

Quaternary Geologic Map of the North-Central Part of the Salinas River Valley and Arroyo Seco, Monterey County, California



Pamphlet to accompany
Scientific Investigations Map 3260

Cover: View looking downstream at a well-preserved sequence of late Pleistocene and inset Holocene strath terraces. Where Arroyo Seco has eroded Tertiary marine sediments, primarily Monterey shale, a broad valley has formed. Each terrace records a floodplain eroded into the bedrock and is capped by rounded gravel derived from the more resistant basement rocks upstream. Photograph by Tony Garcia, California Polytechnic University, San Luis Obispo, 2012.

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By Emily M. Taylor and Donald S. Sweetkind

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**U.S. Department of the Interior
U.S. Geological Survey**

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
yard (yd)	0.9144	meter (m)

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Abstract

Arroyo Seco, a perennial drainage in the central Coast Range of California, records a sequence of strath terraces. These terraces preserve an erosional and depositional history, controlled by both climate change and regional tectonics. These deposits have been mapped and correlated on the basis of field investigations, digital terrain analysis, stream gradient profiles, evaluation of published regional soil maps, and satellite imagery. Seven of the strath terraces and associated alluvial fans have been dated by optically stimulated luminescence (OSL) or infrared stimulated luminescence (IRSL). The OSL and IRSL dates on seven of the strath terraces and associated alluvial fans in Arroyo Seco are approximately >120 ka, >65 ka, 51–46 ka, 36–35 ka, 9 ka, and 2–1 ka. These dates generally fall within the range of ages reported from many well-dated marine terraces on the California coast that are formed during sea-level high stands. Tectonic movements, consistently upward, result in a constantly and slowly emerging coast line, however, the regional effects of climate change and resulting eustatic sea-level rises are interpreted as the driving mechanism for erosion and aggradation in Arroyo Seco.

Introduction

Arroyo Seco, a perennial drainage in the Santa Lucia Range of the central Coast Range of California (fig. 1) adjacent to the Salinas River valley, records in its deposits a sequence of erosional strath terraces. Arroyo Seco cuts a narrow canyon in resistant bedrock in the uplands of the Santa Lucia Range, but opens eastward to a broad, meandering 16-kilometer- (km-) long valley where the drainage flows over more easily erodible sedimentary rocks. Arroyo Seco declines in elevation from about 250 meters (m) at the canyon mouth to 50 m, where it flows into the Salinas River valley. Arroyo Seco is a perennial stream and one of the largest tributary drainages of the Salinas River. The Salinas River valley is drained by the 275-km-long Salinas River, as measured from its headwaters in San Luis Obispo County northwards to Monterey

Bay. Based on data from oil and gas exploration drill holes and deep water wells, the Salinas River valley is filled with as much as 1,800 m of Tertiary and Quaternary marine and terrestrial sediments (Durham, 1974). Preserved stream-terrace deposits within and near sedimentary basins are a record of erosional history that provides a context for downstream basin aggradation, basin-margin fault-related uplift, and paleoclimate events. Understanding the erosion of sediment from Arroyo Seco contributes to understanding the evolution of sedimentation in the northern part of the Salinas River valley. Arroyo Seco erosional strath terraces mark stable periods between base-level changes driven by tectonics or sea-level fluctuations, an indirect result of climate change. Seven of the terraces have been dated by feldspar infrared stimulated luminescence (IRSL) or quartz optically stimulated luminescence (OSL) and range in age from 1 ka to >120 ka. We combined terrain analysis of a digital elevation model with traditional geologic field methods, and relative age and dating techniques to develop a Quaternary geologic map to help interpret the long-term erosional history of Arroyo Seco drainage.

The mapped area covers six 7.5-minute U.S. Geological Survey (USGS) quadrangles or an area of about 33 by 28 km. Previous detailed bedrock mapping was done by Durham (1963, 1970), Page (1998) and by Dibblee and Minch (2006a–e; 2007). Rosenberg and Clark (2009) updated the mapping of the Rinconada and Reliz faults. Quaternary geologic mapping of Arroyo Seco and the northern Salinas River valley areas was done as part of graduate studies (Snetsinger, 1962; Dohrenwend, 1974, 1979; Tinsley, 1975; Tinsley and Dohrenwend, 1979). Our new mapping provides a detailed stratigraphic history of incision and deposition from the early Pleistocene to the present.

Infiltration from the Salinas River and its tributaries is the source of irrigation water in this productive agricultural region. Irrigation water is pumped from the shallow aquifers at depths of about 55 and 120 m (Durbin and others, 1978); however, these have become intruded by seawater, especially between Castroville and Salinas (north of the map area). In those areas, groundwater is mainly pumped from the “deep” aquifer, which is approximately 275–400 m deep. In contrast,

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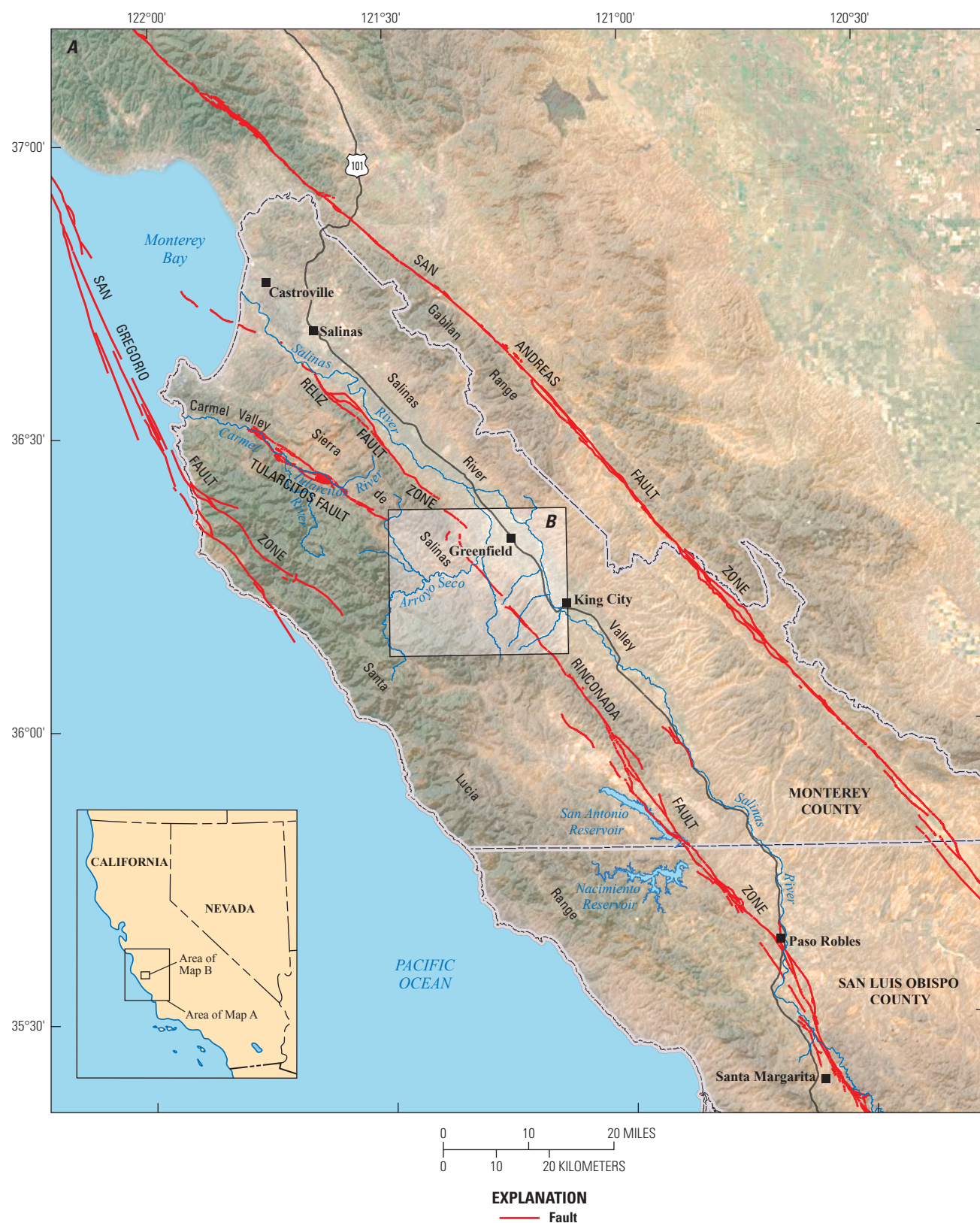


Figure 1. Location Map. Arroyo Seco is located in Monterey County in coastal, central California. Arroyo Seco, in the Sierra de Salinas, is bound on the east by the Salinas River valley.

near Arroyo Seco and King City areas, some wells pump from depths of less than 15 meters. The shallower depth has to do with these wells commonly tapping underflow from the Salinas River where groundwater is kept shallow by controlled releases from San Antonio and Nacimiento dams (L. Rosenberg, USGS, written commun., 2012). The deepest part of the Salinas basin is near the mouth of Arroyo Seco, where depth to pre-Tertiary basement is about 1,800 m (Durham, 1974; Graham, 1978). The saturated thickness in this area is about 450–600 m, and the aquifer materials consist of Miocene to Pliocene sandstones within the Pancho Rico Formation, the Pliocene to middle Pleistocene Paso Robles Formation, and unconsolidated alluvium.

Geologic Setting

The Santa Lucia Range is part of the Salinian block—a structural block underlain by granitic and granitic-gneiss basement rocks—that lies west of the San Andreas fault system, in contrast to adjacent structural blocks that are characterized

by basement rocks consisting of Franciscan Complex, Jurassic ophiolite, and upper Mesozoic forearc deposits (Reed and Hollister, 1936; Dibblee, 1973; Graham, 1978). Cretaceous and older crystalline granitic rock and associated metasedimentary rocks are here designated as **MzPz**, Paleozoic to Mesozoic undifferentiated basement (fig. 2). A sequence of Paleocene–Miocene marine sedimentary rocks, including the Monterey Formation, unconformably overlies the crystalline bedrock (Durham, 1963, 1970, 1974; Seiders and others, 1983). This sequence is here referred to as Tertiary marine sediments (**Tms**) (fig. 15, sheet 2). Successively overlying the **Tms** are the Miocene to Pliocene marine sediments of the Pancho Rico Formation (**Tpr**), a Pliocene nearshore regressive sandstone informally named the sandstone of San Ardo (**Tsa**) (Dibblee and Minch, 2006b, c; 2007), and Pliocene to middle Pleistocene nonmarine alluvial sediments of the Paso Robles Formation (**QTpr**) (Durham, 1970). Quaternary units are subdivided into alluvial deposits, fluvial and alluvial deposits, fluvial deposits, and minor eolian deposits. Mapped units are distinguished on the basis of stratigraphic order, elevation, and soil development (Soil Survey Staff, 2010) primarily based on the accumulation of secondary clay.

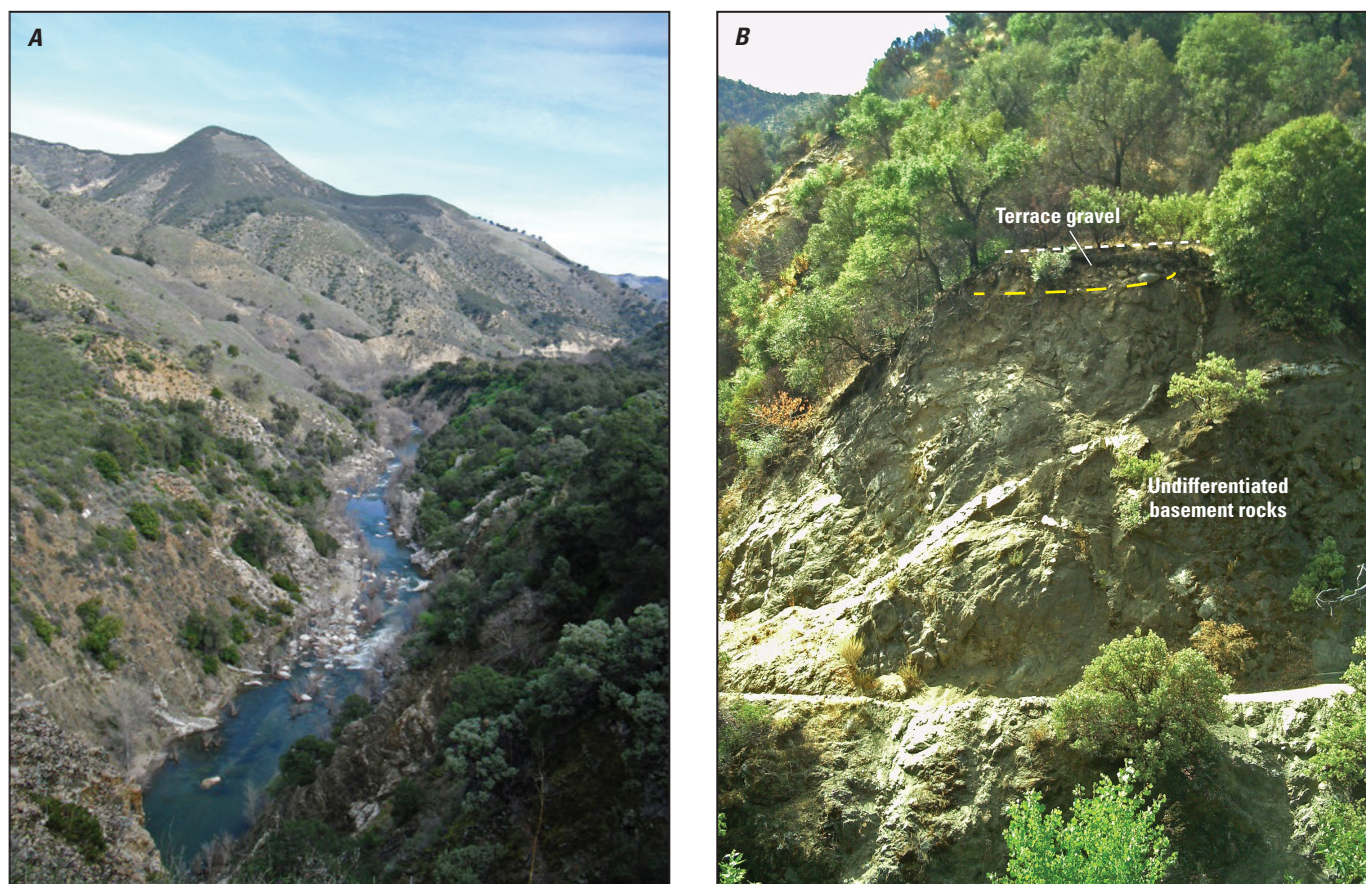


Figure 2. Photographs showing stream-valley morphology of Arroyo Seco. A, narrow canyon formed in the resistant basement rocks; B, terraces are preserved in the resistant basement rocks as narrow treads, typically less than 5 m wide. Dashed yellow line is top of bedrock and dashed white line indicates the terrace surface.

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Arroyo Seco cut a narrow canyon in bedrock through the Santa Lucia Range (fig. 2A) that opens to a broad 16-km-long valley (fig. 15, sheet 2). The narrow canyon is a result of erosion in relatively resistant basement rocks, primarily granitic and metasedimentary rocks that are Cretaceous and older in age. Arroyo Seco opens to a broad meandering drainage at the abrupt contact of the basement rock with the more easily erodible Paleocene- to Miocene-age Tertiary marine sediments (fig. 2B). Arroyo Seco declines in elevation from about 250 m at the canyon mouth to 50 m, where it flows into the Salinas River valley.

Two major range-front faults intersect south of the confluence of Arroyo Seco and the Salinas River valley, near Monroe Canyon (figs. 1 and 3). The Reliz fault zone, a high-angle reverse fault, trends northward, bounds the east side of the Sierra de Salinas, and extends to Monterey Bay (Durham, 1970; Rosenberg and Clark, 2009). Where the fault intersects

Arroyo Seco, there is no evidence for Quaternary offset (Durham, 1970; Rosenberg and Clark, 2009; fig. 13, sheet 2). North of Arroyo Seco, the Sierra de Salinas are partially flanked by older, undeformed (or scarcely deformed) fan deposits (Tinsley, 1975; fig. 2, sheet 1). Southward from Monroe Canyon, the Rinconada section, or “segment” as delineated by Dibblee (2006c), of the Rinconada fault extends to the Rinconada Mine near Santa Margarita (Rosenberg and Clark, 2009, p. 5). The Rinconada fault is a right-lateral fault, similar to the San Andreas Fault 25 km east, with offset as young as Holocene (Rosenberg and Clark, 2009). Where Monroe Creek and Thompson Canyon drainages intersect the valley floor, the stream drainages are offset to the north, indicating right-lateral movement on the Rinconada fault. The drainage offset has caused incision of alluvial fans that are late Pleistocene age, thus supporting regional evidence for Quaternary movement.

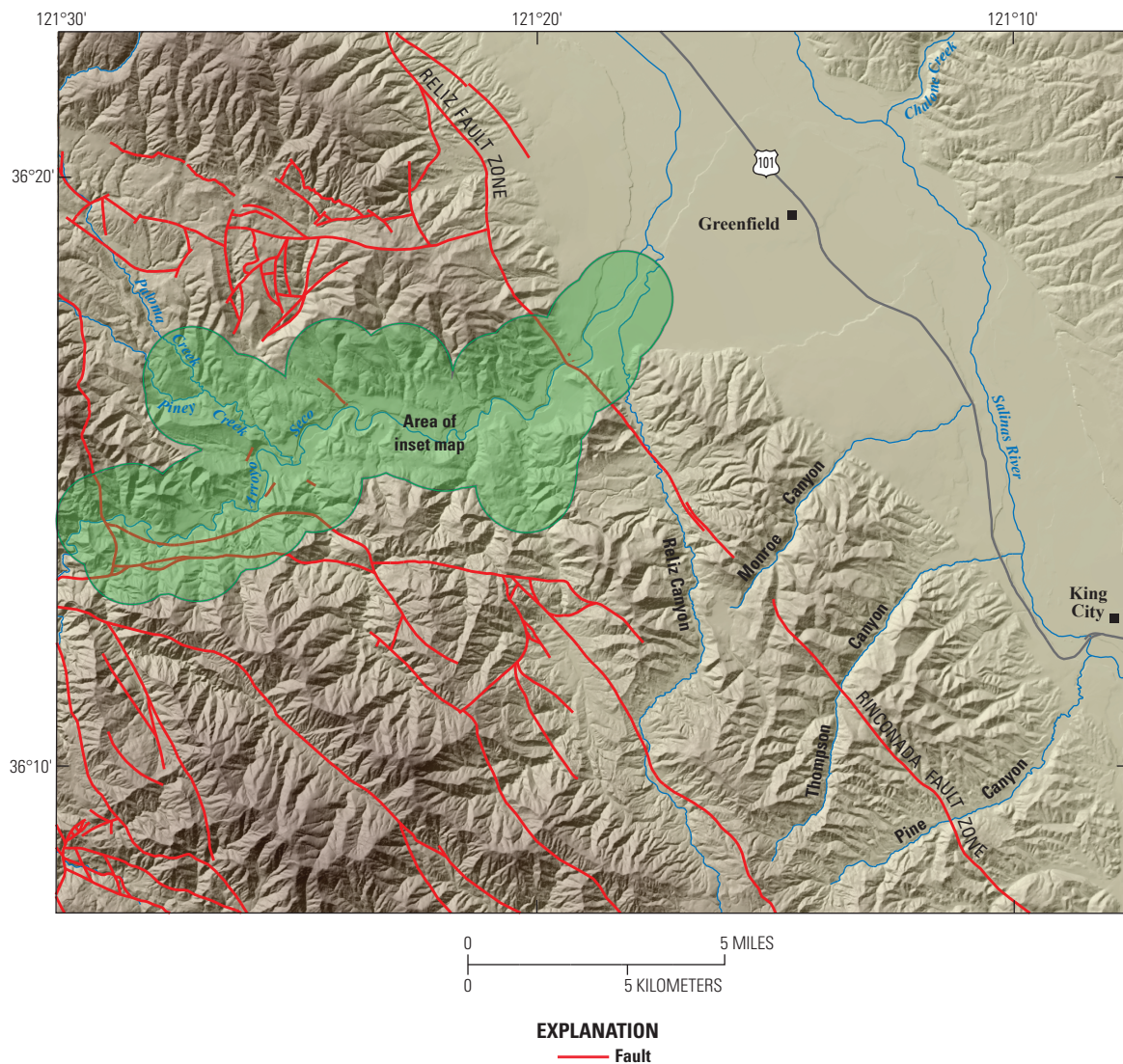


Figure 3. Location of Arroyo Seco inset map of Quaternary-age strath terraces. These terraces were eroded into Tertiary marine sediments in Arroyo Seco and the resulting sediments were deposited in the Salinas River valley. The Salinas River also provides a source for fine-grained sediments on the valley floor producing terrace and floodplain deposits at and adjacent to the river.

Differences in the sense of displacement and amount of slip suggest that the Reliz and Rinconada faults are not a single continuous fault (Ross, 1984; Rosenberg and Clark, 2009). At least some of the strike-slip motion along the Rinconada fault zone may be transferred northwestward to the Tularcitos fault in the upper Carmel Valley (Rosenberg and Clark, 2009). Slip may be transferred along a complex assemblage of faults mapped in bedrock in the northern part of the map (Dunham, 1970); it was beyond the scope of this study to attempt to refine the magnitude and sense of offset on these faults.

Description of Strath Terraces

Strath terraces formed on the thick sequence of the Tertiary marine sediments preserve the incision history of Arroyo Seco. Older strath-terrace deposits are preserved as much as about 550 m above the modern drainage whereas younger deposits are from 150 m to <1 m above the modern drainage (fig. 9, sheet 1). These terraces are capped by coarse, rounded granitic and metasedimentary cobbles and boulders exposed at the surface (figs. 4A and 4B; fig. 7, sheet 1). The rounded stones are derived from the upstream resistant basement rocks. These gravelly, fluvial deposits are typically less than 2-m thick and lie unconformably on the Tertiary marine sediments. The contact between the fluvial deposits

and the Tertiary marine sediments is clear and abrupt. Soils are developed on the fluvial deposits. Road cuts and natural exposures in Arroyo Seco also expose side-stream alluvium and colluvium that bury terrace gravel (fig. 5). Residual soils are also developed on the Tertiary marine sediments where the fluvial deposits are thin or eroded to thin lags. The residual soils may be welded with the overlying soil developed on the fluvial deposits.

The soils formed on the fluvial gravels demonstrate a clear progression of soil characteristics over time (fig. 6). Young soils are poorly consolidated and show little or no horizonation. Over time, clay-rich B horizons thicken and increase in secondary clay concentrations—from 0 to as much as 60 percent clay. As a result of increased clay concentration and secondary weathering, soil colors change from yellow brown (Munsell Color, 2009; 10YR), to reddish brown (7.5YR), to red (5YR) as deposits increase in age. The maximally developed B horizon also thickens from approximately 60 to 120 cm (table 2, sheet 1). In soils of middle Pleistocene age, metasedimentary clasts are decomposed in the maximally developed B horizon. The oldest soil in the mapped area has a silica-cemented horizon or duripan (fig. 6).

In many actively incising river canyons, gravel-capped bedrock strath terraces are tens to hundreds of meters above the active channel and extend discontinuously for kilometers. Long recognized as recording the former river bed and floodplain elevation, strath terraces, when dated, provide a direct means of quantifying rates of vertical bedrock river incision and are thus vital to studies of geomorphology, active tectonics, and the effects of climate change (Molnar and others, 1994).

Strath terraces represent ancient and now-abandoned river floodplains that formed during periods of valley-bottom widening and planation (DeVecchio and others, 2012). Bull (1990)

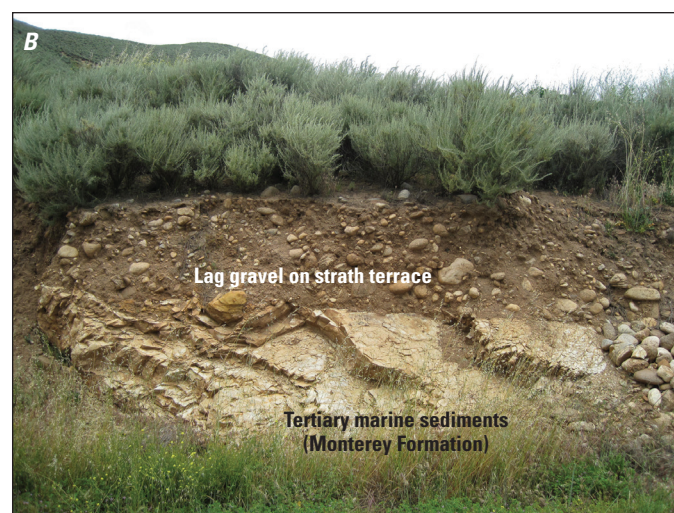
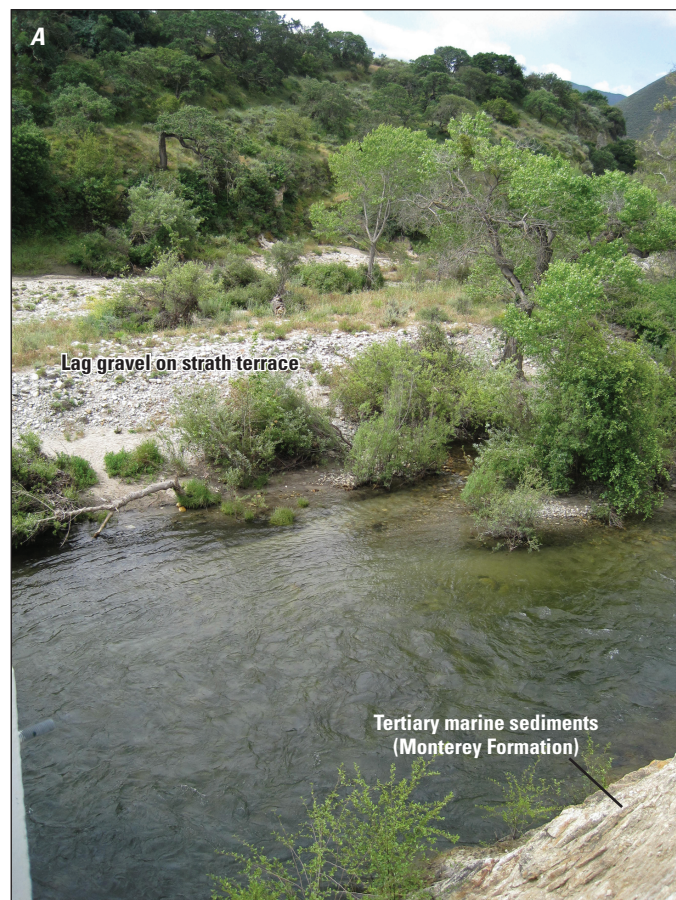


Figure 4. Photographs showing lag gravels and strath terraces. *A*, the active drainage is incising into the Tertiary marine sediments, leaving remnant lag gravel at the top of the eroded surface. *B*, strath terraces and associated soils preserve the same sequence that can be observed in Arroyo Seco today.



Figure 5. Buried terrace gravel exposed in road cut in Arroyo Seco. Buried terrace gravel was dated to determine the age of the buried deposit as well as the implied age of the alluvial fan.

suggested that lateral erosion and strath cutting are the dominant processes when streams are in dynamic equilibrium; that is, where river discharge and sediment load are in balance. Recent quantitative field studies and conceptual numerical models predict that strath terraces form in response to balanced or oscillating sediment supply, elevated sediment supply, and (or) periods of stable base level (Finnegan and Dietrich, 2011).

Explanations for why many incising rivers alternate between periods of dominantly lateral and dominantly vertical incision generally appeal either to temporal variation in base-level stability or in the volume of coarse sediment supplied to rivers. For example, because gravel deposition in rivers armors the bed and suppresses vertical incision (Sklar and Dietrich, 2004), some propose that lateral channel shifting and strath terrace formation is favored during climatic periods of higher sediment supply relative to river transport capacity, whereas vertical incision is favored when sediment supplies are low relative to transport capacity (Molnar and others, 1994). Alternatively, because base-level stability forces a river to remain at one elevation, others propose that either tectonic quiescence punctuated by periodic uplift or sea-level rise and fall superimposed on steady tectonic uplift (Pazzaglia and Gardner, 1993) can generate flights of strath terraces.

Aggradation, during the onset of dry warm climatic cycles, results from increased sediment supply in response to transient vegetative conditions and consequent hillslope destabilization (Bull, 2007). Similar to aggradation events, strath terrace sediment ages may correlate to periods of dry, warm climate (DeVecchio and others, 2012). Increased sediment flux and decreased water discharge enhance lateral erosion rates and inhibit vertical incision. Subsequent incision, abandonment and

strath terrace formation is inferred to occur during intervening wet climate intervals. In the western Transverse Ranges, where DeVecchio and others (2012) dated the strath terraces, they correlated strath terrace ages and aggradational events with environmental changes that are linked to global climate, indicating that climate rather than tectonics exhibits first-order control of depositional, denudational, and incisional processes.

Methods

The tools used to construct this geologic map were field work in combination with digital terrain analysis, stream gradient profiles, evaluation of published regional soil maps, and satellite imagery. Initial field work demonstrated that unique soils existed on both terrace and alluvial fan deposits, and that Arroyo Seco terrace surfaces could be correlated to alluvial fan deposits in the Salinas River valley.

Terrace-tread slopes were calculated from a 10-m digital elevation model using a geographic information system (GIS). Slopes less than 10 degrees were mapped and polygons were drawn around the individual surfaces. After measuring the elevation on each mapped terrace polygon, a longitudinal profile was constructed of all terrace surfaces along Arroyo Seco (fig. 7). Longitudinal profiles are measures of surface elevations along a stream gradient. Longitudinal profiles were also constructed on the other two major drainages in the map area—Reliz Canyon and the Salinas River. Based on these profiles, terrace surfaces were correlated along Arroyo Seco. Twenty unique terraces were mapped from the point at which Arroyo Seco

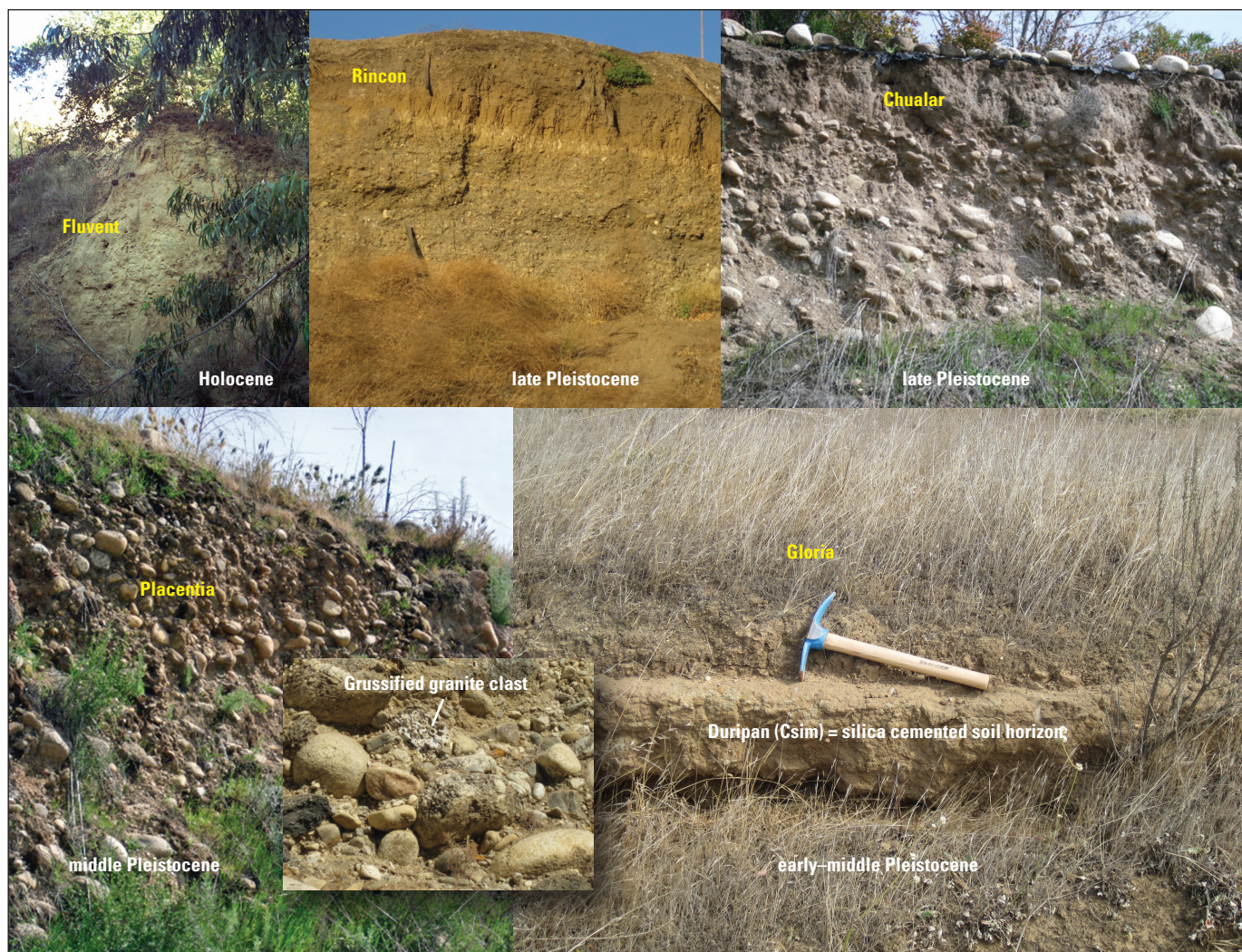


Figure 6. Unique soils are developed on the terrace surfaces. After deposition and fluvial abandonment, soils develop redder and thicker B horizons. These B horizons become increasingly cemented over time. Once intact gravel weathers to grus, only scattered and larger clasts are visible on the surface of the deposit. These photographs are typical of common soils (names in yellow) developed on different-aged deposits (table 2, sheet 1).

emerges from the narrow bedrock canyon to the intersection of Arroyo Seco with the Salinas River valley. Where Arroyo Seco enters the Salinas River valley, fluvial material is deposited and alluvial fans are formed. These fans were correlated to terrace surfaces based on elevation and soil development.

The soil map of Monterey County (Cook, 1978), in digital format [U.S. Department of Agriculture (USDA), 2009], was used to examine the soils developed on each of the unique terrace units. Soils were combined and simplified so that each map unit had a primary characteristic soil or set of soils (table 1, sheet 1). A preliminary geologic map that included both map units and soil types was used for field investigations to check units for consistency. Map-unit ages were initially assigned based on relative soil characteristics on Quaternary depositional units. Soils and bedrock units were observed in natural and existing manmade exposures. Field work focused on discrepancies between map units and soils—locations where soils were mapped on map units that seemed too old

or too young based on the stratigraphic position of the unit. The final map product includes both the map unit and the soil developed on the unit (table 1, sheet 1). Note that soil units may be mapped on more than one map unit, and conversely, the same map unit may have more than one soil unit. Soil units are not mapped on oldest strath terraces (Qfo1–Qfo8) because original soil mappers did not recognize high terraces as being capped in alluvial gravel and only mapped residual soil.

Eight sediment samples were collected to determine age by infrared stimulated luminescence (IRSL) or optically stimulated luminescence (OSL) (S. Mahan, written commun., USGS, 2012) (table 1, sheet 1; table 3, sheet 2). All samples were collected at the base of the soil profile in the unweathered C horizon. Surface soils were sampled with the exception of AS10-9-6 that was sampled in a terrace gravel buried by an alluvial fan and exposed in a road cut in Arroyo Seco (fig. 5). See detailed geologic map for site locations and unit descriptions for discussion.

8 Quaternary Geologic Map of the North-Central Part of the Salinas River Valley and Arroyo Seco, California

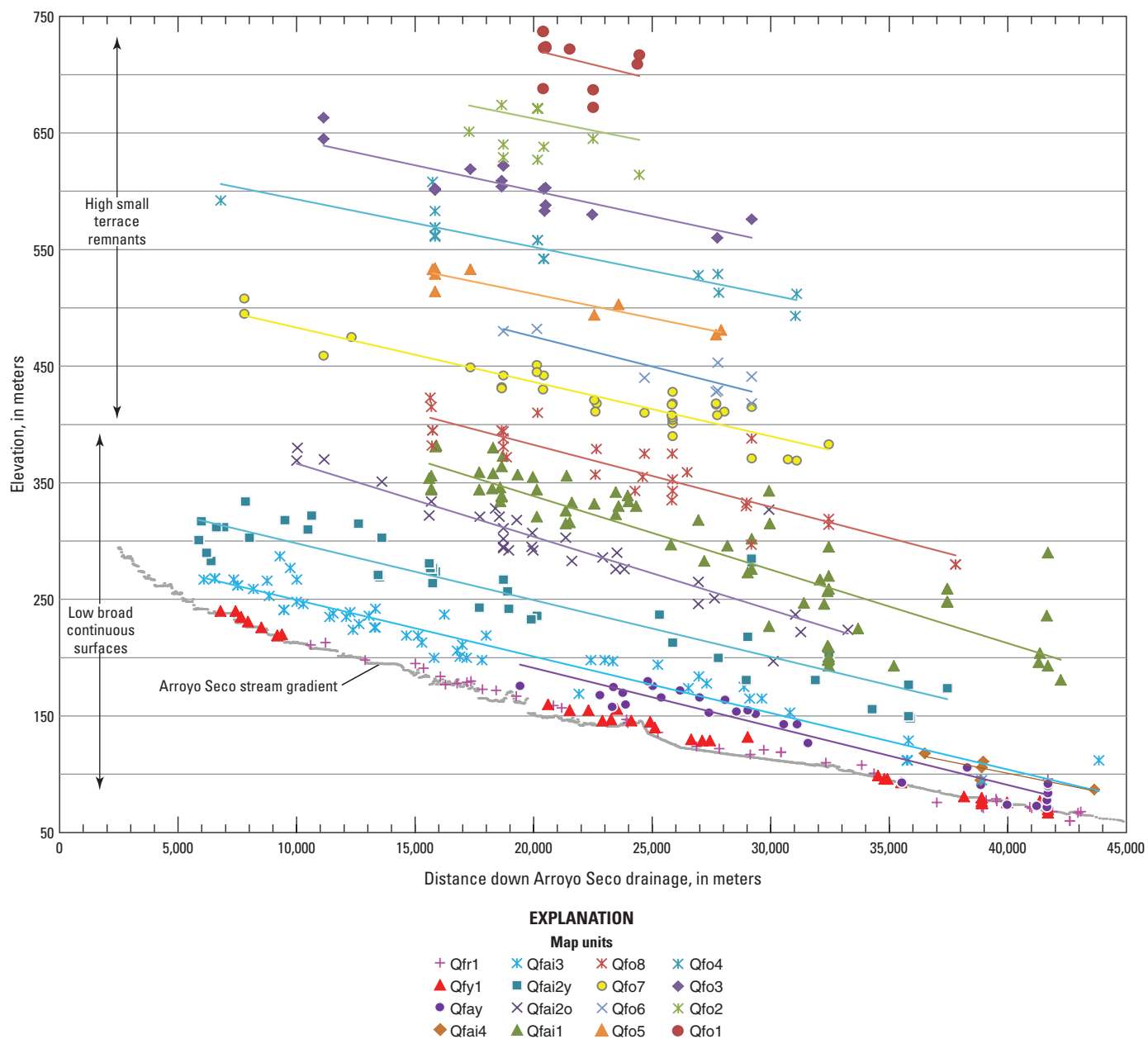


Figure 7. Stream gradient profile of terrace surfaces along Arroyo Seco. Different colored symbols represent different terrace surfaces. Terraces are approximately parallel and range in elevation from 800 to 100 m above sea level.

Discussion and Summary

Mapped strath terraces in the vicinity of Arroyo Seco record an erosion history from the early Pleistocene to latest Holocene. Alluvial fans adjacent to the range front and extending to the central Salinas River valley can be correlated to erosional surfaces in Arroyo Seco using soils and stream-gradient profiles. Young terrace and floodplain deposits can be observed at and adjacent to Arroyo Seco and Salinas River. This suite of erosional and depositional units can be used to generalize the Quaternary history of Arroyo Seco.

Prior to the cessation of the deposition of the Paso Robles Formation (QTpr), an ancestral drainage was eroding the broad paleoerosional surface north of Arroyo Seco (fig. 1, sheet 1). The highest (oldest) deposits (Qfo1–Qfo5) record stream erosion and deposition prior to Arroyo Seco valley incision. Isolated now in the Sierra de Salinas, this paleoerosional surface forms a gently sloping, low-relief geomorphic surface northwest of Arroyo Seco. Like Arroyo Seco, this paleoerosional surface is constrained by basement rocks and lies on the more easily erodible Tertiary marine sediments. Bounded by a complex web of faults on all sides, these isolated erosional remnants are no longer linked to a large active drainage but record a paleodrainage now abandoned and superseded by the Arroyo Seco system. What remain as possible linked drainages are the greatly undersized Paloma and Piney Creeks (fig. 3). Individual erosional surfaces of the ancestral drainage (units Qfo1–Qfo5) tend to decrease in elevation in a northwestward direction. If higher surfaces truly are older than lower surfaces, the mapping suggests a general northwest trend in surface age, linking the paleoerosional surface to the headwaters of the Carmel Valley drainage (Tularcitos Creek). Today the Carmel Valley drainage is separated from the paleoerosional surface by a low divide. An alternative interpretation would link the paleoerosional surface to a drainage flowing southeast prior to the inception of Arroyo Seco, and surface age is convoluted by faulting that surrounds the surfaces, and (or) northwestward tilting. The fan shape of the paleoerosional surface, which extends to the northwest out of the map area, supports a southeast flow direction. The apex of the fan occurs approximately at the divide.

The timing of formation and isolation of strath deposits in Arroyo Seco, which postdate the formation of the paleoerosional surface, was likely controlled primarily by paleoclimatic events and secondarily by tectonics. Contributions to terrace formation that were driven by faulting would have to be attributed to the Rinconada fault because of the lack of evidence for Quaternary movement on the Reliz fault. Fault-related uplift may occur through the transfer of slip onto other faults in the Santa Lucia Range or by transpressive crustal shortening across the Santa Lucia Range (Dickinson, 2005). Net Neogene crustal shortening across the northern Santa Lucia Range of 10–12 percent (Dickinson, 2005) could result in 2.2–2.7 km of bedrock uplift, corresponding to a 0.7–0.9 mm/yr tectonic component of the bedrock uplift (Ducea and others, 2003). The absolute ages of the terraces in Arroyo Seco would be a valuable tool for establishing the magnitude of Quaternary uplift rates in the Santa Lucia Range. During this period of

vertical movement, the level of the ocean has not remained the same. Changes in sea level are primarily produced by climate factors, but tectonics can also be a contributing factor. Taken together, these factors give rise to a complex pattern of continental erosion and deposition, which in this study are expressed as a sequence of strath terraces and associated alluvial fans in Arroyo Seco. DeVecchio and others (2012) have dated strath terraces at 110–100 ka, 50–35 ka, 26–20 ka and 15–4 ka in the southern California Transverse Ranges and correlated these depositional events to the onset of dry, warm climate cycles. The OSL and IRSL dates on seven individual terraces and associated alluvial fans in Arroyo Seco are approximately >120 ka, >65 ka, 51–46 ka, 35 ka, 9 ka, and 2–1 ka (table 1, sheet 1). These dates generally fall within the range of ages reported from the Transverse Range, which has a similar climate to that of Arroyo Seco. DeVecchio and others (2012) support the interpretation that decreased vegetation and water during dry warm climate intervals causes increased sediment flux and increased lateral erosion. Incision and strath terrace formation is inferred to occur during wet climate cycles. In these similar tectonically active environments, climate rather than tectonics is the more influential factor in “deposition, denudation, and incision processes” (DeVecchio and others, 2012).

No terrace in Arroyo Seco is correlative with the older and higher paleoerosional surface. It can be assumed that the drainage, in its current location, did not exist when the paleoerosional surface was formed. Any alluvial fans in the Salinas River valley that may have been associated with the erosion of the paleosurface are long buried by younger fans. The oldest strath terrace remnants (Qfo6–Qfai2), confined to the Arroyo Seco drainage, are preserved as a wide strand across the now-confined valley. Based on the mapped distribution of the strath terraces, this older, much broader drainage was probably a braided stream, indicating a steep gradient with a high flow-velocity. Over time, the gradient decreased and the drainage became confined to a meandering stream (Qfai3–Qfr). Meandering streams flow in low gradient, low flow-velocity environments (Schumm and others, 2000).

Stacked and matching terraces across the Arroyo Seco drainage record an erosional history beginning in the early Pleistocene with the inception of the current drainage. Soils developed on these terraces can be used to constrain the timing of terrace formation and remnant fluvial deposition on eroded bedrock. Base-level change, driven by climate change, is the major contributor to terrace formation in Arroyo Seco.

Acknowledgments

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DESCRIPTION OF MAP UNITS

- Qcb** **Cut bank (latest Holocene)**—Steep exposed bluffs on active drainages
- Qfr2** **Fluvial and minor eolian deposits (latest Holocene)**—Active channel, floodplain including gravel and sand bars, and modern dunes at and adjacent to the distal floodplain of Arroyo Seco and adjacent to the Salinas River with little or no vegetation. Soils are gravelly to sandy Entisols with no horizon development
- Qfr1** **Fluvial deposits (latest Holocene)**—Terrace and floodplain deposits, <1 m above the active channel of Arroyo Seco and Salinas River with sparse vegetation. Soils are sandy Entisols with no horizon development (see Fluvent photo, fig. 6)
- Qfy2** **Fluvial deposits (late Holocene)**—Terrace and floodplain deposits <2 m above the active channel of the floodplain of Arroyo Seco and Salinas River. Soils are fine-loamy Mollisols with an A/C profile
- Qfy1** **Fluvial deposits (late Holocene)**—Terraces adjacent to Arroyo Seco, <3 m above the active channel, prograding to minor terrace remnants on the floodplain where unit may interfinger with **Qfr1**. Within Arroyo Seco, deposit often hosts large, established sycamore trees and unit **Qfy1** has been dated at about 1,000 years old (table 3, sheet 2; see Fluvent photo, fig. 6). Terraces also occur as remnants <7 m above the active channel of the Salinas River. Soils are sandy Entisols with an A/C profile
- Qfay** **Fluvial and alluvial deposits (middle to early Holocene)**—Strath terraces on Arroyo Seco that prograde to alluvial fans. Alluvial deposits enter the Salinas River valley and bury older fan deposits and are dated at $9,570 \pm 650$ years old (table 3, sheet 2). Alluvial fans have been eroded by younger **Qfy1** and **Qfy2** deposits. Inset alluvial terraces of **Qfay** age also occur along Chalone Creek on the east side of the Salinas River valley. No **Qfay** is mapped south of Arroyo Seco. Soils are coarse-loamy Mollisols with an A/C profile
- Qfai4** **Fluvial and alluvial deposits (latest late Pleistocene)**—Alluvial fans and terraces, adjacent to both Arroyo Seco and Salinas River. Deposit is often a thin mantle <2 m thick over **Qfai3** at and adjacent to the range front. **Qfai4** was dated but the age, $8,770 \pm 350$ years old (table 3, sheet 2), is not consistent with the soil formed on the deposit and the deposits close proximity in depositional timing to **Qfai3**. The deposit is probably between 20,000 and 30,000 years old. **Qfai4** occurs as a strath terrace on the east side of the Salinas River, and in Arroyo Seco about 30 m above the active floodplain. Exposures of **Qfai4** extend only about 7 km west of the intersection of Arroyo Seco with the Salinas River valley. Soils are clayey Alfisols with an A/Bt/C profile. Bt horizon has a brownish hue (10YR) with about 45 percent clay. High clay content in maximally developed B horizon (table 2, sheet 1; Rincon soil series) may result from contributions of fine-grained overbank flood deposits. Secondary carbonate is infrequently observed in the C horizon (see Rincon photo, fig. 6)
- Qfai3** **Fluvial and alluvial deposits (latest late Pleistocene)**—Alluvial fans and strath terraces associated with Arroyo Seco and Reliz Canyon. **Qfai4** and **Qfai3** are the dominant inset terraces along the meandering Arroyo Seco and very little time separates the deposition of these two units. Where **Qfai3** forms strath terraces in Arroyo Seco it is about 40 m above the active drainage and where it forms alluvial fans it is about 10 m above **Qfai4**. **Qfai3** alluvial fans are buried by unit **Qfay** near the confluence of Arroyo Seco and Reliz Canyon. Remnants of the **Qfai3** strath terraces extend the entire length of Arroyo Seco. **Qfai3**-age deposits surround the abandoned oxbow lake near the canyon mouth of Arroyo Seco, near the western map edge, suggesting that the meander sweep was abandoned after the erosion of **Qfai3**. **Qfai3** is dated at $35,350 \pm 3,680$ years old (table 3, sheet 2). Soils are predominantly loamy alluvial Mollisols with an A/Bt/C profile. Bt horizon has a brown (10YR) to reddish hue (7.5YR) with 25–35 percent clay (See Chualar photo, fig. 6)
- Qei** **Eolian deposits (latest late Pleistocene)**—Eolian sand dunes modified to terraces, about 30–40 m above the active floodplain of the Salinas River. Deposit is east of the Salinas River, and has been eroded by **Qfai4**-age deposits. This deposit is also southeast of the town of King City, just east of the mapped area. Soils are loamy sandy Alfisols with an A/Bt/C profile. Bt horizon has a brownish (10YR) to reddish hue (7.5YR) with 15 percent clay
- Qfai2y** **Fluvial and alluvial deposits (latest late Pleistocene)**—Alluvial fans and strath terraces. A **Qfai2y** terrace in Arroyo Seco is dated at $50,640 \pm 2,980$ and $45,960 \pm 1,840$ years old (table 3, sheet 2). The erosional event associated with the formation of **Qfai2y** was indirectly dated at <65,000 years old because a **Qfai2y** alluvial

fan buried a terrace gravel that was dated at >65,000 years old (fig. 5). **Qfai2y** is about 80 m above the modern drainage. **Qfai2y** forms a predominant range-front alluvial fan south of Arroyo Seco. Soils are loamy alluvial Mollisols with an A/Bt/C profile. Bt horizon has a brownish hue (10YR) with about 35 percent clay

- Qfai2o** **Fluvial and alluvial deposits (latest late Pleistocene)**—Strath terraces in Arroyo Seco. Terraces are typically remnants located above the modern drainage and large strath terraces within the meandering drainage. Buried **Qfai2o** terrace deposits were dated at >65,000 years old. Soils are the same as those on **Qfai2y** indicating very little time between the abandonment of **Qfai2o** and **Qfai2y**
- Qfai1** **Fluvial and alluvial deposits (early late Pleistocene)**—Strath terraces in Arroyo Seco formed on the Tertiary marine sediments and Paso Robles Formation. Terraces form dramatic erosional features on both the east and west sides of the Salinas River valley, including the range front where Arroyo Seco intersects the broad valley. These terraces, and all older terraces, lack the general meandering nature of the younger terraces and were created in a much broader alluvial floodplain than today. This broader floodplain was probably a braided drainage system suggesting a higher velocity drainage than the current meandering system. Soils are typically coarse-loamy Mollisols and Alfisols developed on granitic alluvium with an A/Bt/C profile (see Placentia photo, fig. 6). The Bt horizon has a brown (10YR) to darker reddish-brown hue (5YR). **Qfai1** also includes silty and clayey residual soils, developed on both Tertiary marine sediments and the Paso Robles Formation. These soils have an A/C profile
- Qao** **Alluvial deposits (late middle Pleistocene)**—Alluvial fans flanking range front north of Arroyo Seco, extending north of the mapped area on the east and west sides of the Salinas River valley. Soils are coarse-loamy Alfisols developed on granitic alluvium with an A/Bt/Csim profile. Silica cementation in the C horizon, called a duripan (Csim), is extremely hard when dry and does not slake during prolonged soaking in water. The Bt horizon has a reddish-brown (7.5YR) to darker reddish-brown hue (5YR) (see Gloria photo, fig. 6)
- Qfo8–1** **Fluvial deposits (middle to early Pleistocene)**—Strath terraces **Qfo8–Qfo1** on Tertiary marine sediments. Stranded or isolated Arroyo Seco terrace treads capped by rounded granitic cobbles to boulders. Terraces are on both sides of the drainage. All surfaces have a less than 10 degree slope. Individual remnants of units **Qfo8–Qfo1** are correlated by stream gradient profile interpretations (fig. 7). Older surfaces (**Qfai1** and older) record a broader, high flow-velocity, steep gradient, braided stream in Arroyo Seco that has subsequently evolved into the current meandering drainage
- QTpr** **Paso Robles Formation (middle Pleistocene to Pliocene)**—Unconsolidated to poorly consolidated heterogeneous coarse sand and gravel, as well as interbedded finer sand, silt, and clay. Coarse fragments are primarily siliceous shale of the Monterey Formation. Environment of deposition is fluvial and includes some debris flows and lacustrine deposits. Datable tephra layers are interbedded with clastic strata. Tephra samples from the Paso Robles Formation in the Gabilan Range include the Nomlaki Tuff (3.4 ± 0.4 Ma) and the Lawlor Tuff (4.1 ± 0.2 Ma) (Sarna-Wojcicki and others, 1991). The Paso Robles Formation is exposed in the hills on the east and west sides of the Salinas River valley. On the east, it overlies unit **MzPzub** (undifferentiated basement) and on the west Tertiary marine sediments (**Tms**). Unit is commonly capped by erosional strath terraces. Ranges in thickness from 60 to 600 m
- Tsa** **Shallow nearshore marine regressive sediments (Pliocene)**—*Informal sandstone of San Ardo*. Sandstone, light gray, friable, medium grained, vaguely bedded, contains shell fragments. Unit occurs along the range front where Arroyo Seco intersects the Salinas River valley and in Reliz Canyon
- Tpr** **Pancho Rico Formation (Pliocene to Miocene)**—Siltstone, light gray diatomaceous mudstone to fine-grained silty sandstone, vaguely bedded. Shallow-marine, estuarine, and lagoonal sediments. In the map area, **Tms** occurs on the west side of the Salinas River valley, however, south of the map area, the Pancho Rico Formation flanks the east side of the Salinas River valley
- Tms** **Tertiary marine sediments (Miocene to Paleocene)**—*Primarily Monterey Formation*. Siliceous shale and sandstone. Shale is white to gray, thinly bedded, soft to hard, platy, contains thin, hard layers of limestone. Abundant fish fossils. Sandstone is light gray to tan, massive to thick-bedded, medium-grained, arkosic. Includes a small outcrop of Paleocene to Eocene Reliz Canyon Formation south of Arroyo Seco
- MzPzub** **Undifferentiated basement rocks (Mesozoic to Paleozoic)**—Plutonic basement, primarily granitic rocks, and metasedimentary rocks, mostly schist and gneiss. Metasedimentary rocks are intruded by granitic rocks. Rounded granitic rocks derived from unit occur as field stones capping strath terraces (fig. 7, sheet 1)

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