Prepared in cooperation with the California Geological Survey and the San Luis Obispo County Planning and Building Department

Map of the Rinconada and Reliz Fault Zones, Salinas River Valley, California

By Lewis I. Rosenberg and Joseph C. Clark

Tightly folded Monterey Formation within the Rinconada Fault Zone exposed in the San Antonio Dam area, near Bradley, California.

Pamphlet to accompany

Scientific Investigations Map 3059

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Introduction

The Rinconada Fault and its related faults constitute a major structural element of the Salinas River valley, which is known regionally, and referred to herein, as the “Salinas Valley” (fig. 1). The Rinconada Fault extends 230 km from King City in the north to the Big Pine Fault in the south (figs. 1, 2). At the south end of the map area near Santa Margarita, the Rinconada Fault separates granitic and metamorphic crystalline rocks of the Salinian Block to the northeast from the subduction-zone assemblage of the Franciscan Complex to the southwest. Northwestward, the Rinconada Fault lies entirely within the Salinian Block and generally divides this region into two physiographically and structurally distinct areas, the Santa Lucia Range to the west and the Salinas Valley to the east (fig. 2).

The Reliz Fault, which continues as a right stepover from the Rinconada Fault, trends northwestward along the northeastern base of the Sierra de Salinas of the Santa Lucia Range and beyond for 60 km to the vicinity of Spreckels, where it is largely concealed. Aeromagnetic data suggest that the Reliz Fault continues northwestward another 25 km into Monterey Bay, where it aligns with a high-definition magnetic boundary (R.C. Jachens, U.S. Geological Survey, written commun., 2002).

Geomorphic evidence of late Quaternary movement along the Rinconada and Reliz Fault Zones has been documented by Tinsley (1975), Dibblee (1976, 1979), Hart (1976, 1985), and Klaus (1999). Although definitive geologic evidence of Holocene surface rupture has not been found on these faults, they were regarded as an earthquake source for the California Geological Survey [formerly, California Division of Mines and Geology]/U.S. Geological Survey (CGS/USGS) Probabilistic Seismic Hazards Assessment because of their postulated slip rate of 1±1 mm/yr and their calculated maximum magnitude of 7.3 (Petersen and others, 1996, p. A-7).

Except for published reports by Durham (1965, 1974), Dibblee (1976), and Hart (1976), most information on these faults is unpublished or is contained in theses, field trip guides, and other types of reports. Therefore, the main purpose of this project is to compile and synthesize this body of knowledge into a comprehensive report for the geologic community. This report follows the format of Dibblee (1976) and includes discussions of the sections of the Rinconada Fault and of the Reliz Fault, as well as their Neogene history and key localities. Accompanying this report is a geologic map database of the faults, key localities, and earthquake epicenters, in ESRI shapefile format.

Methods of Investigation

Preparation of the present report and compilation of the map included the following major tasks:

1. Reviewing pertinent literature related to the geology of the study area and surrounding region. Sources of data included government agencies (USGS, CGS, and Monterey and San Luis Obispo County Planning Departments), M.S. theses and Ph.D. dissertations, unpublished oil company (Chevron) mapping, and unpublished reports by geotechnical consultants.
2. Compiling a fault strip map that is based largely on previous work by Thorup (unpub. data, 1950), Durham (1964, 1968, 1970, 1974), Dibblee (1971a,b,c,d,e,f; 1974), Tinsley (1975), Hart (1976, 1985), Gribi (1979), Clark and others (2000), and Rosenberg (unpub. data, 2001), as well as on unpublished Chevron mapping and unpublished geotechnical-consultant reports.
3. Field checking critical localities along the Reliz and Rinconada Fault Zones from Santa Margarita northwestward to Spreckels, including detailed mapping at San Antonio Dam. The fieldwork was accomplished largely during a two-week period in April and May 2002.
4. Incorporating findings from unpublished aeromagnetic data of R.C. Jachens (USGS) to help delineate the buried trace of the Reliz Fault northwest of Spreckels.
5. Creating a geologic map database using ESRI ArcGIS 9.3 geographic information system (GIS) software. This database contains fault locations and activity status, key localities, and earthquake epicenters. Metadata files in both text format and “Frequently Asked Questions” hypertext format were prepared for each data set using ESRI ArcCatalog 9.3 software. The text files can be viewed with most word-processing programs, and the hypertext files can be viewed with most web browsers. These metadata comply with the Federal Geographic Data Committee Content Standard for Digital Geospatial Metadata.

Acknowledgments

We gratefully acknowledge the help of Russell W. Graymer and Earl E. Brabb (both USGS) for their interest in this study and their assistance in facilitating the work. We also thank William A. Bryant (CGS) and John C. Tinsley (USGS)

Figure 1. Map showing main physiographic and cultural features, Rinconada and Reliz Fault Zones, Salinas Valley, California. Shaded relief from U.S. Geological Survey 1:250,000-scale Digital Elevation Models: Bakersfield, 1994; Fresno, 1994; Los Angeles, 1994; Monterey, 1994; San Luis Obispo, 1994; Santa Maria, 1994.

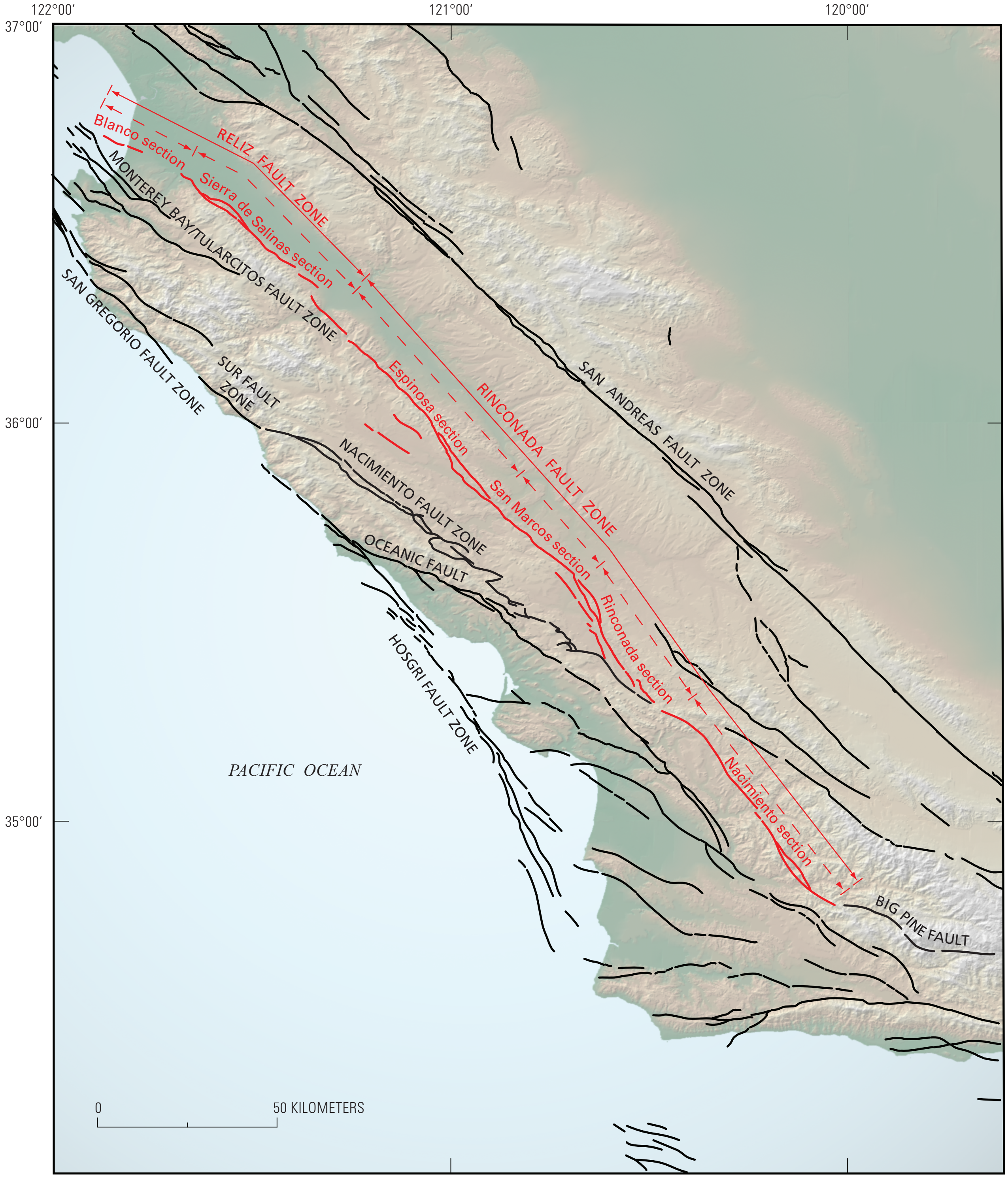


Figure 2. Map showing sections of Rinconada and Reliz Fault Zones (red lines), Salinas Valley, California, in relation to other faults in region (black lines). Faults modifed from California Geological Survey Quaternary Fault database (Bryant, 2005). Shaded relief from U.S. Geological Survey 1:250,000-scale Digital Elevation Models: Bakersfield, 1994; Fresno, 1994; Los Angeles, 1994; Monterey, 1994; San Luis Obispo, 1994; Santa Maria, 1994.

for their useful peer reviews and for joining us in the field to examine the Rinconada and Reliz Faults over the last several years. Editing by Taryn A. Lindquist (USGS) greatly improved the map and text.

Because much of the information in this study relies on unpublished data, we thank the following individuals for their generosity in sharing data or providing access to private land:

- Hans AbramsonWard (Geomatrix Consultants), who discussed his trenching of the Rinconada Fault for the Nacimiento Water Project with us.
- Barbara Bilyeu (Paso Robles Public Library), who provided a chronology of the hot springs and bathhouse development in the area of the Paso Robles Library/City Hall parking lot.
- Richard T. Gorman (Earth Systems Pacific), who showed us the Rinconada Fault exposure in the railroad cut near Paso Robles and provided copies of the trench logs from the fault study at Atascadero State Hospital.
- Christopher S. Hitchcock (William Lettis & Associates, Inc.), who contributed unpublished field notes from his site visit at Santa Ysabel Ranch.
- Michael F. Hoover (Chicago Grade Landfill), who invited Rosenberg to view the fault trenches at the Chicago Grade Landfill.
- Robert C. Jachens and Victoria Langenheim (both USGS), who provided preliminary aeromagnetic and gravity data for the Reliz Fault near Salinas.
- Robert Johnson (Monterey County Water Resources Agency), who granted us access for mapping at San Antonio Dam.
- John M.D. Kammer (GeoSolutions, Inc.), who invited us to examine fault trenches at Santa Ysabel Ranch.
- The late Richard R. Thorup (independent consulting geologist), who shared copies of his unpublished detailed geologic mapping for the critical juncture of the Rinconada and Reliz Faults.

The San Luis Obispo County Planning and Building Department provided financial support to Rosenberg for his work on this project. The CGS provided financial support to us for fieldwork in the Spreckels 7.5' quadrangle during 1998. The results of the present study were provided to the CGS, for use in their compilation efforts for the International Lithosphere Program's "World Map of Major Active Faults," and to the USGS, for their Quaternary fault and fold database of the United States (Rosenberg and Bryant, 2003a,b,c,d).

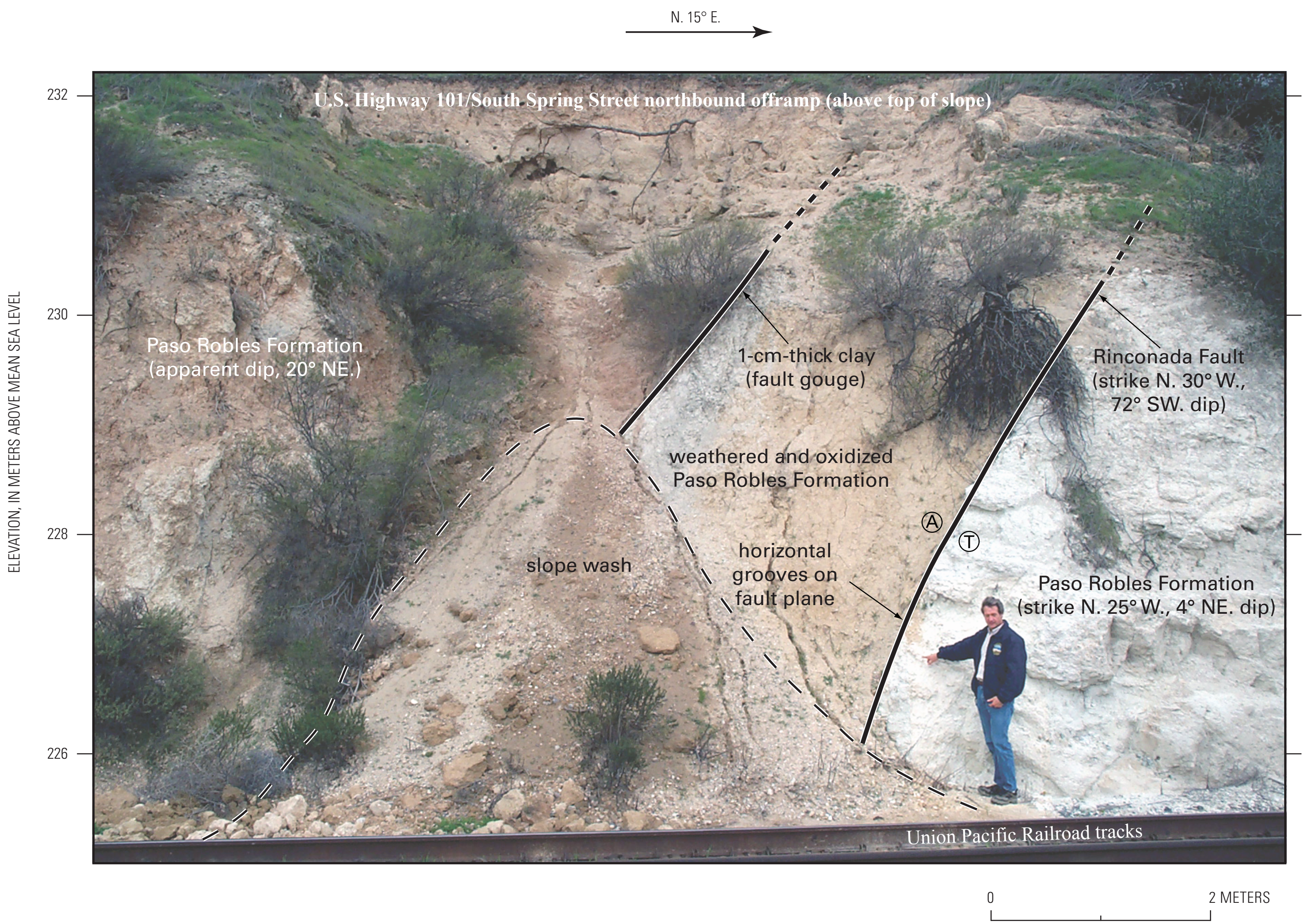
Sections of the Rinconada Fault Zone

General Statement

Dibblee's mapping (1976) indicated the near continuity and through-going nature of the Rinconada Fault Zone, which extends from the Big Pine Fault in the San Rafael Mountains northward to King City, and of the Reliz Fault, which continues northward to Salinas. Dibblee (1976) proposed that the Rinconada Fault Zone consists of the following five segments, from south to north: the Nacimiento segment, the Rinconada segment, the San Marcos segment, the Espinosa segment, and the Reliz Fault. However, for a number of reasons, we believe that the Reliz Fault is a separate fault, and so we discuss it separately. In addition, because of the lack of detailed mapping and evidence of Quaternary displacement along the Rinconada Fault south of Santa Margarita (the Nacimiento segment), we have omitted this segment from our discussion; instead, the present report focuses on the other segments of the Rinconada and Reliz Faults. We also use the term "section" rather than "segment:" Haller and others (1993, p. 2) defined a segmented fault as one that has been "studied in a paleoseismological sense (trenching and dating) with supporting geomorphological and geologic data (scarp morphology, stratigraphic control on times of faulting, geologic structures that may control physical segmentation, etc.);" therefore, owing to the lack of paleoseismological data for the Rinconada and Reliz Fault Zones, we choose to describe these faults as "sections" rather than "segments."

Rinconada Section

The Rinconada section, or "segment" as delineated by Dibblee (1976), of the Rinconada Fault extends from the Rinconada Mine near Santa Margarita northwestward to the complex intersection with the San Marcos section near Paso Robles. This fault separates Franciscan Complex basement on the southwest from Salinian basement on the northeast, in a zone of closely spaced, parallel to branching faults (Hart, 1976). Although much of the Rinconada section is concealed beneath alluvium of the Salinas River valley, it offsets Oligocene-Miocene sedimentary rocks (Vaqueros Formation and Monterey Formation) from the Pliocene-Pleistocene Paso Robles Formation. Locally, the fault is exposed in roadcuts and



EXPLANATION

Approximate contact

Fault—Dashed where location is inferred

Ⓐ Indicates strike-slip movement away from viewer

Ⓣ Indicates strike-slip movement toward viewer

Figure 3. Generalized log of railroad-cut exposure along Rinconada Fault Zone, Paso Robles, California (key locality 5, on map sheet). Exposure logged by E.E. Brabb, J.C. Clark, and L.I. Rosenberg, April 24, 2002. Photograph taken January 9, 2003.

streambanks, where steeply dipping beds crop out. Hart (1976) recognized geomorphic expression of this section in the form of aligned saddles, notches, drainages, and low scarps.

Indications of late Pleistocene or Holocene movement along the fault include sag(?) ponds near Fivemile Bridge in Santa Margarita. Although he indicated uncertainty in the origin of the ponds, Hart (1976, p. 35) also noted locally offset and clockwise-rotated drainages(?) and, from aerial photographs, faint lineaments in the area, which provided additional geomorphic evidence for a tectonic origin of the ponds. Quaternary movement is evident where the fault is well exposed in a railroad cut near the southern city limits of Paso Robles (fig. 3; see also, key locality 5, on map sheet). Here, the fault cuts the Paso Robles Formation, and horizontal grooves are exposed on both sides of the steeply dipping fault plane. Hart (1976) also noted similar horizontal grooves elsewhere along the Rinconada section, which suggests that strike-slip is the dominant movement along the Rinconada section.

Hot springs are spatially associated with the Rinconada section. On the basis of the alignment of these hot springs, Dibblee (1971e) mapped a “concealed, queried” north-striking branch of the Rinconada Fault that runs northward through the city of Paso Robles, just west of Spring Street. However, his later maps of the Paso Robles and the Templeton 7.5' quadrangles omitted this branch (Dibblee, 2004a,b, respectively), with no explanation as to why the fault was omitted. We include this fault herein because it aligns with the following features: ground-temperature-isotherm highs (Geothermal Surveys, Inc., unpub. data, 1983); aeromagnetic and Bouger gravity contours (Campion and others, 1983); existing geothermal springs and wells at the north end of Paso Robles; and the hot spring that erupted in the parking lot of the Paso Robles Library/City Hall during the 2003 San Simeon earthquake (Lubick, 2004).

The currently active hot spring in the parking lot of the Paso Robles Library/City Hall had long been a natural, free-flowing spring used by Native Americans, travelers, and wild animals (key locality 6, on map sheet). The first true bathhouse, which was built at the spring in 1864, was replaced by a new bathhouse built in 1888 at the same location (Bowler, 2003, p. 17, 37). The 1888 bathhouse burned to the ground in 1913 in what was suspected to have been an arson fire (Bowler, 2003, p. 73), and remnants of it have been found during excavations in the currently active spring (B. Bilyeu, Paso Robles Public Library, written commun., 2004). No written information exists at this time as to what happened to this spring after the bathhouse burned; oral histories recount that it was “plugged,” but it was not found when workers dug down after the 2003 earthquake to reseat the plug (B. Bilyeu, written commun., 2004). Thus, it is uncertain whether the currently active Library/City Hall hot spring is a reactivated existing spring or is flow from a new source.

Another area of geothermal springs aligns with the Rinconada section at the Santa Ysabel Ranch (key locality 4, on map sheet). Waring (1915, p. 77) correctly recognized that these springs are associated with faulting and noted, “Santa Ysabel Springs may be of artesian origin, but their position, 50 feet above the river valley, suggests that faulting has here taken place and allows the escape of water from a moderate depth.” The principal spring, whose temperature was measured at 36°C (96°F) (Waring, 1915, p. 77), started in a canyon about 1.2 km east of the Salinas River and flowed across the meadow to the river. Two other springs of warm sulfur water, which lay nearby on either side of the largest, were measured at about the same temperature. Farther up the canyon were two “white sulfur” or cold mineral-water springs that had a measured temperature of 15°C (59°F) (Rowland, 2004).

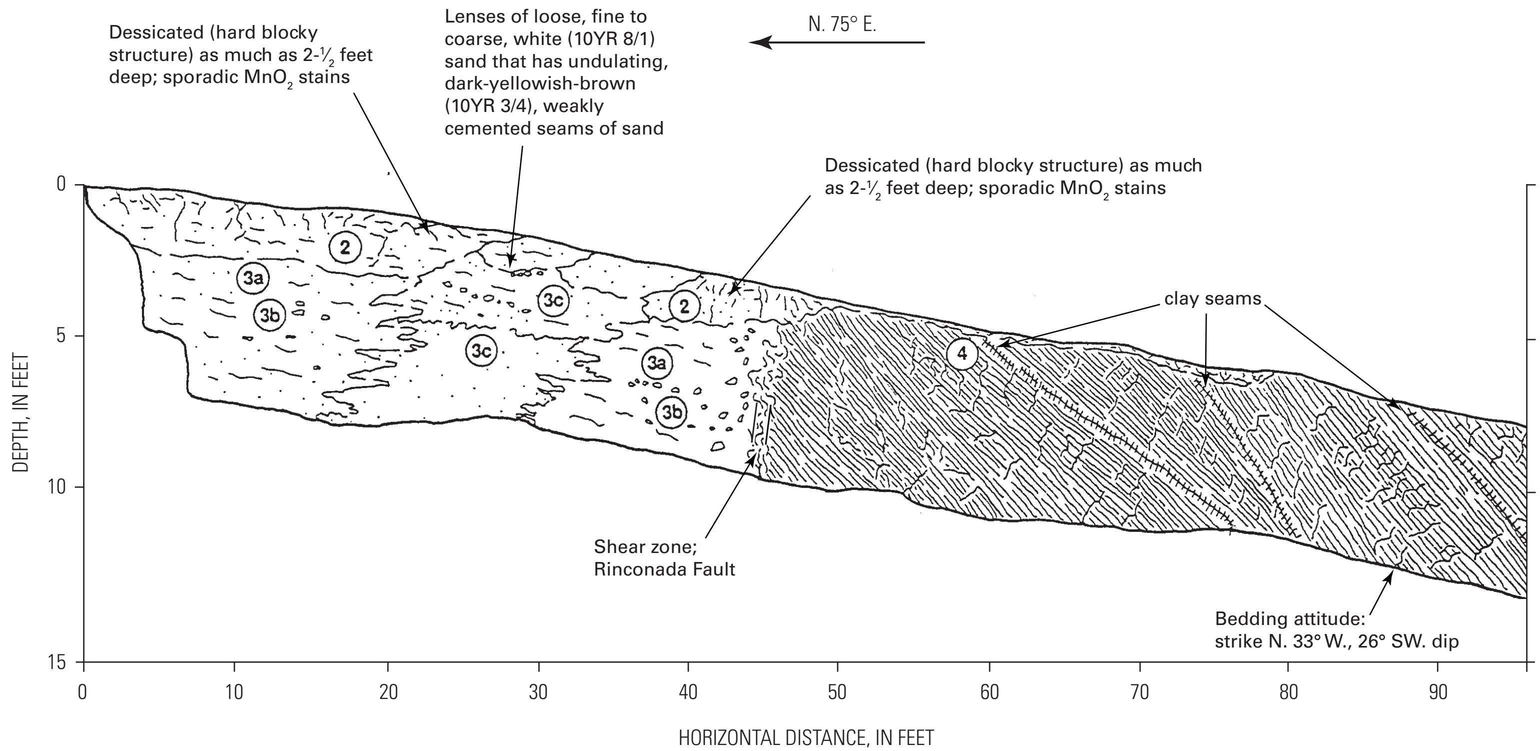
In their evaluation of geothermal resources in the Paso Robles area, Campion and others (1983), citing well logs and gravity and magnetic data, proposed an alternative (not fault related) explanation for the Paso Robles area hot springs, that Tertiary sedimentary rocks lapping against a bedrock high forced the water to the surface. In addition, Campion and others (1983) noted the high boron content of the springs, which they believed was derived either from sands below the Paso Robles Formation or from faults that serve as conduits for deeper aquifers. On the other hand, the alignment of both the hot-spring-fed channel at Santa Ysabel Ranch and the hot spring at Paso Robles Library/City Hall parking lot with the Rinconada section of the Rinconada Fault provides additional evidence for a fault-related origin of these hydrothermal waters.

Trenching Studies

Four trenching studies (Atascadero State Hospital, 2 trenches; Nacimiento Water Project, 3 test pits; Chicago Grade Landfill, 2 trenches; Santa Ysabel Ranch, 16 trenches) have been performed on the Rinconada section of the Rinconada Fault. These studies were not detailed paleoseismology studies, but, instead, their focus was to locate faults at potential land-development sites; however, these excavations do provide additional geologic evidence for late Quaternary movement on the Rinconada Fault.

Atascadero State Hospital

The first study (Pacific Geoscience, Inc., unpub. data, 1990) involved trenching across the fault just north of Atascadero State Hospital (key locality 1, on map sheet; see also, fig. 4). Trench T-2 revealed a near-vertical contact between the Paso Robles Formation and highly fractured and shattered rocks of the Monterey Formation. Trench T-1



EXPLANATION

Arrows show relative direction of fault movement

Shear zone

(2) **Weathered (C horizon) Paso Robles Formation:**
Yellowish-brown (10YR 5/4) to yellow (10YR 7/8), dry to moist, very stiff, fine- to coarse-grained, sandy clay. Sand-to-clay proportions vary. Trace gravels, ¼ in to ½ in diameter, of Monterey Formation; subrounded to angular clasts. Dessicated at surface to depths of as much as 2-½ ft

(3a) & (3b) **Paso Robles Formation:**
Predominantly yellow (10YR 7/8), moist to very moist, fine- to coarse-grained, sandy clay; contains scattered stringers of gravel from Monterey Formation. Interstratified with minor light-olive-brown (2.5Y 5/4), fine- to medium-grained, clayey sand

(3c) **Paso Robles Formation:**
Reddish-yellow (7.5YR 6/8), clayey, medium- to coarse-grained sand that has common lenses of loose, white (10YR 8/1) to gray (10YR 5/1), medium- to coarse-grained sand. Lenses contain few undulating seams of partially cemented, dark-yellowish-brown (10YR 3/4), medium- to coarse-grained sand

(4) **Monterey Formation:**
Thin-bedded siliceous shale and minor claystone. Beds 2 to 4 in thick; highly fractured or shattered. Common clay seams along bedding planes. Color of beds range from very pale brown (10YR 8/3) to gray (10YR 5/1)

Figure 4. Log of exploratory trench T-2, Atascadero State Hospital, Atascadero, California (key locality 1, on map sheet). From Pacific Geoscience, Inc. (unpub. data, 1990); trench logged by Paul Marshall and R.T. Gorman, June 20 and 25, 1990.

encountered “vertical linear fractures filled with loose, fine to coarse white sand,” along strike with the contact between the Paso Robles Formation and the Monterey Formation visible in trench T-2. Pacific Geoscience interpreted the Paso Robles Formation/Monterey Formation contact as an erosional feature; however, we interpret the contact to be the Rinconada Fault herein, owing to its near-vertical orientation, as well as the presence of sheared rocks in the Monterey Formation and its parallel orientation to the sand-filled linear fractures. Pacific Geoscience did not estimate the recurrence interval, slip rate, or timing of the most recent paleoevent.

Nacimiento Water Project

In the second study (Geomatrix Consultants, Inc., unpub. data, 2007), three test pits were dug along the trace of the Rinconada section of the Rinconada Fault (key locality 2, on map sheet; see also, fig. 5), and evidence of faulting was found in all three test pits (RC-UF-6T, RC-UF-7T, RC-UF-11T). Test pits RC-UF-7T and RC-UF-11T revealed several, steeply dipping to near-vertical faults in a zone approximately 2 m wide that separates the Paso Robles Formation and the Monterey Formation. Within this zone of faulting, rocks of the Paso Robles Formation and the Monterey Formation are crushed and altered to pervasively sheared, highly plastic, clayey fault gouge. However, the faults in these two test pits do not cut the overlying colluvium. Test pit RC-UF-6T exposed a zone of secondary faulting that consists of a 1-m-wide fault zone filled with sheared clay and rotated clasts of Monterey Formation. The contact between the Monterey Formation and the overlying colluvium in test pit RC-UF-6T is irregular, having as much as about a meter of relief. Geomatrix Consultants did not estimate the age of the colluvium; thus, the most recent episode of faulting is not well constrained.

Chicago Grade Landfill

In the third study (GeoSyntec Consultants, Inc., unpub. data, 2002), field mapping revealed several fault splays exposed in a landfill borrow pit (key locality 3, on map sheet; see also, fig. 6). These splays, which are subsidiary branches of the Rinconada section, have poor geomorphic expression. During this study, trenching of these splays showed that two faults (F1, F2) exposed in Chicago Grade Landfill trench T-1 clearly offset the lower part of the Paso Robles Formation. Fault F1 shows as much as 1.2 m of apparent west-side-up vertical separation of a stage II+ to stage III carbonate seam (estimated age, 100–500 ka). Fault F2 offsets the Paso Robles Formation by approximately 30 cm (west side up). A mudstone unit that also has an estimated minimum age of 50–100 ka, on the basis of stage II+ to stage III carbonate development, truncates fault F2 and, therefore, postdates F2 faulting. GeoSyntec Consultants used these apparent carbonate ages to establish “seismic horizons” for the most recent paleoevents for faults F1 and F2 of 100–500 ka and 50–100 ka, respectively. They did not estimate recurrence intervals or slip rates.

These apparent carbonate-age determinations by Rice and Moody (unpub. data, 2002) were based on correlation with soils in the southwestern United States (Gile and others, 1966; Machette, 1985), and not with another soil chronosequence of the Chicago Grade Landfill. It should be noted that pedogenic carbonate horizons are actually paleosols, and, although estimates of the time needed to form the paleosols may yield a relative age, the absolute age is imprecise.

Santa Ysabel Ranch

The fourth study (GeoSolutions, Inc., unpub. data, 2000) was performed for a residential subdivision at the Santa Ysabel Ranch (key locality 4, on map sheet; see also, figs. 7, 8). Trenching exposed the Rinconada Fault in 11 out of 16 trenches logged. In the trenches, the Paso Robles Formation is clearly offset along nearly vertical faults in a zone that ranges from 3 to 60 m wide; however, the amount of horizontal displacement is unknown. Faults exposed in the trenches align with topographic breaks in slope, with cut stream-terrace deposits, and possibly with colluvium (figs. 7, 8). In addition, more than one episode of movement is suggested by features that we interpret as fissure fill or colluvial wedges; this combination of features suggests Holocene displacement along the Rinconada section of the Rinconada Fault. GeoSolutions did not offer estimates of the recurrence interval, slip rate, or timing of most recent paleoevent.

San Marcos Section

Taliaferro (1941, p. 153) described the fault that extends northwestward from Paso Robles to the San Antonio Valley as the “San Marcos Fault.” The San Marcos section or “segment” of Dibblee (1976) extends from Paso Robles northwest to near the San Antonio Reservoir, where it joins the Espinosa section. As mapped by Dibblee (1971a,b,e; 1976), the San Marcos section is characterized by two main, parallel, right-lateral strike-slip faults bordered by tight, northwest-trending folds, as well as reverse or thrust faults.

At the overlook on the south side of San Antonio Dam, a steeply dipping shear zone, which strikes N. 35° W. and is as much as 40 m wide, separates the Monterey Formation to the northeast from the Santa Margarita Sandstone to the southwest (key locality 7, on map sheet; see also, fig. 9). Here, fossiliferous beds of the Santa Margarita Sandstone dip 86° to the southwest. This shear zone, which we interpret as a main strand of the San Marcos section, aligns with both the San Antonio Thrust Fault to the southeast and the mapped Espinosa section trace to the northwest and, thus, marks the division between the San Marcos and Espinosa sections of the Rinconada Fault Zone.

Durham (1965) reported as much as 17.5 km of dextral offset of the middle to upper Miocene Santa Margarita Sandstone and the Pliocene Pancho Rico Formation along the San Marcos section. Dibblee (1976) and Hart (1985) noted along the San Marcos section geomorphic evidence of right-lateral late Quaternary movement such as linear and right-deflected drainages, saddles, benches, and weak tonal features on aerial photographs. Hart (1985), however, observed that the San Marcos section lacks ephemeral, fault-produced geomorphic features that are indicative of Holocene offset.

Espinosa Section

In his regional mapping of the Salinas Valley, Dibblee noted "the presence of a major fault zone alined between the San Marcos and Reliz Faults" (Dibblee, 1976, p. 25). Hill and Dibblee (1953) named this fault as the "Reliz Canyon/San Marcos Fault." Both the Santa Cruz (Jennings and Strand, 1958) and San Luis Obispo (Jennings, 1959) 1° × 2° quadrangle maps show the part of the fault zone between San Antonio Reservoir and Monroe Canyon as the "Espinosa Fault." Dibblee (1976) proposed that the Espinosa Fault of Jennings and Strand (1958) and Jennings (1959) is a part of the Rinconada Fault Zone and called this structure the Espinosa "segment" of the Rinconada Fault Zone.

The Espinosa section or "segment" of Dibblee (1976), which extends from near San Antonio Reservoir northwest through the San Antonio Hills to near Monroe Canyon, about 12 km west of King City, consists of predominantly right-lateral strike-slip faults (Gribi, 1963; Dibblee, 1976; Hart, 1985). Indications of late Pleistocene movement along the Espinosa section include right-lateral offset of streams near Espinosa Canyon (Dibblee, 1976, p. 29–30). Hart (1985) identified truncated older alluvium and associated alluvial fan surfaces between Loeber and Glau Canyons (key locality 8, on map sheet). On the basis of moderate preservation of alluvial fan surfaces and soil-profile development, Hart (1985) estimated that the offset surfaces are late Pleistocene. The youngest faulted unit is alluvium, and its probable late Pleistocene age is based on preservation of constructional-surface morphology and soil-profile development (Hart, 1985). Klaus (1999, p. 75–76) also noted about 3 to 6 m of postdepositional vertical offset of a postulated 400- to 300-ka surface along the Espinosa section (key locality 9, on map sheet).

Other Faults Possibly Related to the Rinconada Fault Zone

Other workers have mapped several faults that are possibly related to the Rinconada Fault Zone (for example, Durham, 1974; Gribi, 1979). These faults include the Jolon, Mincey, and Paraiso Faults, and the Los Lobos and San Antonio Thrust Faults.

Jolon Fault

The Jolon Fault is exposed about 3 km northwest of Jolon, where it juxtaposes the Monterey Formation against the Paso Robles Formation. As with other faults of the Rinconada Fault Zone, both the nomenclature and the interpreted structural significance of the Jolon Fault are complicated. Clark (1929) first mapped this fault and named it the "San Antonio Fault." Jennings (1959), who used the name "Jolon Fault," presumably to avoid confusion with the San Antonio Thrust Fault to the south, showed the fault extending as far south as the Nacimiento River, where it merged with the San Marcos Fault. Locally, the San Antonio Thrust Fault overrides the Jolon Fault (Durham, 1968, plate 3), indicating that the San Antonio Thrust Fault is younger than the Jolon Fault.

Durham (1968) described the Jolon Fault as a system of anastomosing faults that form the boundary between two distinct stratigraphic sections and suggested that the regional relations of these strata indicate at least 18 km of right-lateral displacement along the fault. Durham (1974) also considered the Jolon Fault to be part of a larger structural feature, which he referred to as the "Jolon-Rinconada Fault Zone," that extends for more than 80 km from the San Antonio Valley southeastward to the western margin of the La Panza Range (Durham, 1974). In contrast, Dibblee (1976), because of the lack of direct field, subsurface, or geophysical evidence, believed the Jolon Fault to be a minor northeast-dipping reverse fault that dies out just north of Jolon.

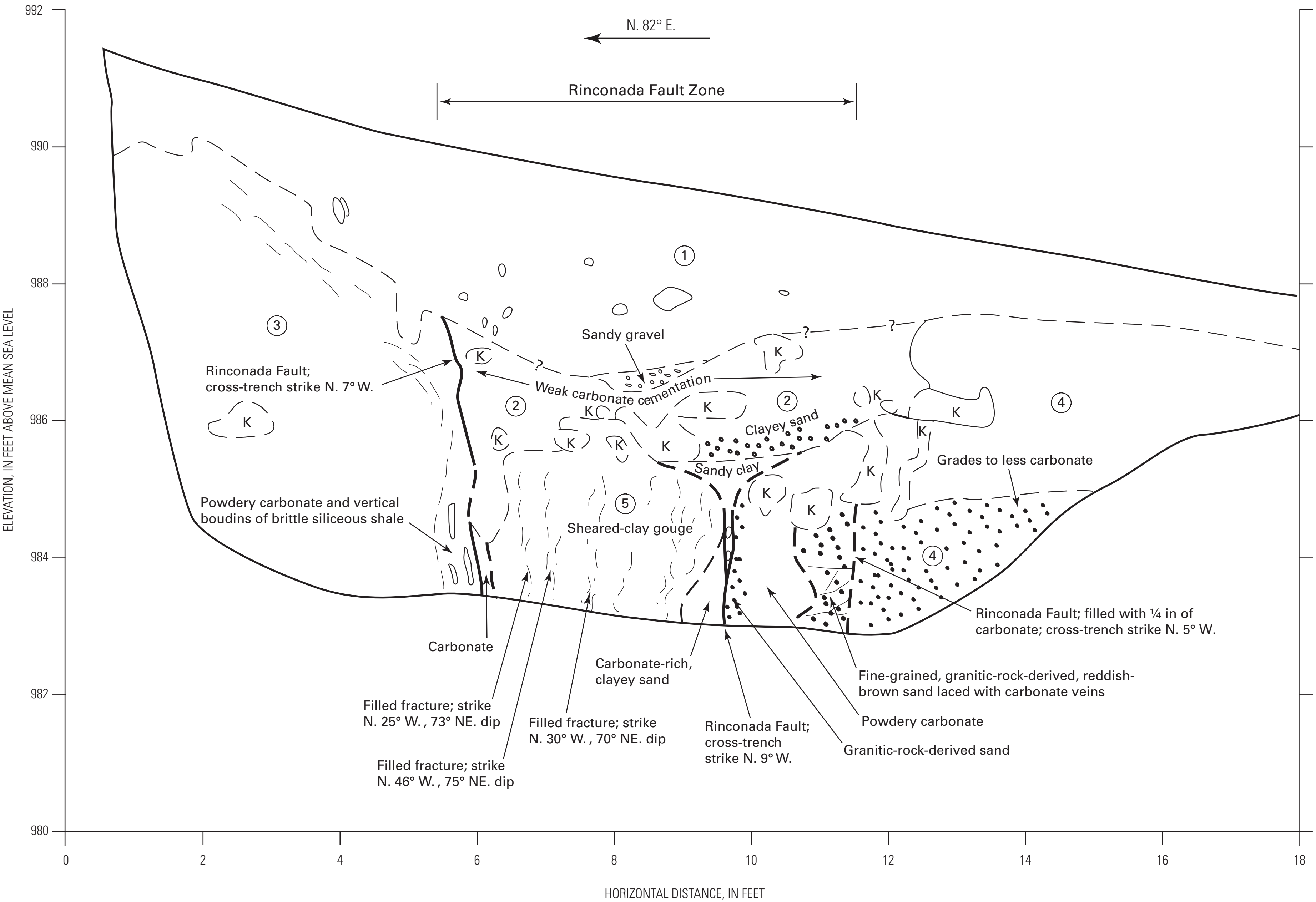


Figure 5. Log of test pit RC-UF-7T, Rocky Canyon Road, Atascadero, California (key locality 2, on map sheet). From Geomatrix Consultants, Inc. (unpub. data, 2007); trench logged by Hans AbramsonWard, July 12, 2006. See next page for explanation of units and symbols.

EXPLANATION

Fault—Solid line where accurately located; dashed where approximately located

Contact—Solid line where accurately located; dashed where approximately located; queried where identity or existence may be questionable

Area of sheared-clay fault gouge

Krotovina

Colluvium

① Soft to medium-stiff clay and sand, very dark grayish-brown (10YR 3/2), dry, medium plasticity, vesicular; sand is fine- to coarse-grained and includes scattered fine gravel derived from the Monterey Formation; includes sandy gravel channel at base

② Medium-stiff, dark grayish-brown sandy clay (10YR 4/2), dry, includes scattered pebbles and coarse sand, slight carbonate development; includes local layers of clayey sand; grades to pale brown (10YR 6/3) downsection and in fissure fills

Monterey Formation

③ Very pale brown (10YR 8/2) to white where fresh, brownish-yellow (10YR 6/8) where oxidized, siliceous siltstone and porcellanite; very closely fractured, hard, strong, fresh to moderately weathered

Paso Robles Formation

④ Dense to very dense sand, olive (5Y 5/3) and pale yellow (2.5Y 7/4) to brownish-yellow (10YR 6/8) where oxidized; dry, thickly bedded, pervasive carbonate development in upper 3 feet; weakly cemented, carbonate-filled fissures $\frac{1}{32}$- to 1-inch thick; coarse-grained, granitic-rock-derived sand that has few rounded to subrounded pebbles derived from the Monterey Formation

Fault gouge

⑤ Stiff clay, olive (5Y 5/3), slightly moist, high plasticity, pervasively sheared; shear planes commonly lined with carbonate; fractures and shears are polished and locally show subhorizontal slickenlines

Figure 5—Continued.

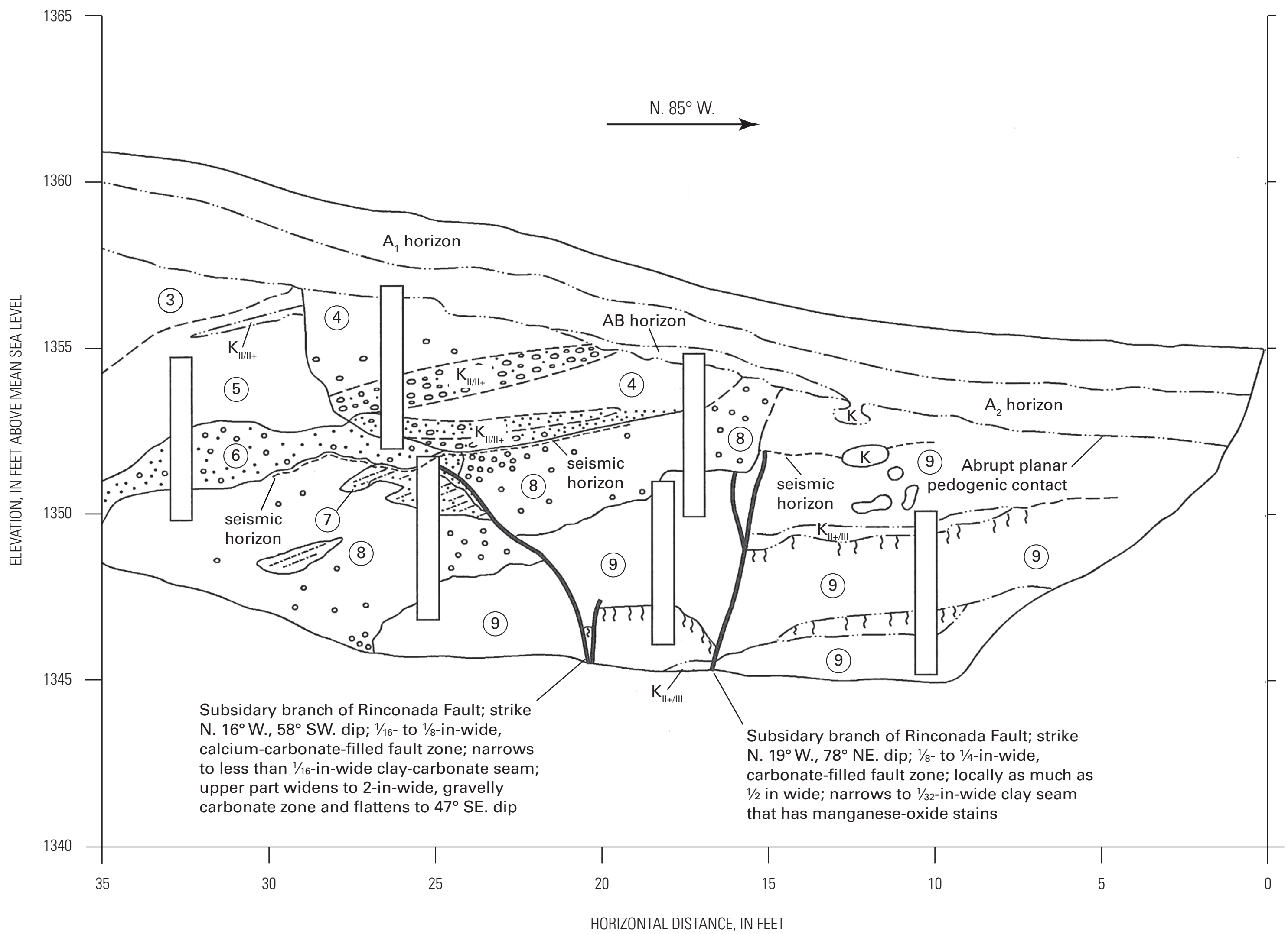


Figure 6. Extract from log of exploratory trench T-1, Chicago Grade Landfill, Templeton, California (key locality 3, on map sheet). From GeoSyntec Consultants (unpub. data, 2002); trench logged by L.D. Gurrola, April 2002. See next page for explanation of units and symbols.

EXPLANATION

Fault—Approximately located

Bedding contact—Solid where location is accurate; dashed where location is approximate

Pedogenic contact

Seismic horizon

Paleosol

(6) **Unit number**

K **Krotovina**

Stage II+ to III pedogenic carbonate

Trench shore

A-Horizon Soil

Undifferentiated subhorizons; dark-brown to very dark-grayish-brown, gravelly, coarse-grained sandy, silty clay; dry; low density to low-medium density; common very fine to fine vesicular pores, locally few vesicular pores; angular to subangular fine gravel clasts; common to few fine roots; abrupt and planar to gradational contact with underlying pedogenic units

Paso Robles Formation

(3) White to slightly brownish-white, clayey, fine gravelly to very coarse-grained sandy silt to silty, very coarse-grained sand; dry; dense to medium dense, massive; few diffuse, vertical, ¼- to ?-in-wide, anastomosing fractures filled with carbonate; weak to moderate carbonate cementation; contains thin to thick, discontinuous carbonate stains on clasts; clasts and matrix locally engulfed in carbonate; diffuse erosional contact with underlying unit 5

(4) White to grayish-white, slightly cobbly, matrix-supported, very coarse-grained, sandy gravel conglomerate; well graded, subangular to subrounded clasts of Monterey Formation, chert, and volcanic rocks; dry; hard to very hard, dense to very dense, moderate to strong carbonate cementation; mostly very thick carbonate rinds to fully engulfed clasts and matrix plugging; locally approaching laminar structure; massive bedding to diffusely bedded; diffuse to distinct erosional scours; erosional contact with underlying unit 8. Base contains thin bed of gray-white, fine gravelly to very coarse-grained sand, weak to very weak carbonate cementation; poorly graded; loose, dense, dry, planar erosional basal contact with underlying unit 8

(5) Brown to pale-brownish-white, slightly clayey, fine-grained sandy silt that contains scattered fine gravel; locally grades to fine gravelly to fine- to coarse-grained silty sand containing some clay; massive; discontinuous planar to undulatory fractures less than about 1/32- to ?-in-wide, filled with carbonate; few anastomosing root burrows; thin stains to thick, discontinuous carbonate rinds on gravel clasts; dry; undulatory and locally gradational contact with underlying unit 6

(6) White to slightly brownish-white, well-graded, silty to very coarse-grained sandy gravel conglomerate; massive to diffusely bedded; normal grading to coarse-grained sandy silt; subangular to subrounded fine-grained gravel; matrix-supported, having clast-supported zones; weak to strong carbonate cementation; thin continuous to thick discontinuous carbonate rinds on clasts; localized carbonate-engulfed matrix; dense to very dense; dry; erosional contact with underlying unit 7 and unit 8

(7) Pale-brown to slightly brownish-white, silty, very coarse- to very fine-grained sand that has some fine gravel; well-graded, normal grading; weak to strong carbonate cementation; carbonate stains on grains, to thin, continuous rinds on grains and gravel clasts; locally carbonate-engulfed matrix; medium dense; dry; erosional contact with underlying unit 8

(8) White to pale-gray, slightly cobbly, matrix supported, very coarse-grained sandy gravel conglomerate; subrounded to subangular clasts; common Monterey Formation and chert clasts and scattered volcanic-rock clasts; dry; hard, dense; slightly strong to moderate carbonate cementation, to locally weak, thin, continuous to very thick, discontinuous carbonate rinds on grains and clasts, to carbonate-engulfed clasts; carbonate rinds approaching laminar pedogenic carbonate; massive bedding to lensoidal; diffuse to distinct erosional channel scours; undulatory erosional contact with underlying unit 9

(9) Orangeish-brown to pale-orangeish-brown to locally pale-orangeish-white, clayey silt to slightly clayey silt; poorly graded, blocky fabric; low to medium density, firm, massive, diffuse beds of slightly clayey, very coarse-grained sandy silt; less than 1/32-in-wide planar fractures filled with disseminated carbonate, to 1/32- to ?-in-wide discontinuous to continuous carbonate zones deposited on discontinuous to continuous, thin clay skins; few spherical pods 1- to 2-in-diameter and 2- to 6-in-thick, white laminar carbonate bands; hard to very hard cementation; contains many krotovina that are backfilled with A-horizon soil

Figure 6—Continued.

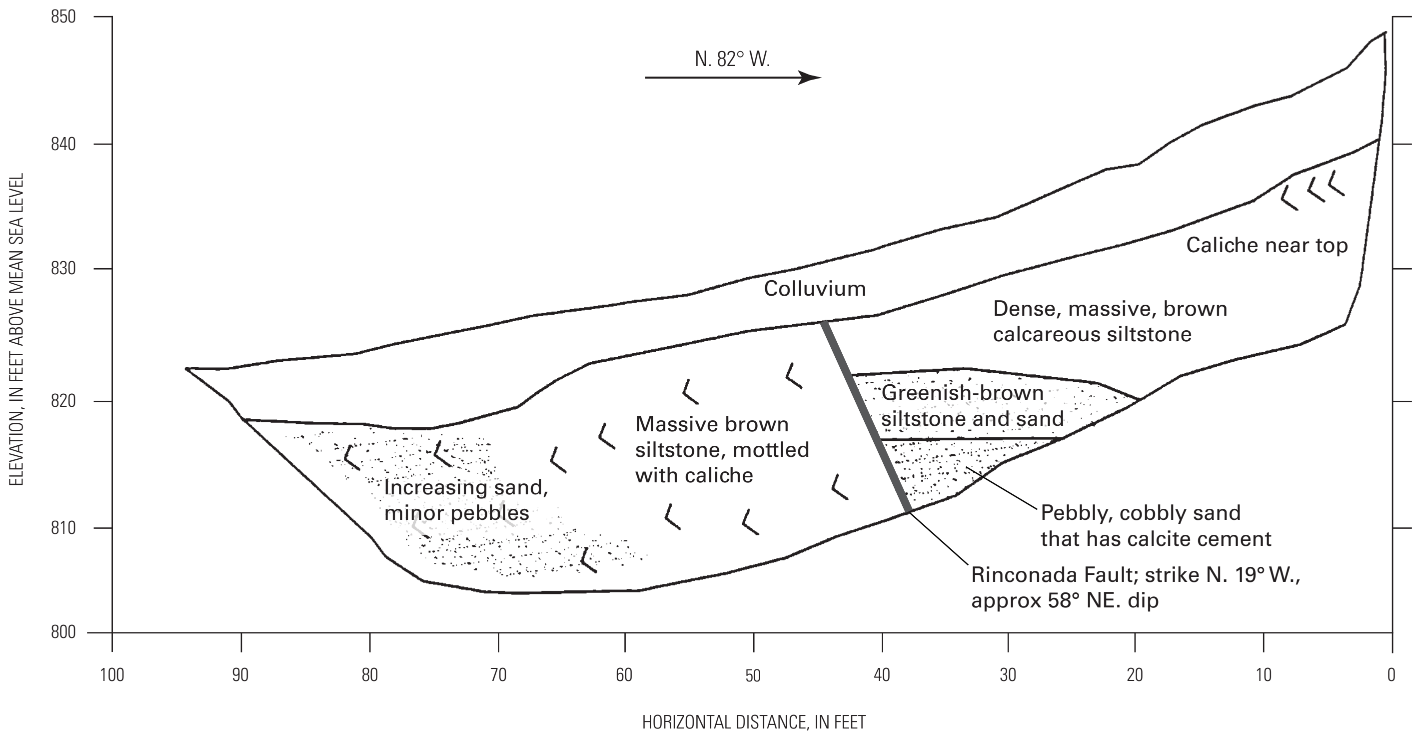


Figure 7. Generalized log of exploratory trench 3A, Santa Ysabel Ranch, Paso Robles, California (key locality 4, on map sheet). From GeoSolutions, Inc. (unpub. data, 2000); trench logged by J.M.D. Kammer, October 12, 1999. Left-facing arrowhead symbol denotes caliche.

Mincey Fault

The Mincey Fault is a parallel branch of the Rinconada Fault that was first mapped in the Williams Hill area by M.G. Edwards (Edwards, 1933, *cited in* Weidman, 1959, p. 180). Weidman (1959) described the Mincey Fault as “a line of topographic notches, brecciation, and locally abnormally steep dips” in the Monterey Formation that extends almost 19 km across the King City and Bryson 15' quadrangles. Although Weidman (1959) could not find slickensides or marker beds that would document the dip or displacement of the Mincey Fault, he postulated that it is a thrust fault that dips steeply to the northeast and has about 100 m of dip-slip displacement within the Monterey Formation. Weidman (1959) also believed that the Mincey Fault experienced right-lateral strike-slip movement but did not estimate the amount of lateral displacement.

Paraiso Fault

Schombel (1943) was the first to map the Paraiso Fault, which he depicted as juxtaposing “Monterey sandstone” and “Santa Lucia series” granitic basement. This mapping was later refined by Thorup (unpub. data, 1950), who mapped the fault as offsetting “Sur Series” schist against “Miocene continental beds” (northwest side up). Although the Paraiso Fault is probably not a Quaternary-active fault, this important structure provides a conduit for hydrothermal waters that are used for bathing at the hot springs at Paraiso Springs resort, approximately 300 m east of the fault.

Los Lobos Thrust Fault

Earlier geologic maps of the Salinas Valley (Reed, 1933; Taliaferro, 1941) show the “King City Fault” in the general location of the Los Lobos Thrust Fault. During the initial period of exploration in the San Ardo Oil Field, 7 km south of San Ardo, in the late 1940s, it became apparent that the “King City Fault” in this area was, in fact, a thrust fault (Baldwin, 1953). Kilkenny and others (1952) were the first to use the name “Los Lobos Thrust” to describe this fault. We recommend that the term “King City Fault” be abandoned because it has been used to include faults that are different types and have different recency of movement, such as the Reliz Fault and the Rinconada Fault.

We interpret the Los Lobos Thrust Fault, which is concealed beneath alluvium and fluvial terraces on the west side of the Salinas River near San Ardo, as a splay of the Espinosa section. Gribi (1979) correlated oil-well electric logs and determined that the Los Lobos Thrust Fault juxtaposes the Monterey Formation over the Paso Robles Formation along a fault plane that progressively flattens toward the northwest. During field mapping, Gribi (1979) discovered an excavation east of the Salinas River and found folded rocks of the Paso Robles Formation in the footwall of the fault (key locality 10, on map sheet); however, the overlying middle to late Pleistocene stream-terrace deposits were essentially horizontal and unfaulted, suggesting that the most recent activity of the Los Lobos Thrust Fault is middle to late Pleistocene.

Additional evidence of late Quaternary activity is suggested from a trench dug by R.R. Thorup in 1970 along the Los Lobos Thrust Fault about 17 km northwest of San Ardo (Dibblee, 1979) (key locality 11, on map sheet), where he found diatomaceous mudstone of the Pancho Rico Formation of Miocene age thrust over shale-pebble gravel of the Paso Robles Formation along a fault that dips about 40° to the southwest.

San Antonio Thrust Fault

The San Antonio Thrust Fault is a northeast-dipping thrust fault in which the Monterey Formation on the northeast side is juxtaposed against the Paso Robles Formation and Pleistocene alluvium. Jennings (1959) first used the name “San Antonio Fault” to refer to the strand of the San Marcos Fault that extends northwestward from the San Antonio River to Lockwood. Similarly, Dibblee (1976) considered the San Antonio Thrust Fault to be the southwest strand of his San Marcos “segment” that follows the western base of the San Antonio Hills for about 19 km to rejoin the southwest strand of the Espinosa “segment.”

Dibblee (1976, fig. 19) showed the San Antonio and Los Lobos Thrust Faults as positive flower structures resulting from transpression across the Rinconada Fault Zone. In a concurrent view, E.A. Gribi (written commun., 1988) believed the San Antonio Thrust Fault to be the mirror image of the Los Lobos Thrust Fault: the result of compression of the tremendous thickness of rocks of the Monterey Formation against the more rigid crystalline rocks of the Santa Lucia Range. We agree with Dibblee’s and Gribi’s interpretations.

Figure 8. Close-up view of possible fissure fill and faulted colluvium, Santa Ysabel Ranch, Paso Robles, California (key locality 4, on map sheet). Red line shows position of Rinconada section of Rinconada Fault (dashed where location is inferred; arrows show direction of relative movement). Photo courtesy of C.S. Hitchcock, William Lettis & Associates, Inc. (written commun., 1999).

Sections of the Reliz Fault Zone

General Statement

As early as 1908, geologists have recognized a zone of faulting along the eastern slope of the Sierra de Salinas that continued northward into Monterey Bay. Lawson (1908), who called it the "Santa Lucia Fault," wrote,

> "one of the dominant structural lines of the Coast Ranges is the Santa Lucia Fault, at the base of the Santa Lucia Range on the border of the Salinas Valley. It is traceable from the vicinity of Bradley to the Bay of Monterey and it is probably the chief factor in determining the course of the Salinas Valley and the steep easterly front of the Santa Lucia Range."

The name "Reliz Canyon Fault" was applied by Nickell (1931, p. 314) to an exposure of the fault near Reliz Canyon; he considered this fault to be a branch of what he called the "King City Fault." Schombel (1940, 1943) also mapped this fault as the "Reliz Thrust," showing its north end truncated at an oblique angle by the "King City Fault."

The continuity of the Rinconada Fault Zone with the Reliz Fault Zone to the northwest is controversial, as outlined by Gribi and Thompson (1988). Durham (1970) regarded the Reliz Fault as a feature that extended from Paraiso Springs about 27 km southeastward. On the other hand, Dibblee (1976) interpreted the Reliz Fault to be the northern component of a major structural feature he called the "Rinconada-Reliz Fault Zone."

Although the Rinconada and Reliz Fault Zones are roughly aligned, a 10° to 15° difference in strike is present at their juncture. More significantly, kinematic fold modeling suggests that approximately 80 percent of post-Pliocene displacement on the Rinconada Fault Zone is strike-slip partitioned (Titus and others, 2007). In contrast, the steep east face of the Sierra de Salinas suggests the dominant style of displacement on the Reliz Fault Zone is reverse dip-slip movement, although the amount of slip partitioning is unknown.

Thus, we believe that the Reliz Fault is a separate fault zone because of the change in overall strike, the difference in type of displacement, and the likelihood that slip is partitioned at different rates between the Rinconada Fault Zone and the Reliz Fault Zone. The Reliz Fault Zone consists of the following two sections, from south to north: the Sierra de Salinas section, and the Blanco section (fig. 2).

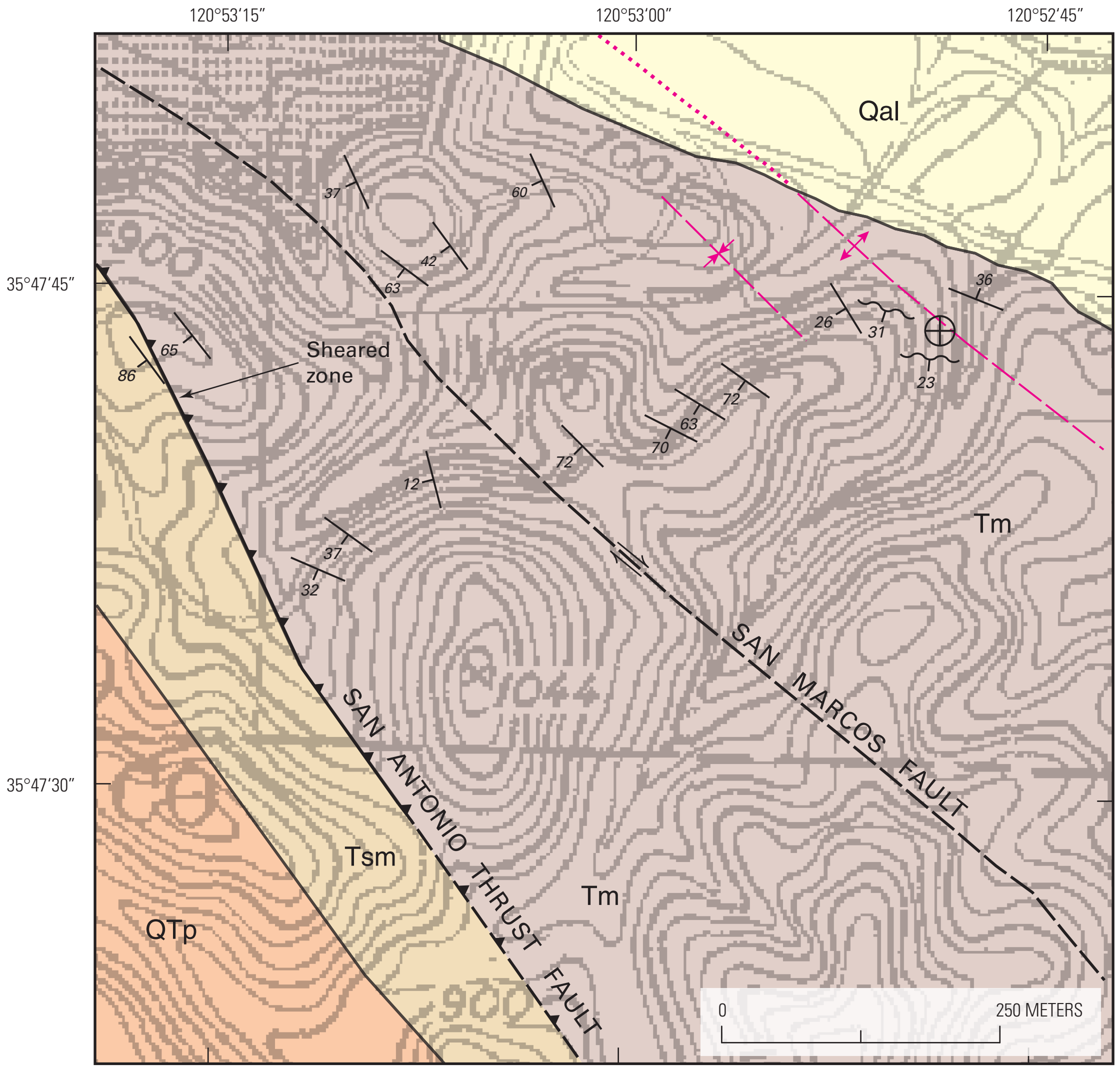
Sierra de Salinas Section

This section, herein named the Sierra de Salinas section, includes the part of the Reliz Fault that extends from Monroe Canyon northward to Spreckels, where the Sierra de Salinas ends. In the Sierra de Salinas section, the fault is best exposed in a roadcut on the north side of the iron bridge that crosses the Arroyo Seco (key locality 12, on map sheet; see also, fig. 10). Here, it strikes N. 30° W. and dips 74° to the southwest; a 1- to 2-m-wide zone of sheared rock and gouge separates the Pancho Rico Formation of Miocene age on the northeast from the Monterey Formation of middle to late Miocene age on the southwest. At this exposure, the late Pleistocene stream terrace and its overlying terrace gravel have not been displaced vertically for about the past 100,000 years (Tinsley and Dohrenwend, 1979).

Snetsinger (1962) reported offset terraces near the mouth of the Arroyo Seco that he regarded to be the result of repeated movement along the Reliz Fault. Evidence for this concealed part of the fault includes the deformed rocks of the Paso Robles Formation, the magnetic anomalies discovered as part of a geophysical survey (Wire, unpub. data, 1974) (key locality 13, on map sheet), and the changes in water-well yields across the fault (Tinsley, 1975).

North of Paraiso Springs, the Sierra de Salinas section continues northwestward to Spreckels as a range-front fault of the Sierra de Salinas; in this area, the fault is largely concealed beneath late Pleistocene alluvial fans. In his study of the morphology of these alluvial fans, Tinsley (1975, p. 107) observed that the alluvial fans along the southwestern margin of the Salinas Valley are smaller and steeper than the larger, more gently sloping fans along the northeastern valley margin. He attributed this to the contrasting tectonic history of the Sierra de Salinas compared to that of the Gabilan Range to the northeast. Prominent scarps are present at the base of the fans along the southwestern valley margin; however, analysis of scarp morphology, lithology, and soil stratigraphy indicated a probable fluvial origin for the scarps (Tinsley, 1975), although a tectonic origin cannot be ruled out.

Also included in the Sierra de Salinas section is the Las Palmas Fault of Clark and others (2000), which strikes northwestward along the foothills south of the Salinas River. Its mapped trace is marked by the following: aligned springs (Clark and others, 2000); steeply dipping Pliocene(?)-Pleistocene continental deposits (Tinsley, 1975) (key locality 15, on map sheet); local offset of the Pliocene(?)-Pleistocene continental deposits but not of late Pleistocene colluvium (Terratech, Inc., unpub. data, 1989); and a pronounced gravity gradient that indicates that this fault dips steeply to the southwest beneath the quartz monzonite of Pine Canyon (Langenheim and others, 2002). Its parallel orientation to the Reliz Fault Zone and its similar sense of displacement suggest that the Las Palmas Fault is probably a branch of the Reliz



EXPLANATION

Qal — **Alluvium** (Holocene)

QTp — **Paso Robles Formation** (Pliocene–Pleistocene)

Tsm — **Santa Margarita Sandstone** (middle to late Miocene)

Tm — **Monterey Formation** (middle Miocene)

Horizontal bedding

40 — **Inclined bedding**—Showing strike and dip

25 — **Inclined contorted bedding**—Showing approximate strike and dip

Contact—Identity and existence certain, location accurate

Anticline—Identity and existence certain, dashed where location is approximate, dotted where location is concealed

Syncline—Identity and existence certain, location approximate

Strike-slip fault, right-lateral offset—Identity and existence certain, location approximate. Arrows show relative motion

Thrust fault—Identity and existence certain; solid where location is accurate; dashed where location is approximate. Sawteeth on upper (tectonically higher) plate

Figure 9. Geologic map showing San Antonio Dam area, near Bradley, California (key locality 7, on map sheet). Mapped by E.E. Brabb, J.C. Clark, and L.I. Rosenberg, April 24, 2002, and January 9, 2003. Base from U.S. Geological Survey 1:24,000-scale Digital Raster Graphic (DRG): Tierra Redonda Mountain, 1979.

Fault Zone. The offset Pliocene(?)-Pleistocene continental deposits and mapping by Clark and others (2000) support Tinsley's (1975, p. 152) conclusion regarding the Sierra de Salinas section, that "a continuous zone of faulting younger than Gloria alluvial fans [middle Pleistocene, 250–550 ka] cannot be shown to exist immediately adjacent to the mountain front of the Sierra de Salinas."

Trenching Study

One trenching study (Terratech, Inc., unpub. data, 1989) has been performed along the Sierra de Salinas section. The Terratech study was not a detailed paleoseismologic study; instead, its focus was to locate faults at potential land-development sites. The study involved excavating five trenches across the fault on the Las Palmas Ranch property (key locality 14, on map sheet; see also, fig. 11). Trenches TR-1, 2, and 4 exposed a 4.5-m-wide fault zone that displaces a duripan (estimated age, several tens of thousands to a few hundred thousand years old) within the Pliocene(?)-Pleistocene continental deposits but does not offset late Pleistocene colluvium (estimated age, 30–50 ka). These age estimates are based on visual observations of the trench stratigraphy by J.C. Tinsley (*cited in* Terratech, Inc., unpub. data, 1989, p. 2). Terratech did not estimate the recurrence interval, slip rate, or timing of most recent paleoevent.

Blanco Section

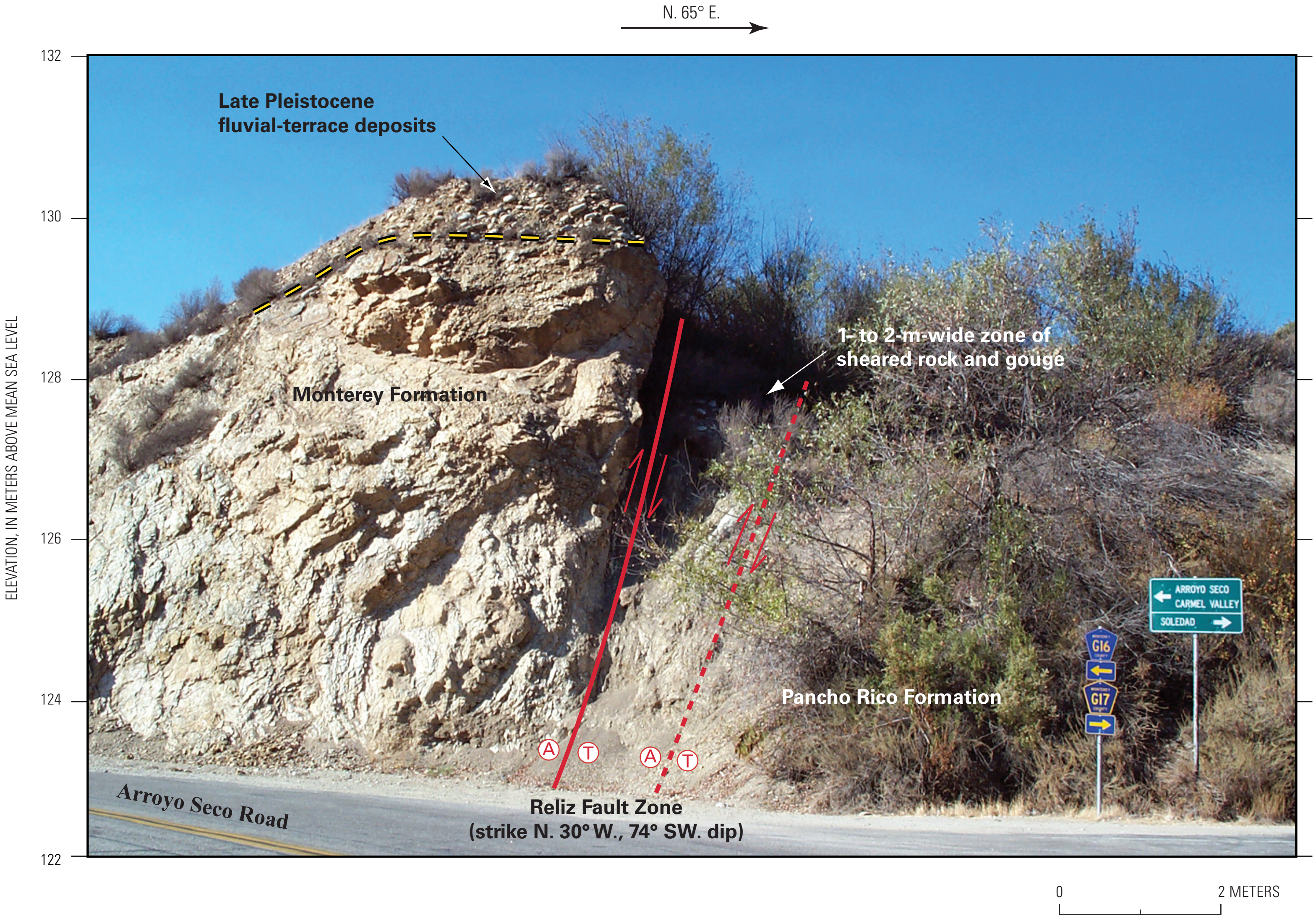
This part of the Reliz Fault Zone is herein named the Blanco section (for the old settlement of Blanco in the Salinas Valley), where the fault is buried by alluvium. Herold (1935) showed the fault as being concealed beneath valley alluvium but then extending northwestward of the north end of the Sierra de Salinas, on the basis of differences in depth of the basement surface reached in water wells. He also noted that "sedimentary beds that dip under the alluvium near Spreckels are believed to be truncated by the King City fault a short distance east of their surface exposure" (Herold, 1935, p. 135).

Gravity surveys by Fairborn (unpub. data, 1963) and Sieck (unpub. data, 1964) provide additional information about the geometry of the Reliz Fault beneath the alluvium. Fairborn (unpub. data, 1963) interpreted his Bouger gravity anomalies to show the Reliz Fault as a high-angle reverse fault that has about 3,000 m of vertical displacement. Fairborn also stated that the Reliz Fault did not continue beyond the north end of the Sierra de Salinas. In contrast, Sieck (unpub. data, 1964) interpreted his gravity data as supporting a northwestward continuation of the Reliz Fault, showing about 900 m of vertical displacement on the fault. Vertical offset along the Reliz Fault could partly explain the unusually thick section of Miocene to Pliocene Purisima Formation found in a 613-m-deep monitoring well (key locality 16, on map sheet) (Hanson and others, 2002).

The Blanco section of the Reliz Fault Zone continues offshore, as first proposed by Martin and Emery (1967), who noted approximately 300 m of vertical offset of Pliocene strata onland relative to similar strata in the offshore Monterey Canyon. Martin and Emery (1967, p. 2,292) concluded, "This fault in Monterey Canyon may be a northward extension of the Reliz Fault in the Salinas Valley…but until the connection can be proved, the writers use the term 'Gabilan Fault'." Greene and others (1973) showed the Blanco section (their "King City Fault") as projecting into the Monterey Bay Fault Zone (fig. 2), on the basis of apparent differences in the subsurface elevation of the Paso Robles Formation, which has a post-Pleistocene vertical separation of 30 m (southwest side up). However, the connection of the Tularcitos Fault with the Monterey Bay Fault Zone (and probably the transfer of slip) is more throughgoing than the connection of the Reliz Fault with the Monterey Bay Fault Zone.

Gravity data (Langenheim and others, 2002) and magnetic-anomaly data (R.C. Jachens, USGS, written commun., 2002) supported the connection of the onland Reliz Fault with splays of the offshore Monterey Bay Fault Zone (key locality 17, on map sheet). A compilation map of isostatic gravity contours shows a prominent gravity low, which has a value of about –46 mGal near the western boundary of the former Fort Ord. This low extends in a northwest-southeast direction and continues southeastward, forming a trough parallel to the axis of the Salinas Valley that is bounded by the projection of the Blanco section (Langenheim and others, 2002). We interpret this gravity low, which is penetrated by several deep water wells, as a concealed sedimentary basin that is deepest near Marina and the former Fort Ord military base.

In this same area, the Blanco section also aligns with a high-definition magnetic boundary. The mapped locations are those of the aeromagnetic fault trace at the basement surface, projected to the surface. However, if the fault dips, or if the fault produces a flower structure in the sedimentary rocks that overlie the basement, the location of the magnetically defined trace may not correspond precisely to the trace at the earth's surface. This is important to remember when locating the northernmost onshore position of the Reliz Fault because the granitic basement rocks there probably are covered by 2 km of sedimentary deposits (R.C. Jachens, USGS, written commun., 2002).



EXPLANATION

Approximate contact

Fault—Dashed where location is inferred. Arrows show local direction of relative movement

Ⓐ Indicates strike-slip movement away from viewer

Ⓣ Indicates strike-slip movement toward viewer

Figure 10. Generalized log of roadcut exposure along Reliz Fault Zone, Greenfield, California (key locality 12, on map sheet). Exposure logged by E.E. Brabb, J.C. Clark, and L.I. Rosenberg, April 24, 2002. Photograph taken October 18, 2002.

Seismicity of the Rinconada and Reliz Fault Zones

The relatively youthful geomorphic expression of the Rinconada and Reliz Faults suggests that, although no Holocene movement has been documented, these faults may be seismically active. Previous workers have noted the apparent alignment of small-magnitude (**M**=0.7–4.5) earthquake epicenters with the Reliz Fault Zone (Greene and others, 1973; Tinsley, 1975). To evaluate the regional seismicity, earthquake epicenters occurring from January 1, 1967 to August 29, 2008 and having magnitudes of 2 or greater in the USGS Northern California Seismic Network catalog were downloaded from the Northern California Earthquake Data Center (NCEDC) website (http://www.ncedc.org). The epicenters were imported into ArcGIS software, where they were projected geographically, clipped to the study-area boundary, and included in the GIS database.

To obtain a catalog of well-located earthquakes, we excluded events that have less than six reporting stations and RMS travel-time residuals of 0.2 seconds or more. In order to include events in the western offshore part of the study area, we did not apply an azimuthal gap filter (an angular gap in degrees between the epicenter and two adjacent stations). First-motion mechanisms are not available from the NCEDC website for most of these events associated with the Rinconada and Reliz Fault Zones.

Most epicenters shown on the accompanying map sheet herein are associated with the San Andreas Fault Zone. However, clustered epicenters in the Santa Lucia Range align with the Holocene-active San Gregorio/Hosgri and Oceanic Fault Zones. In addition, scattered seismicity along the west side of the Salinas Valley may be associated with the Rinconada and Reliz Fault Zones; although this scattered seismicity along the Rinconada and Reliz Fault Zones lacks the density and linearity of that of the San Andreas Fault Zone, the following three areas are of note.

First, an area of seismicity that includes 29 events (**M**=2.0–3.8) is present near the juncture of the San Marcos and Rinconada sections, approximately 2 km west of the city of Paso Robles. This cluster began in May 1982 as a series of **M**=2 to **M**=3 earthquakes but had little activity until three weeks after the December 22, 2003 **M**=6.5 San Simeon earthquake, at which point the earthquake activity greatly increased. This cluster also includes two more recent events: the **M**=3.8 earthquake on November 28, 2006, and the **M**=3.7 earthquake on July 6, 2008. Local newspaper accounts did not report any ground rupture or damage from the **M**=3.8 earthquake (originally reported by the press as **M**=4.1) or the **M**=3.7 earthquake (Paso Robles Press, 2006; San Luis Obispo Tribune, 2008). The proximity of these earthquakes to the Rinconada Fault Zone suggests that they are not aftershocks of the 2003 San Simeon earthquake. In addition, focal-mechanism solutions indicate that the fault plane for the **M**=3.8 earthquake strikes N. 25° W. and dips 83° to the southwest; for the **M**=3.7 earthquake, the fault plane strikes N. 24° W. and dips 82° to the southwest. Thus, the **M**=3.8 and **M**=3.7 earthquakes are compatible with having occurred on a dip-slip reverse fault like that of the Rinconada Fault Zone; they are less compatible with having been aftershocks of the 2003 San Simeon earthquake, which was reverse movement on a northeast-dipping fault (McLaren and others, 2008). It is uncertain if the cause of these two earthquakes and their aftershocks were caused by increased stress on the Rinconada Fault Zone from the 2003 San Simeon earthquake or by stress within the Rinconada Fault Zone.

The second area contains two groups of epicenters near San Ardo. The first group includes 41 events (**M**=2.0–4.2) in the foothills on the west side of the Salinas Valley. The epicenters lie east of the Espinosa section of the Rinconada Fault and are probably on the southwest-dipping Los Lobos Thrust Fault, which is on the east edge of the cluster. The other group is a tightly grouped, north-northeast-striking cluster of 96 events (**M**=2.0–4.5) that overlies the San Ardo Oil Field. Poley (1988) analyzed focal-plane solutions for these events and concluded that a north-striking, near-vertical fault plane having dextral slip was defined by the hypocentral locations. Hart (1985) suggested that these earthquakes were caused by fluid withdrawal from the San Ardo Oil Field. Furthermore, enhanced recovery procedures at San Ardo include steam and water injection, which could also cause small earthquakes. Considering the lack of mapped faults, the northerly strike, and the active oilfield operations, these events more likely were caused by human activity rather than tectonic forces.

The third area of seismicity is a cluster of 20 epicenters (**M**=2.1–4.2) near the Reliz Fault Zone, west of the city of Gonzales. Tinsley (1975) examined focal-mechanism solutions for one of these events (**M**=2.8, 03/05/1972) and found two solutions pairs that result in four possible nodal planes: one pair is compatible with a dip-slip reverse fault that strikes N. 74° E. and dips either 64° to the south or 26° to the north; the other pair is compatible with an oblique-slip fault having a left-lateral horizontal component that either strikes N. 14° E. and dips 45° to the west or strikes N. 76° W. and dips 45° to the south. However, none of these solutions corresponds with mapped faults, and Tinsley (1975) concluded that, although the cluster reflected an actual pattern of seismicity, the events were probably on a subsidiary fault or cross-fault within the Reliz Fault Zone.

Despite the fact that no Quaternary faulting has been documented along the Reliz Fault north of Spreckels, recent movement may have occurred owing to its location adjacent to the active Monterey Bay Fault Zone. However, any evidence of young strike-slip movement along the fault is likely lost in the late Holocene floodplain deposits of the Salinas Valley. The relatively sparse seismicity suggests that there may not be much activity on this part of the Reliz Fault at present.

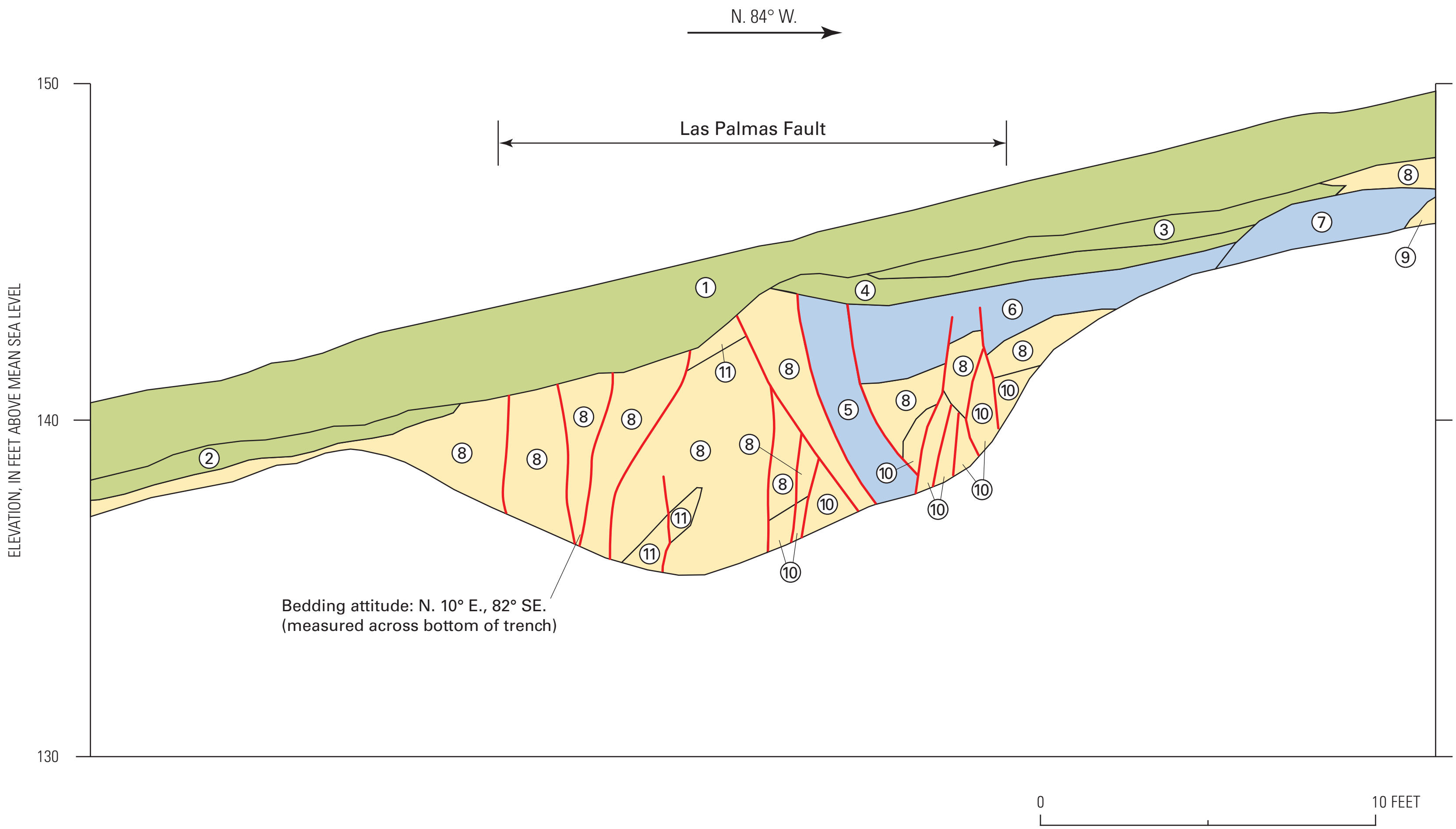


Figure 11. Extract from log of exploratory trench TR-1, Las Palmas Ranch, near Spreckels, California (key locality 14, on map sheet). From Terratech, Inc. (unpub. data, 1989); trench logged by J.L. Nelson and F.J. Groffie, November 17, 1989. See next page for explanation of units.

EXPLANATION

Younger colluvium

① Brownish-gray (at top) to light-brownish-gray (in lower several inches) sandy silt to silty sand; dry; loose to medium dense; 40–60% silt; 35–55% fine- to medium-grained sand; 5% rounded gravel; filled burrows and rootlets

② Dark-brown, damp, hard clay; 65–90% fat clay; 10–35% sand

③ Alternating streaks of dark-brown and light-olive-green, damp, very stiff to hard sandy clay, having fine- to medium-grained sand and localized coarse-grained sand and fine gravel

④ Brown, dry to damp, hard sandy clay

Continental deposits

⑤ Dark-grayish-brown, damp, very stiff clay, having fine- to coarse-grained sand and fine gravel

⑥ Light-olive-green to tan, dry to damp, very stiff to hard clay that has fine- to coarse-grained sandstone fragments; moderately to severely weathered

⑦ Buff-white (fresh) and purple (weathered) siltstone; dry; medium hard; closely to intensely fractured, moderately to severely weathered

Continental deposits (cemented)

⑧ Light-yellowish-brown to light-brownish-gray, conglomeratic silty sandstone; dry; 40–70% sand; 30% silt; trace to 30% conglomerate (rounded, as much as 2-inch-diameter, mostly porcellanite from Monterey Formation, some meta-sedimentary clasts from Sur Series, and granitic clasts); unstratified; soft to medium hard; unfractured to slightly fractured, having randomly oriented, ¼-inch-thick, clay-filled fractures; slightly weathered; duripan

⑨ Orangeish-brown, dry to damp, medium-hard conglomeratic sandstone; includes siltstone cobbles derived from Santa Margarita Sandstone; duripan

⑩ Light-orangeish-brown, dry, unstratified, medium-hard sandstone; unfractured; slightly weathered; duripan

⑪ Buff-white, dry, medium-hard sandstone; moderately fractured; slightly weathered; duripan

Faults

Characterized by $\frac{1}{16}$- to 1-inch-thick clay seam or by hard, especially well-cemented rock seam as much as to 1½ inches thick

Characterized by 1- to 2-inch-thick, dark-brown, damp, hard, sandy clay; localized slickensides that strike N. 8° E. and dip 57° NW.; gravel clasts locally parallel strike of fault

Figure 11—Continued.

Neogene History of the Rinconada and Reliz Fault Zones

The pre-Neogene history of the Rinconada and Reliz Fault Zones is unclear. Where the southern part of the Rinconada Fault separates the Salinian granitic terrane from the Franciscan Complex to the southwest, we favor the interpretation of Page and others (1979) that the younger Rinconada Fault is “superposed” on the Sur/Nacimiento Fault Zone and that this terrane juxtaposition resulted either from subduction or possibly from lateral movement in early Paleogene time.

Dibblee (1976) suggested that lateral movement on the Rinconada Fault occurred in Oligocene(?) time, on the basis of the apparent separation of the very thick Upper Cretaceous and lower Tertiary sedimentary sequence that overlies the Salinian basement complex. This separation more probably resulted from erosion of the Upper Cretaceous–lower Tertiary sequence during the Oligocene, as that was a time of regional uplift and extension in the central Salinian Block.

During middle Miocene time, the early stages of a period of wrench-style tectonics converted the central Salinian Block into fault-bounded basins and elevated ridges (Garrison and others, 1979). The Lockwood high (a granitic bedrock high located near the town of Lockwood) developed at this time, strongly influencing the distribution of facies in the Monterey Formation to the southwest (Garrison and others, 1979). Likewise, the entire porcelaneous and diatomaceous Monterey Formation of middle to late Miocene age, which is extensively developed east of the city of Monterey, changes facies eastward into a thick section of arkosic sandstone in the eastern part of the Spreckels 7.5' quadrangle west of the Salinas Valley (Clark and others, 2000). This facies change suggests that uplift and exposure of the Salinian granitic basement to the east occurred during middle to late Miocene time.

The Arroyo Seco Trough and the southern Salinas Basin, both of which contain very thick sections of Monterey Formation, developed during middle Miocene time as a single elongate basin but are now separated by about 38 km of right-lateral displacement on the Rinconada Fault Zone (Dibblee, 1976, 1979). The exposed granitic rocks on the northeast side of the Rinconada Fault Zone just northwest of Paso Robles probably are separated from the Lockwood high southwest of the fault by about 38 km of right-lateral displacement as well (Dibblee, 1976). Thus, 38 km appears to be the maximum amount of right-lateral displacement on the Rinconada Fault Zone, all of which has occurred since late Miocene time.

Offset of the limits of deposition of the Santa Margarita Sandstone and the Pancho Rico Formation indicates about 18 km of right-lateral strike-slip displacement on the central Rinconada Fault Zone since early Pliocene time (Durham, 1965). Thus, we believe that strike-slip movement on the Rinconada Fault Zone was initiated in late Miocene time: about 20 km of right slip occurred during the late Miocene, and about 18 km of additional right slip took place since the early Pliocene, much of which probably occurred during Pleistocene time.

Extensive evidence of Pleistocene movement exists along the Rinconada Fault Zone, including the disruption of the Paso Robles Formation, the right-lateral offset of streams near Espinosa Canyon (Dibblee, 1976), the apparent truncation of probable upper Pleistocene alluvial fan deposits near Williams Hill (Hart, 1985), and the approximately 5 m of vertical offset of alluvial fan surfaces (key locality 9, on map sheet) that have an estimated age of 300,000 to 400,000 years (Klaus, 1999). Definitive geologic evidence of Holocene surface rupture has not been found along the Rinconada Fault Zone, although exploratory trenches excavated across the Rinconada section suggest probable late Quaternary activity (key localities 1, 2, 3, and 4, all on map sheet).

North of Arroyo Seco, the Reliz Fault Zone steps right, nearly aligning with the Rinconada Fault Zone; however, compelling evidence of significant strike-slip displacement along the Reliz Fault Zone is lacking. Indeed, on the basis of the distribution of the Schist of the Sierra de Salinas, Ross (1984, p. 18) saw “no compelling reason to believe that this schist belt was significantly faulted or offset” by the Reliz Fault Zone. Scanty subsurface data (Ross, 1984, fig. 11) suggest that this schist terrane continues to the east across the Reliz Fault Zone, disallowing right-slip displacement in excess of 23 km since Cretaceous time. Most of the offset on the Reliz Fault Zone appears to have been reverse dip-slip displacement, uplifting the Sierra de Salinas and Salinian basement to the southwest by as much as 3,000 m (Dibblee, 1976).

The Reliz Fault Zone was active after deposition of Pliocene(?)-Pleistocene continental deposits but before late Pleistocene time. Alluvial fans of late Pleistocene age cross the trend of the Reliz Fault Zone at the base of the Sierra de Salinas without apparent disruption (Tinsley and Dohrenwend, 1979); in addition, the related Las Palmas Fault does not offset alluvial fan deposits of middle(?) to late Pleistocene age (Clark and others, 2000). Definitive Holocene activity along the Reliz Fault Zone has not been documented.

Because displacement is largely strike-slip on the Rinconada Fault Zone and primarily reverse dip-slip on the Reliz Fault Zone, the continuity of these two faults is uncertain, at least during Pleistocene time. The total documented right-slip on the Rinconada Fault Zone is 38 km, whereas the maximum possible right-slip on the Reliz Fault Zone probably does not exceed 23 km, and it may be less. Thus, some, if not all, of the strike-slip motion along the Rinconada Fault Zone may have been partitioned northwestward into the Salinian Block via the Tularcitos Fault of upper Carmel Valley. The Tularcitos Fault is Holocene active and may have at least 16 km, and possibly as much as 40 km, of right-lateral displacement (Clark and others, 1997).

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