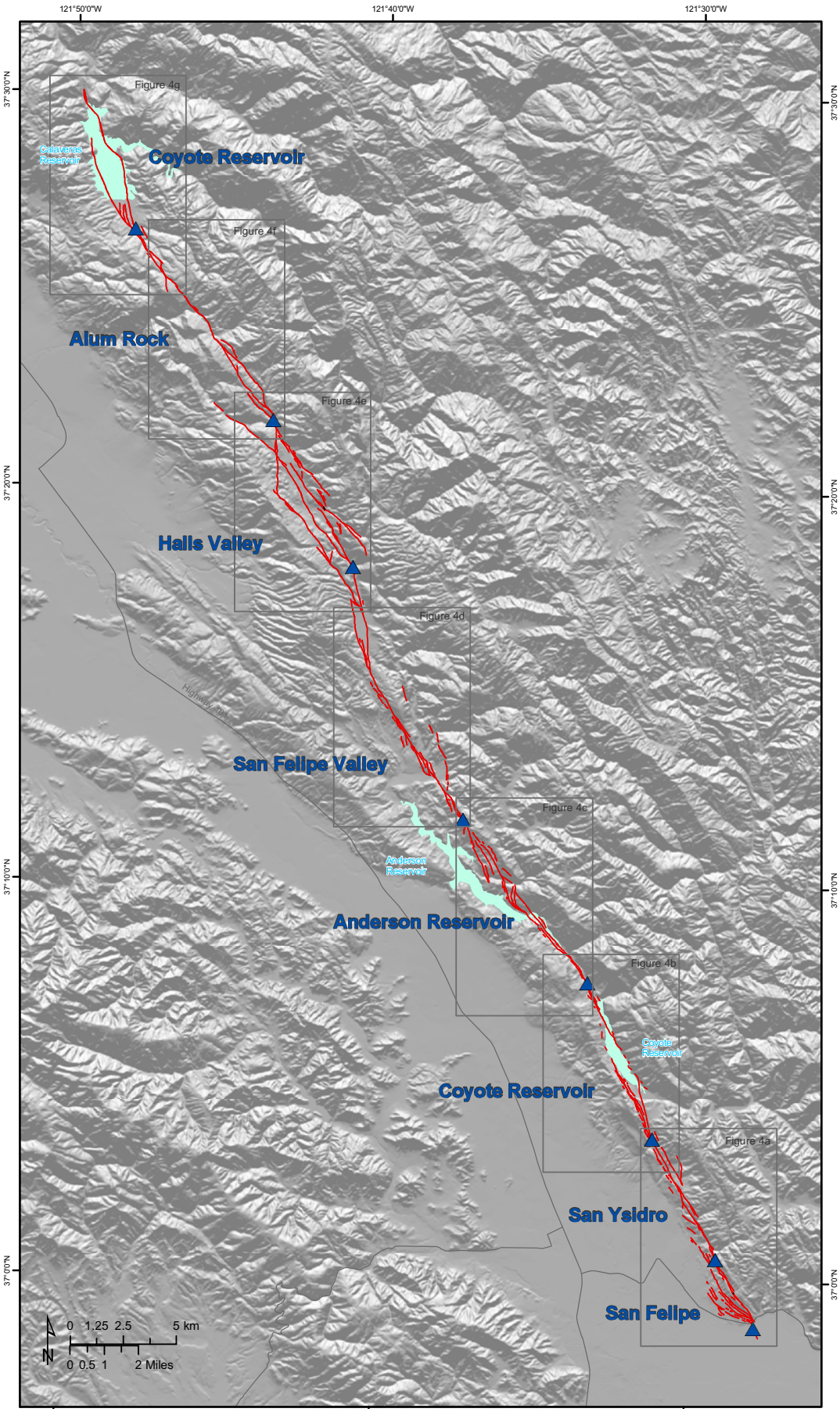


CENTRAL CALAVERAS FAULT

Shaded Relief Map of the Major Active Faults in the Southern San Francisco Bay Region

WLA William Lettis & Associates, Inc. | Figure 1



Explanation

- Sub-section boundary
- Central Calaveras fault

CENTRAL CALAVERAS FAULT

Central Calaveras Fault and Subsection Boundaries

WLA William Lettis & Associates, Inc. | Figure 2

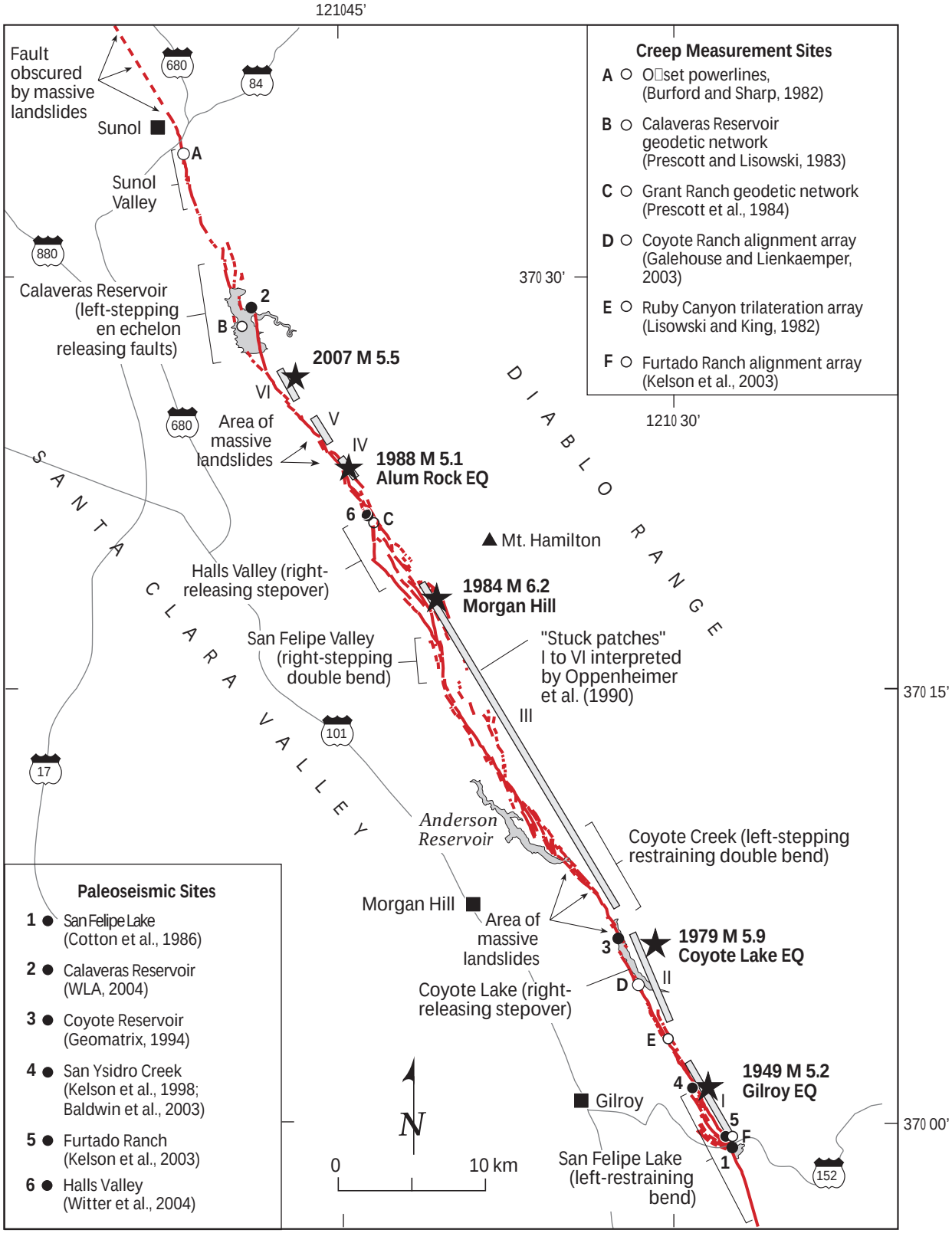
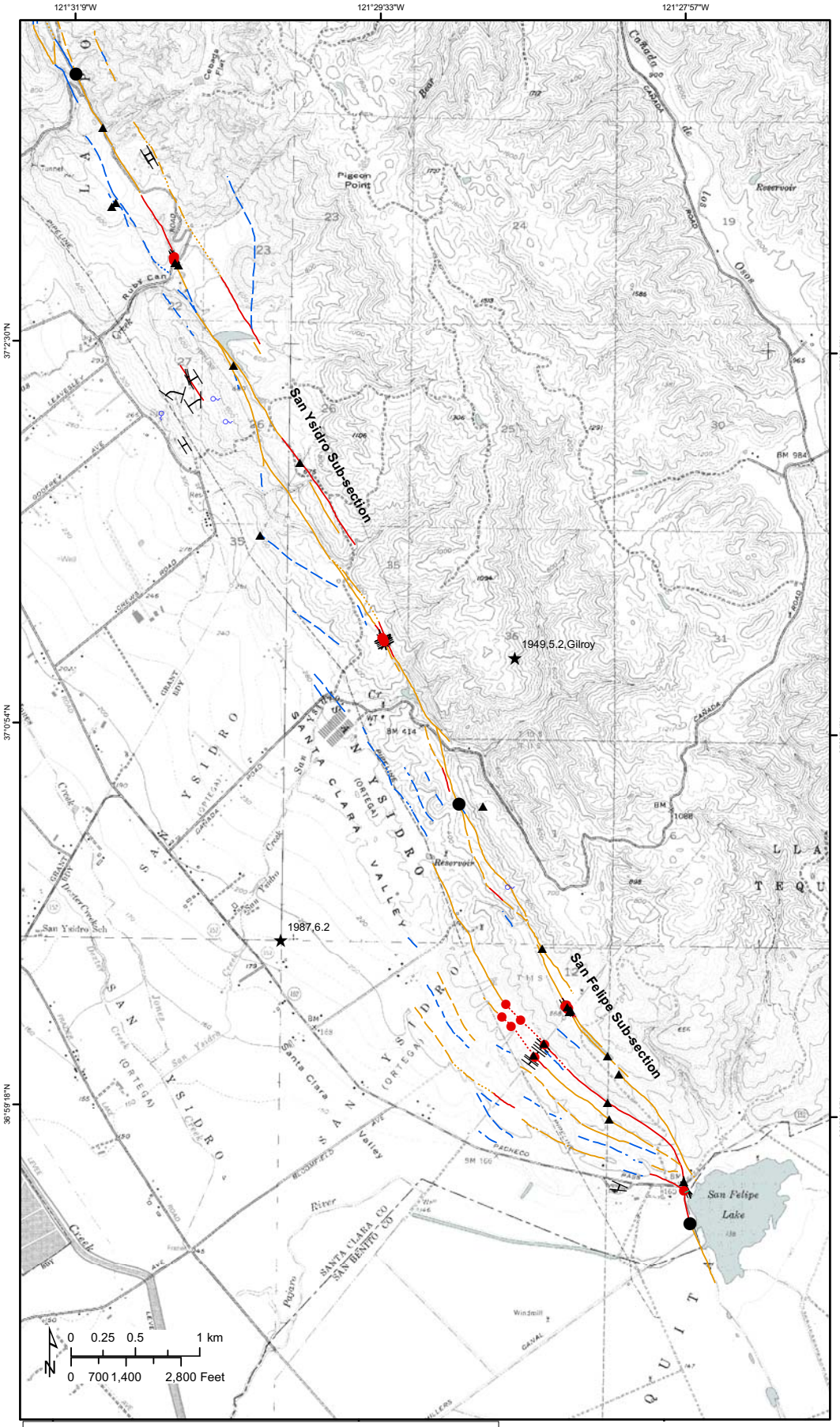


Figure 3. Simpli ed map of active traces of the central Calaveras fault, showing previous sites of paleoseismic investigation (shown by ●) and existing creep measurement sites (shown by ○). Historic M >5 earthquake epicenters (stars) and "stuckpatches" (bars labeled I to VI) inferred to represent potential fault rupture lengths (Oppenheimer et al., 1990).

CENTRAL CALAVERAS FAULT	
Paleoseismic and Creep Studies on the Central Calaveras fault	
WLA William Lettis & Associates, Inc.	Figure 3



Explanation

Central Calaveras fault

- Well Constrained, Certain
- Well Constrained, Approximate
- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

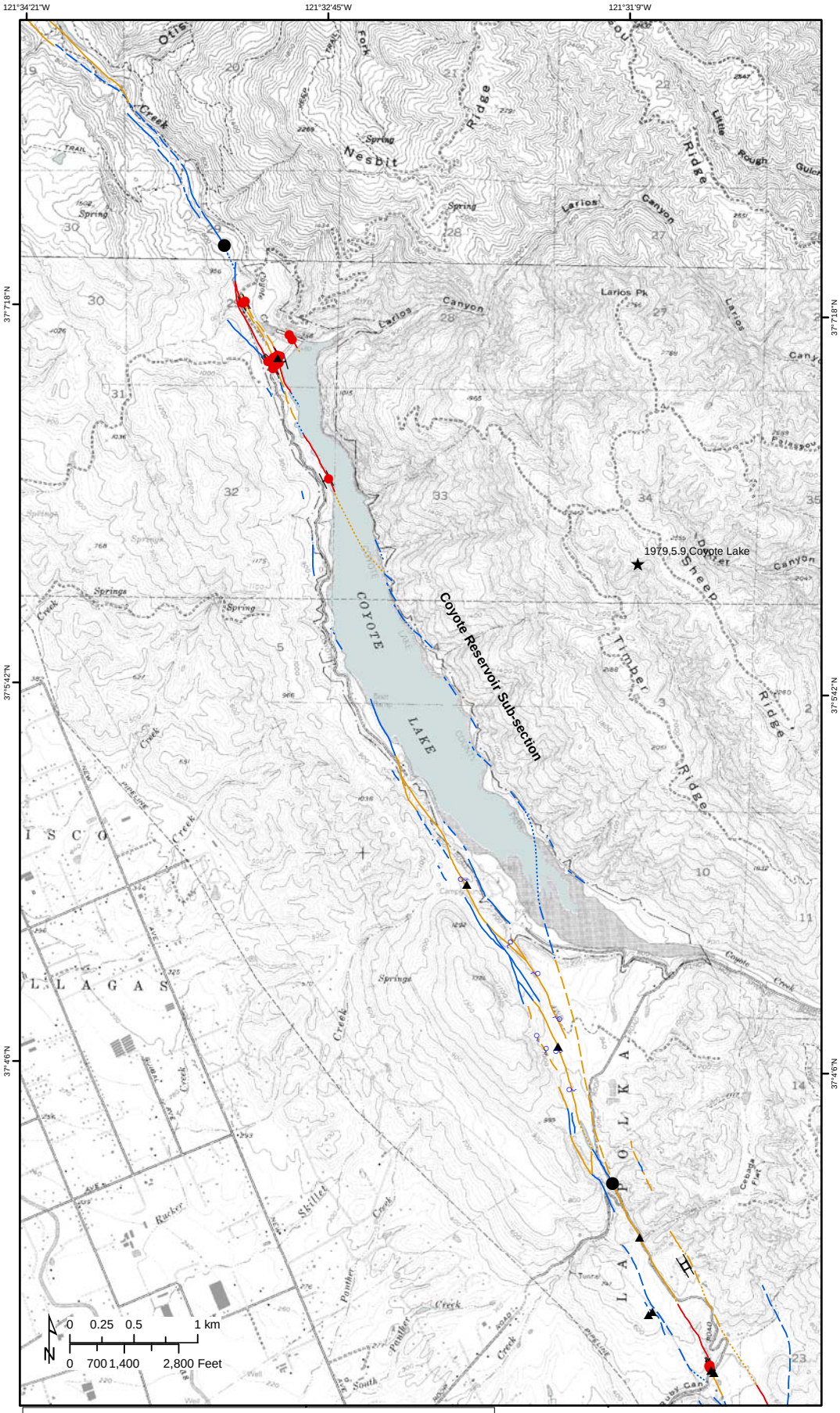
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
San Felipe and San Ysidro

WLA William Lettis & Associates, Inc.

Figure 4a



Explanation

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- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

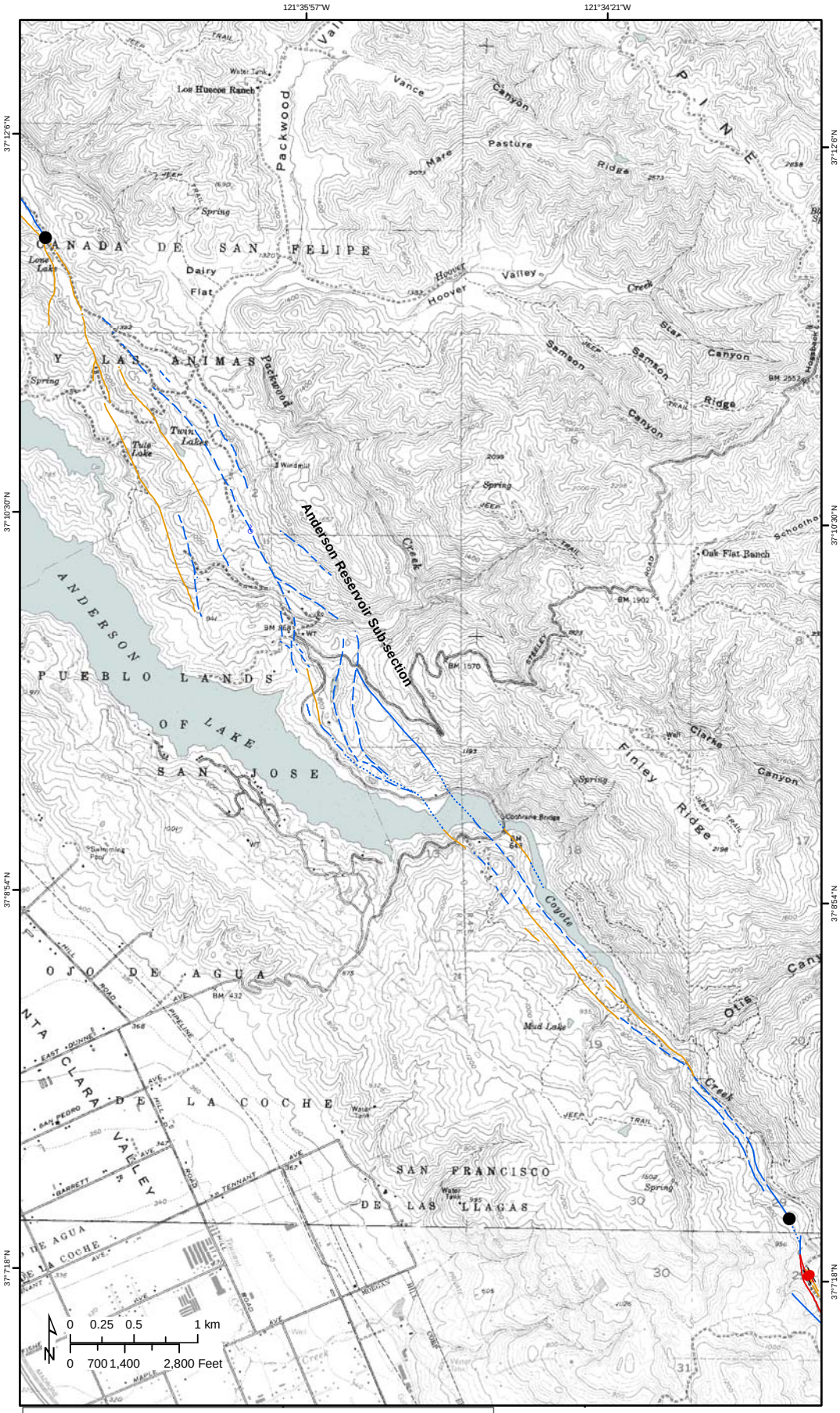
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Coyote Reservoir

WLA William Lettis & Associates, Inc.

Figure 4b



Explanation

Central Calaveras fault

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- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

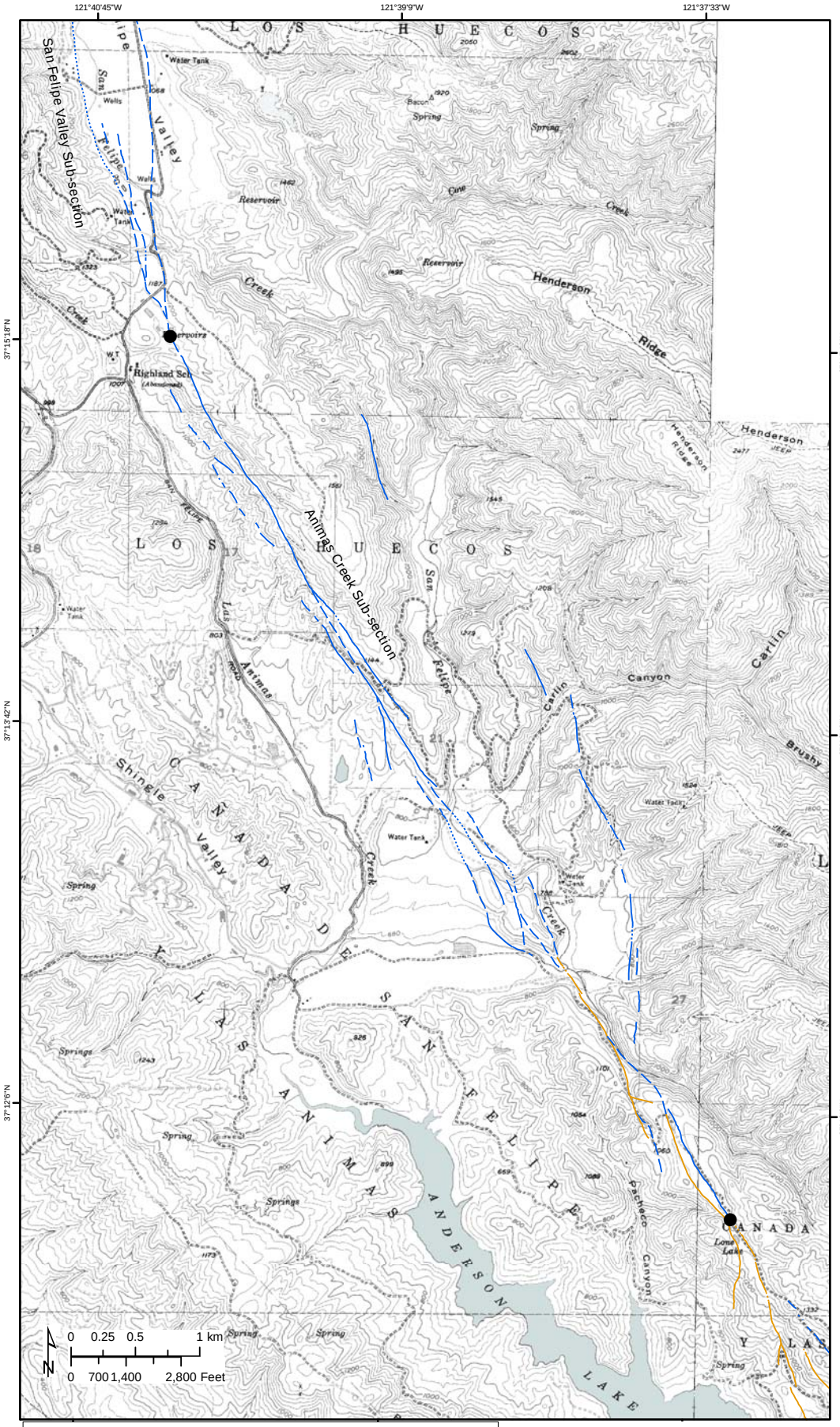
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Anderson Reservoir

WLA William Lettis & Associates, Inc.

Figure 4c



Explanation

Central Calaveras fault

- Well Constrained, Certain
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- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

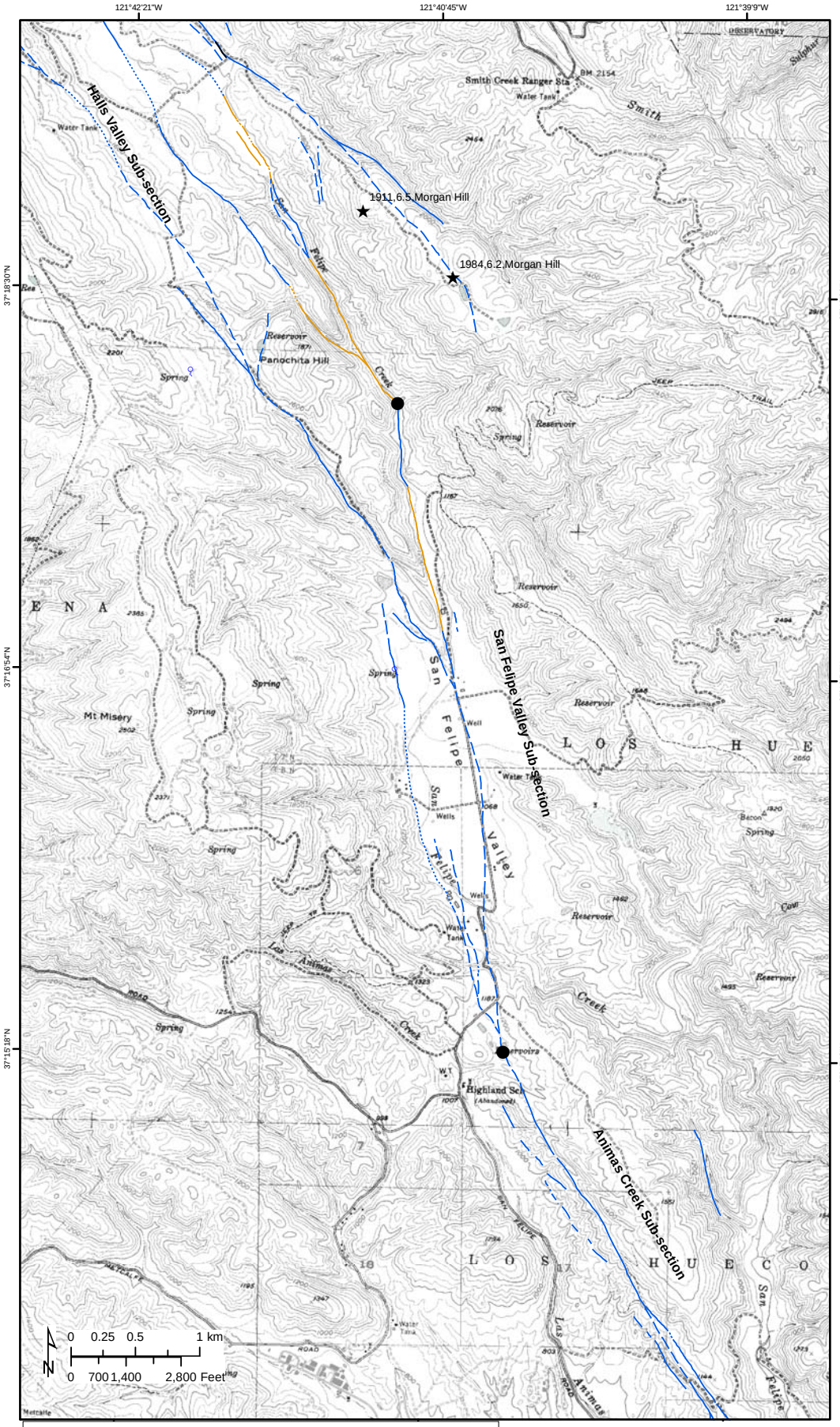
- Trench
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Animas Creek

WLA William Lettis & Associates, Inc.

Figure 4d



Explanation

Central Calaveras fault

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- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

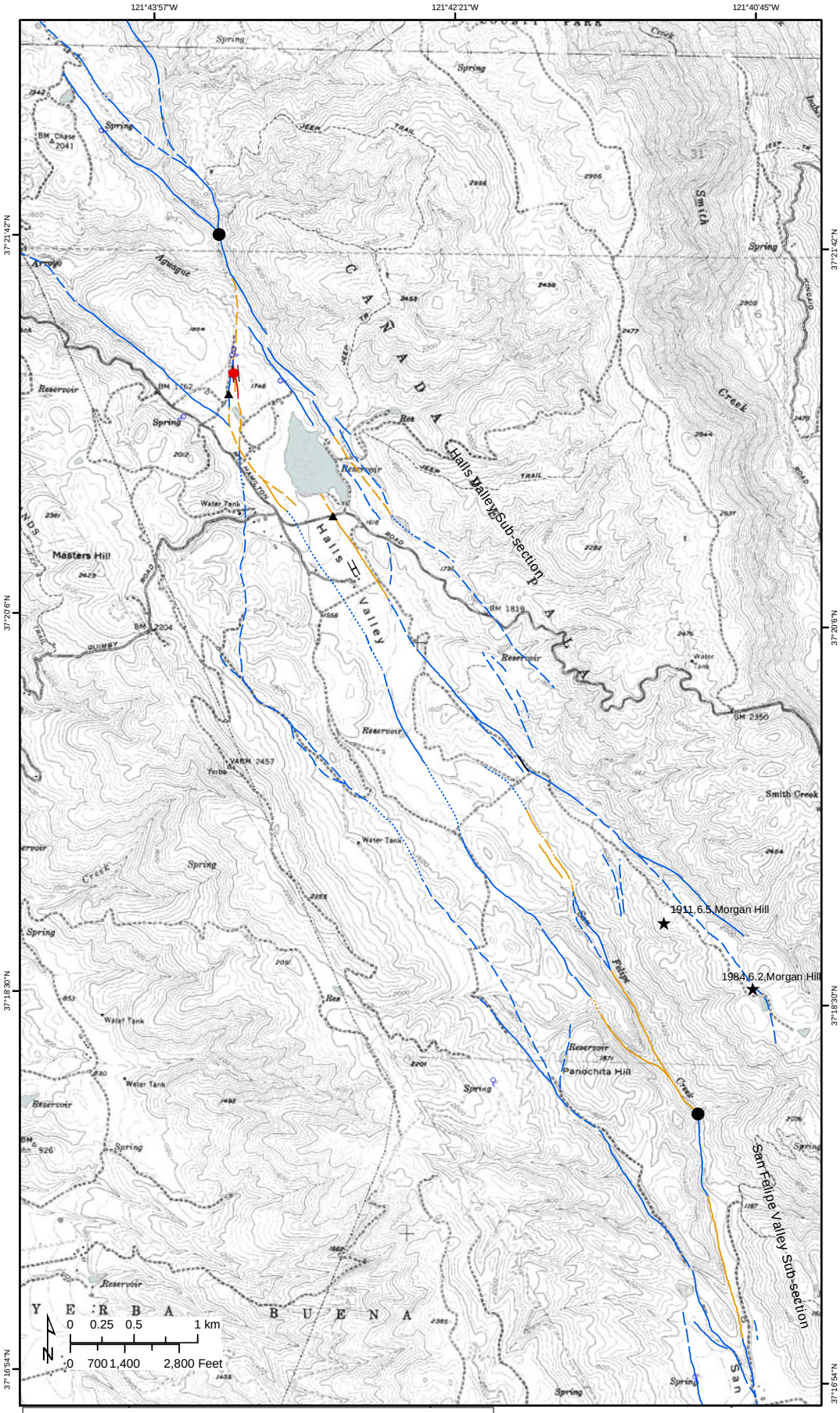
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
San Felipe Valley

WLA William Lettis & Associates, Inc.

Figure 4e



Explanation

Central Calaveras fault

- Well Constrained, Certain
- Well Constrained, Approximate
- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

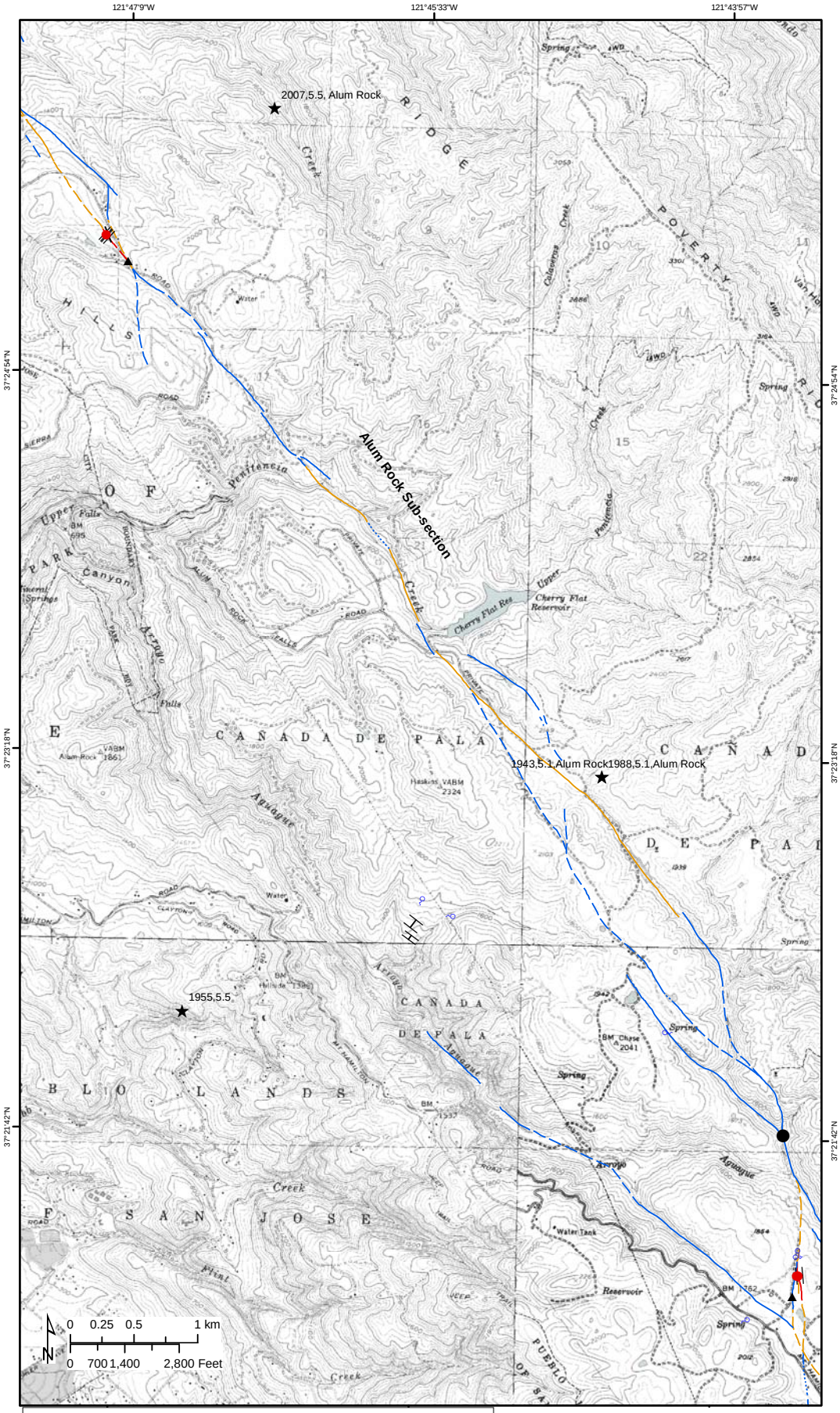
- Trench
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Halls Valley

WLA William Lettis & Associates, Inc.

Figure 4f



Explanation

Central Calaveras fault

- Well Constrained, Certain
- Well Constrained, Approximate
- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

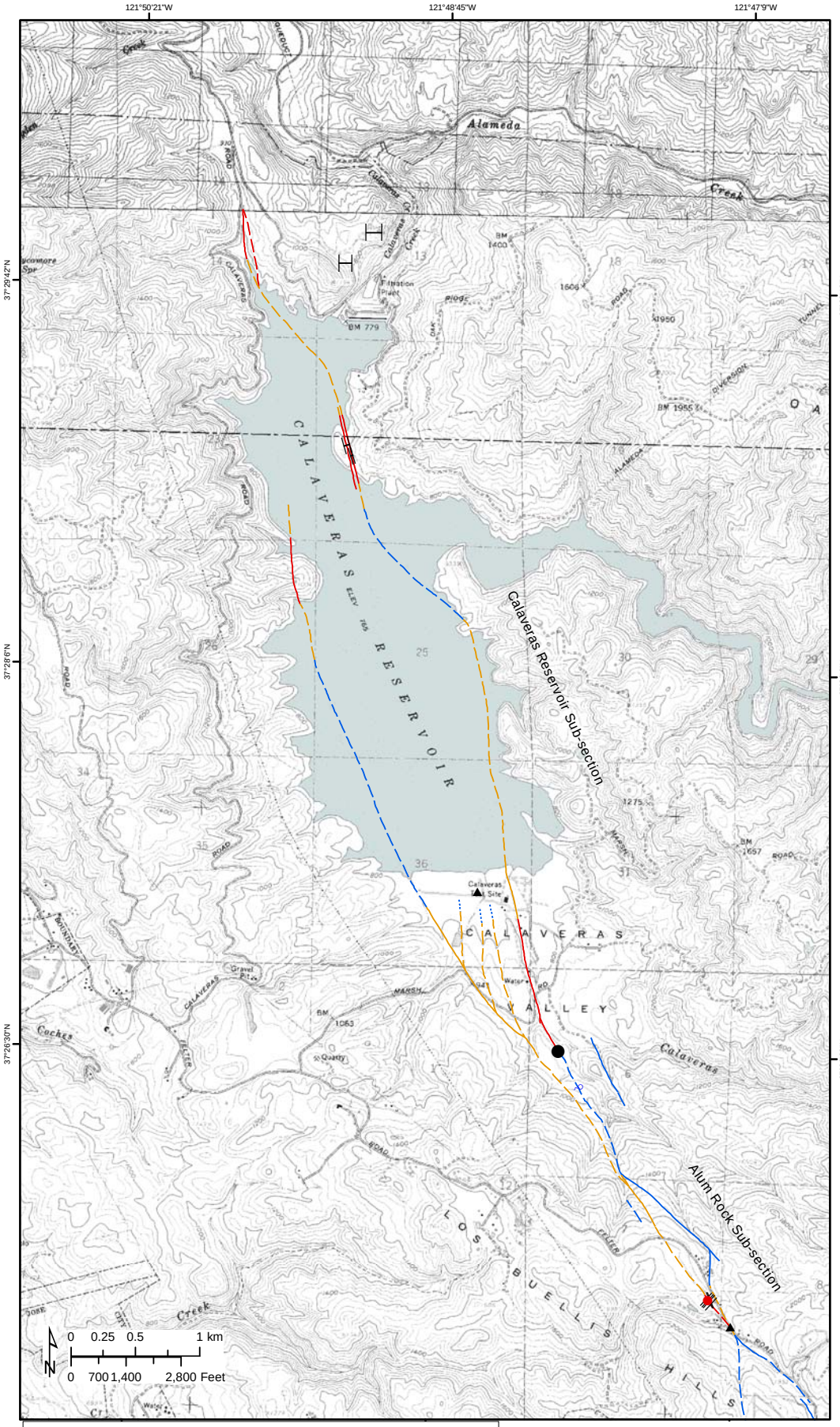
- **Trench**
- **Sub-sections**
- **Fault locales**
- **Creep locations**
- **Springs**
- **Historic seismicity**

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Alum Rock

WLA William Lettis & Associates, Inc.

Figure 4g



Explanation

Central Calaveras fault

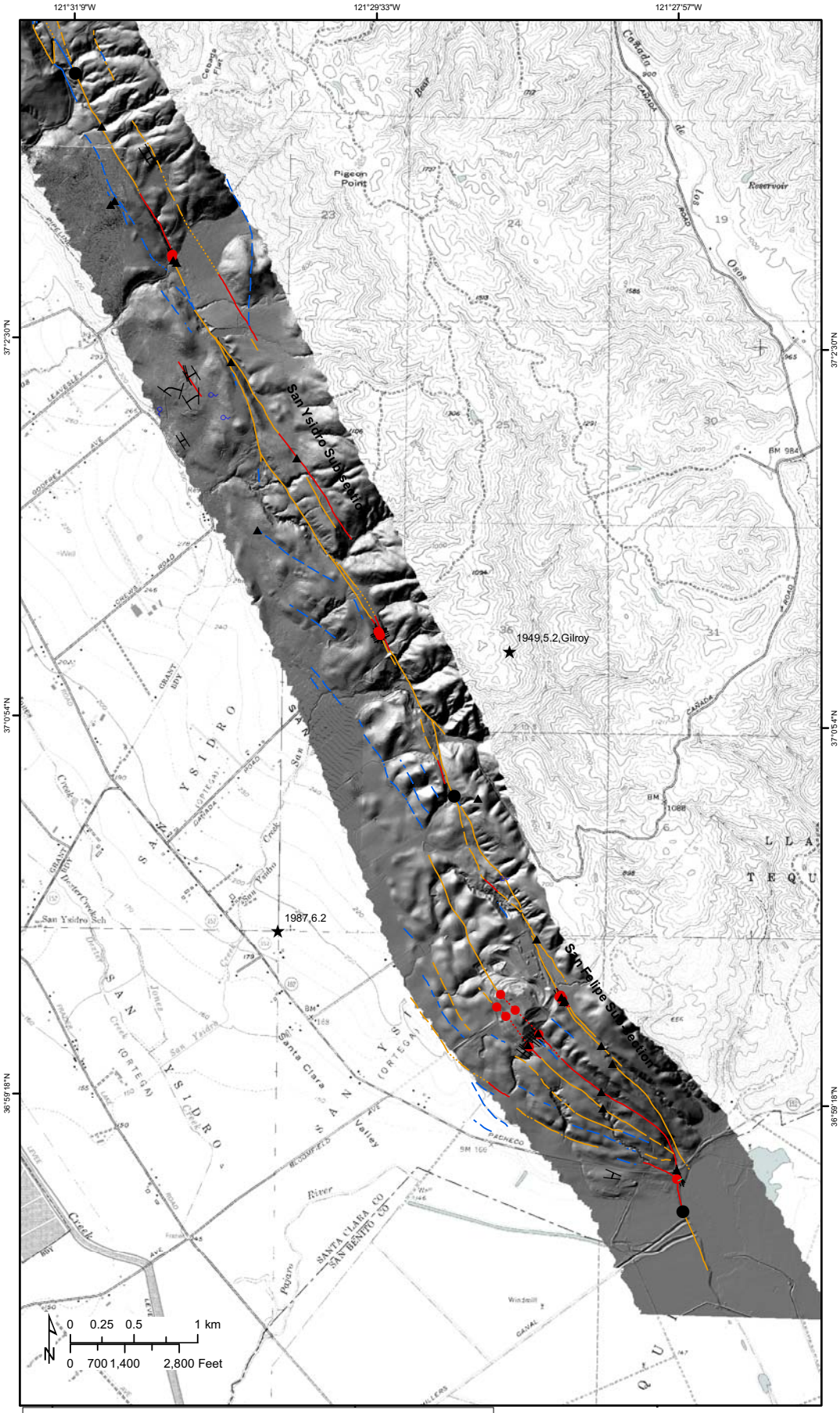
- Well Constrained, Certain
- Well Constrained, Approximate
- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed
- Trench
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Calaveras Reservoir

WLA William Lettis & Associates, Inc.

Figure 4h



Explanation

Central Calaveras fault

- Well Constrained, Certain
- Well Constrained, Approximate
- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
- Moderately Constrained, Concealed
- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

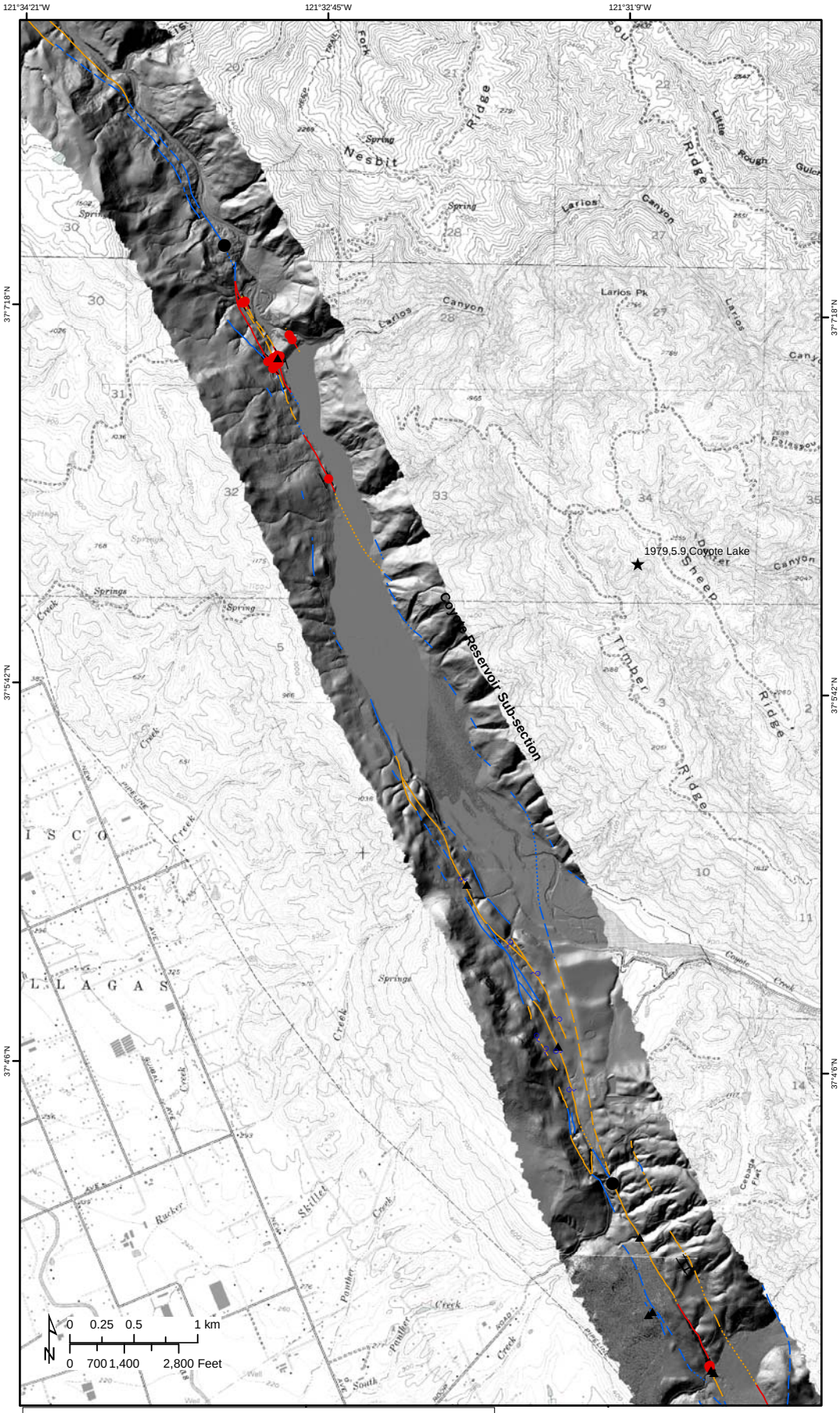
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
San Felipe and San Ysidro

WLA William Lettis & Associates, Inc.

Figure 5a



Explanation

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- Well Constrained, Concealed
- Moderately Constrained, Certain
- Moderately Constrained, Approximate
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- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

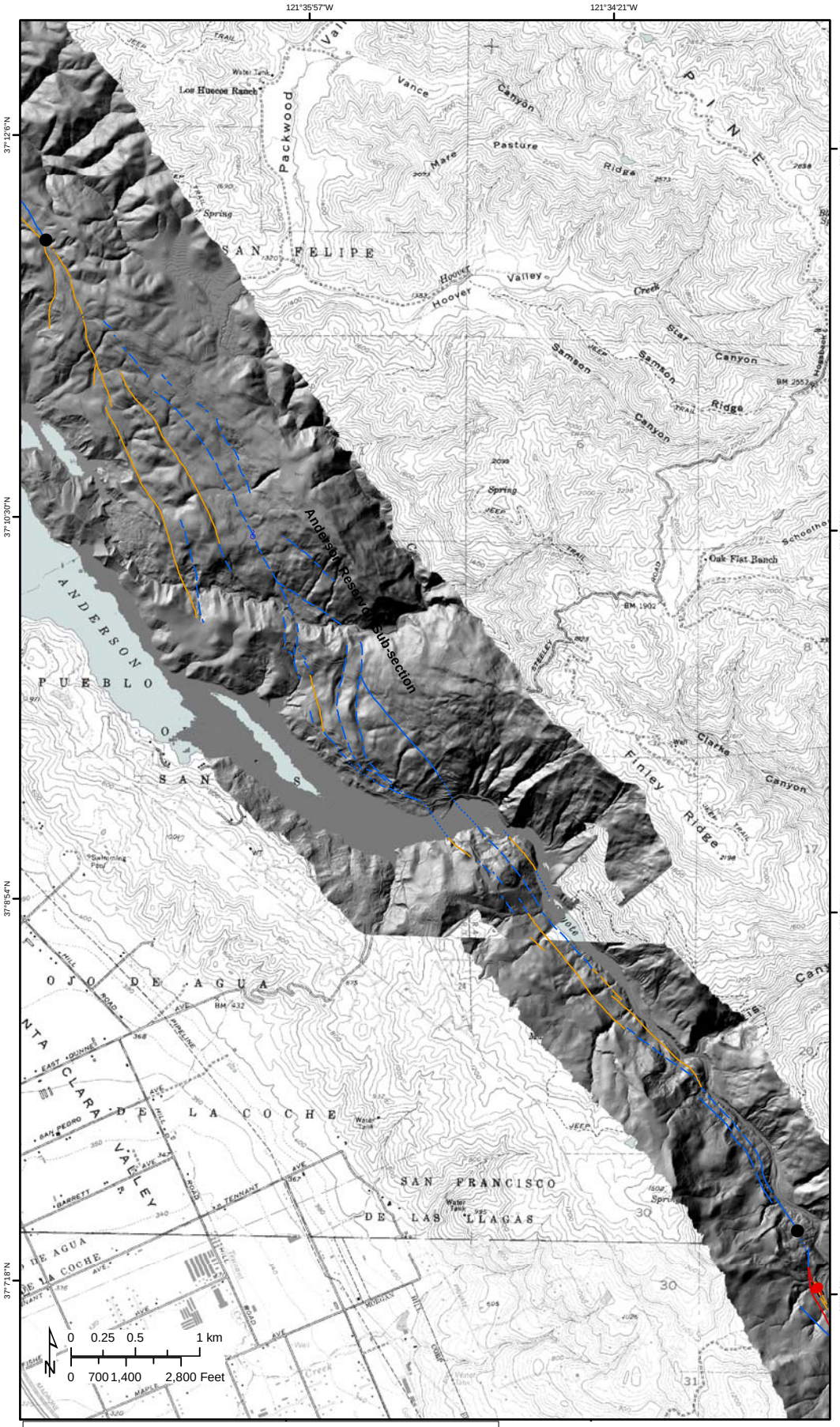
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Coyote Reservoir

WLA William Lettis & Associates, Inc.

Figure 5b



Explanation

Central Calaveras fault

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- Well Constrained, Concealed
- Moderately Constrained, Certain
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- Poorly Constrained, Certain
- Poorly Constrained, Approximate
- Poorly Constrained, Concealed

Trench

Sub-sections

Fault locales

Creep locations

Springs

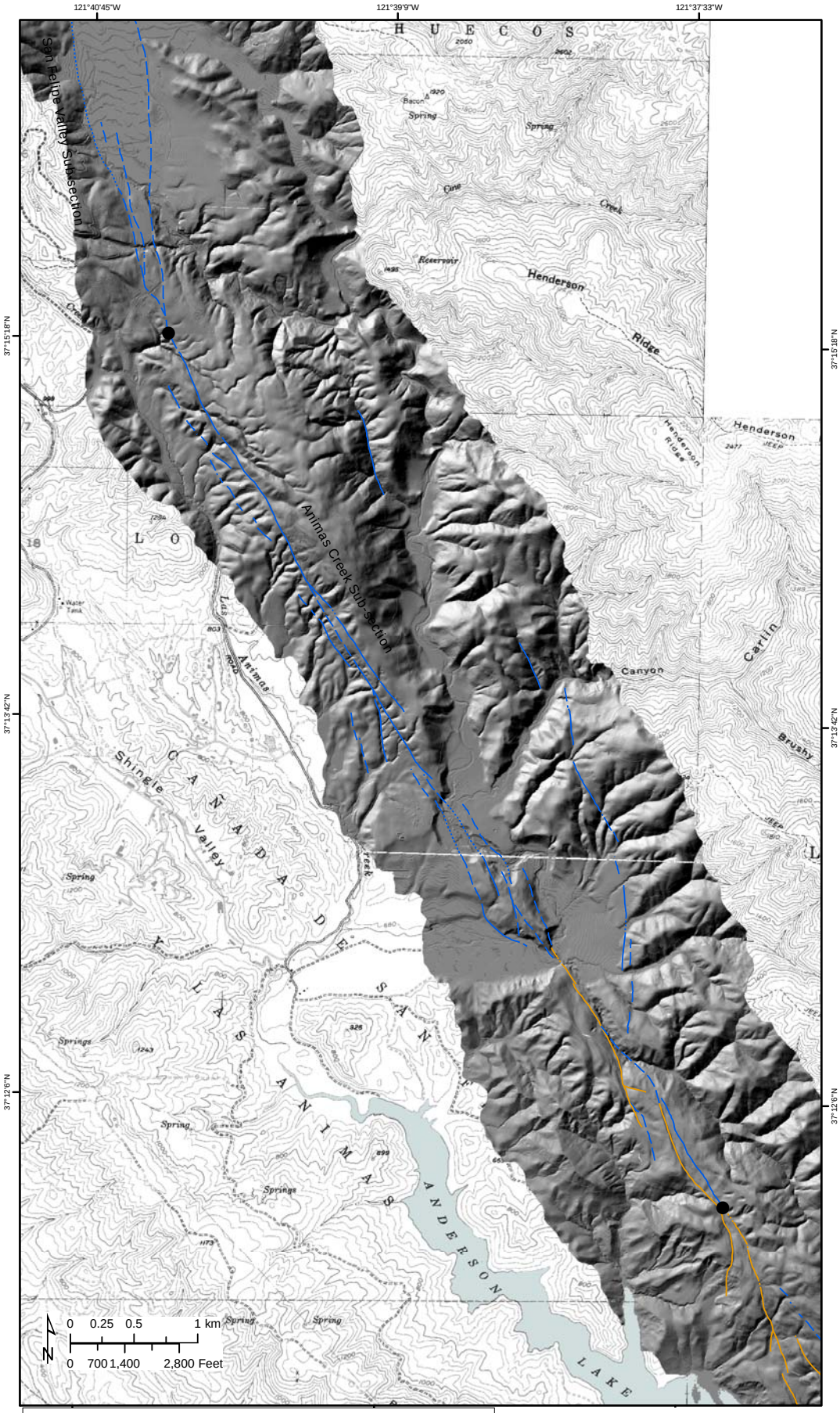
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Anderson Reservoir

WLA William Lettis & Associates, Inc.

Figure 5c



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- Poorly Constrained, Approximate
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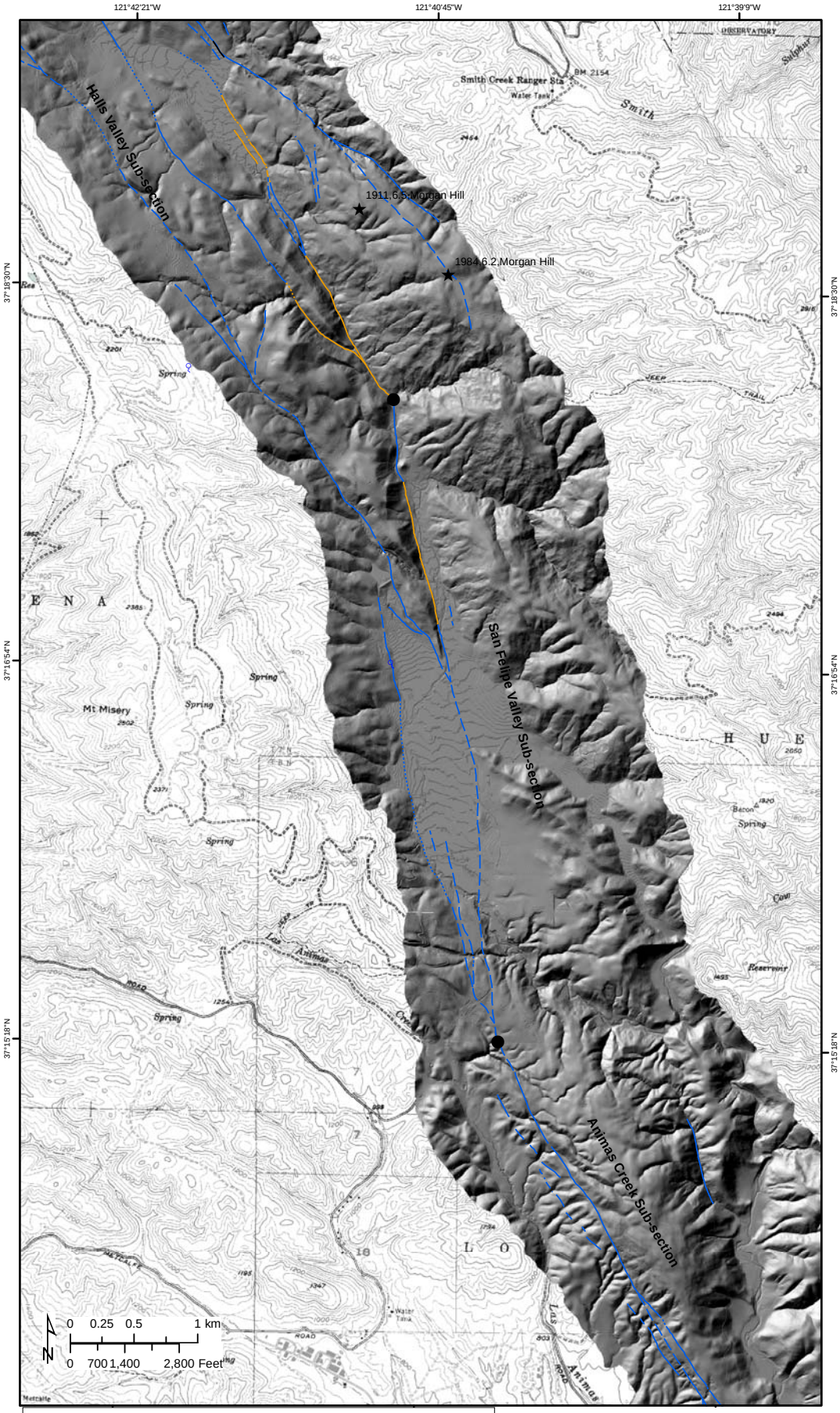
- Trench
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Animas Creek

WLA William Lettis & Associates, Inc.

Figure 4d



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Trench

Sub-sections

Fault locales

Creep locations

Springs

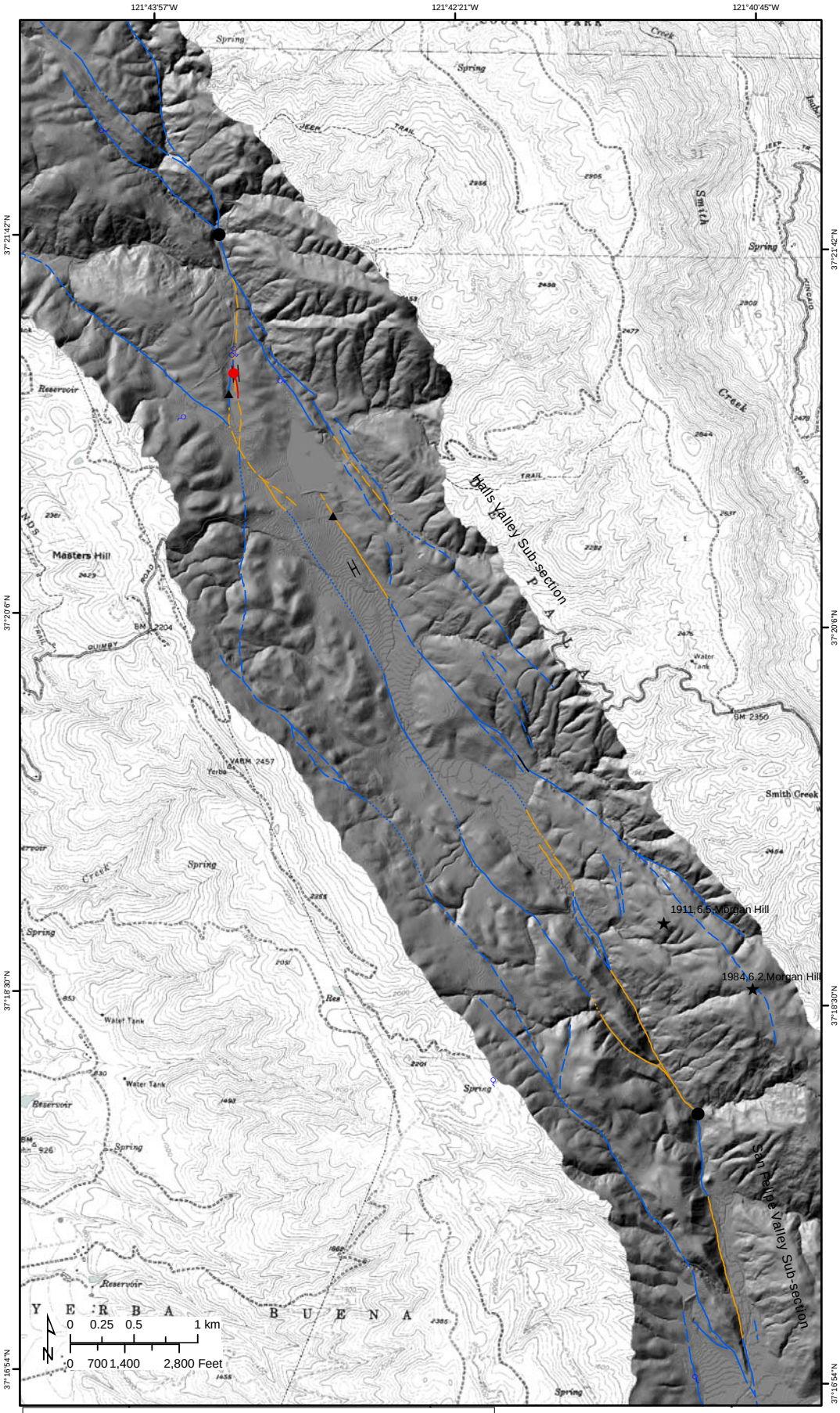
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
San Felipe Valley

WLA William Lettis & Associates, Inc.

Figure 4e



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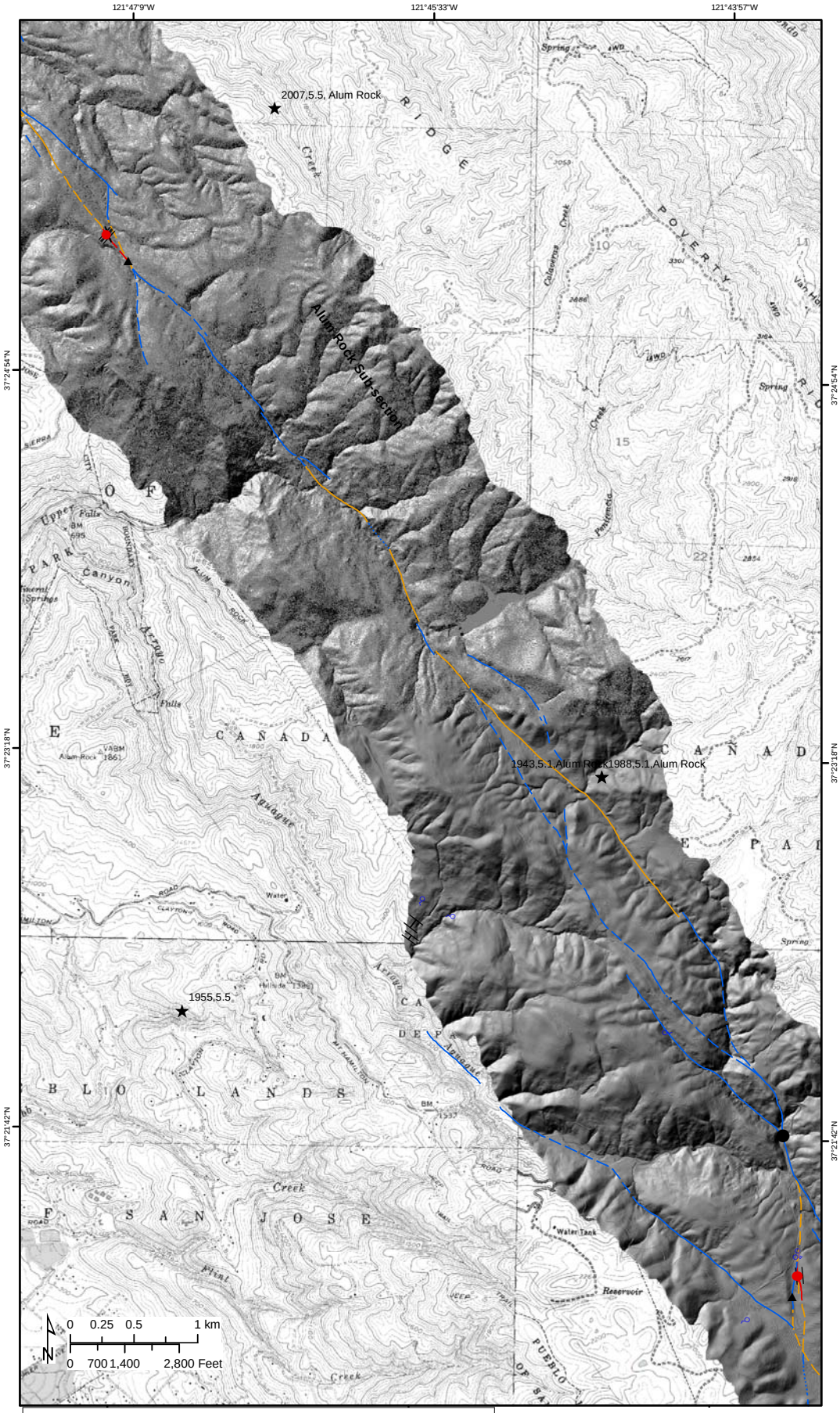
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Halls Valley

WLA William Lettis & Associates, Inc.

Figure 4f



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Trench

Sub-sections

Fault locales

Creep locations

Springs

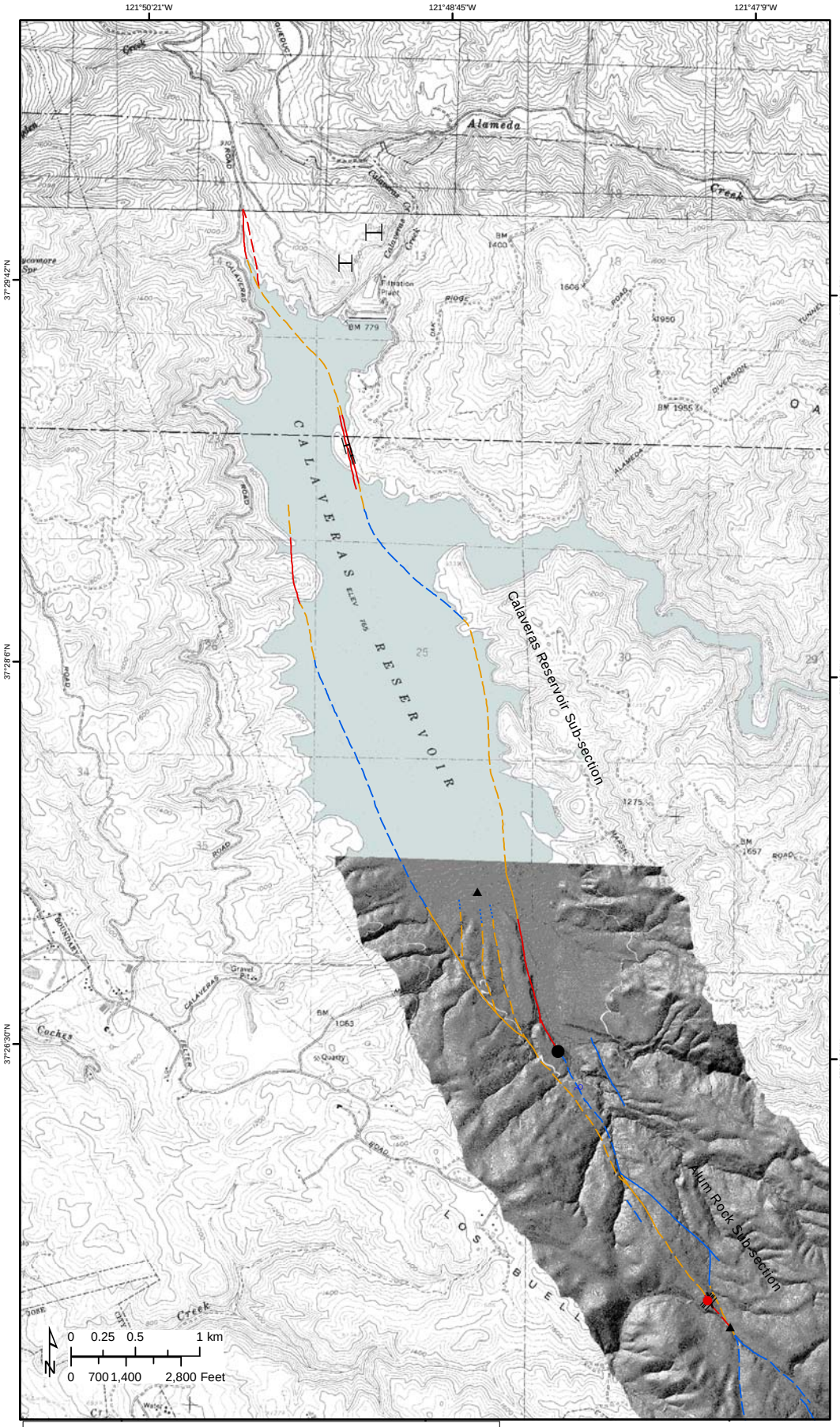
Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Alum Rock

WLA William Lettis & Associates, Inc.

Figure 4g



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- Trench
- Sub-sections
- Fault locales
- Creep locations
- Springs
- Historic seismicity

CENTRAL CALAVERAS FAULT MAP

Fault Map Sub-sections
Calaveras Reservoir

WLA William Lettis & Associates, Inc.

Figure 4h