1999

Qaternary alluvial surfaces and deformation, Monterey County, California

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QUATERNARY ALLUVIAL SURFACES AND DEFORMATION, MONTEREY COUNTY, CALIFORNIA

A Thesis

Presented to

The Faculty of the Department of Geology

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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May 1999

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ABSTRACT

QUATERNARY ALLUVIAL SURFACES AND DEFORMATION, MONTEREY COUNTY, CALIFORNIA

By Alisa C. Klaus

Four generations of Quaternary alluvial surfaces were studied to assess Quaternary movement on the Rinconada and San Antonio faults in southern Monterey County, California. Relative elevation, surface steepness, soil development, and other weathering characteristics were used to determine relative ages of the surfaces. Longitudinal profiles were constructed to evaluate base level changes and tectonic deformation of the surfaces.

A fault scarp and longitudinal profiles of 300,000- to 400,000-year-old surfaces reflect at least 5 m of vertical offset on the Rinconada fault; timing of the movement remains uncertain. Longitudinal profiles of surfaces that formed 100,000 to 200,000 years ago suggest that the relative level of Lockwood Valley has dropped since that time, probably due to regional base level changes rather than tectonic uplift along the range front. Late Pleistocene surfaces appear to have been deformed by movement along the range-bounding San Antonio fault. Tectonic activity has evidently not affected Holocene surfaces.

ACKNOWLEDGEMENTS

Financial support for this study was provided by the San Jose State University Geology Department and Marshall Klaus. I am grateful to the landowners who generously allowed me to roam their land, and to the staff of the Environmental Department of Fort Hunter Liggett Military Reservation for arranging access to portions of the reservation. I would like to thank Professor Deborah Harden for her guidance in interpreting my field observations and for her perseverance with the project over the several years it took me to complete it. I also thank Professors David Andersen and Richard Sedlock for their high standards of prose and presentation and their close reading of this thesis.

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INTRODUCTION

The Rinconada fault in coastal central California has accommodated about 18 km of right-lateral offset since the early Pliocene (Durham, 1965a; Dibblee, 1976; Graham, 1976, 1978). However the overall significance of the Rinconada fault in the region's tectonic history and the extent and timing of Quaternary movement on the Rinconada and associated faults remain unclear. Evidence for Quaternary displacement on the Rinconada fault is concentrated on the Espinosa and San Marcos segments, between Paso Robles and King City (Fig. 1). Dibblee (1976) observed scattered evidence of Pleistocene movement on the Rinconada fault north of Paso Robles (Fig. 1), an apparent scarp in Pleistocene alluvium and possible elevation of Tertiary marine rocks against Quaternary older alluvium near Lockwood Valley (Fig. 2), and deflected and otherwise disrupted drainages along the trend of the fault. Hart (1985), however, noted the absence of the ephemeral geomorphic features usually associated with active strike-slip faulting.

Quaternary alluvial surfaces along the northeastern range front of Lockwood Valley and the eastern edge of Jolon Valley (Fig. 3), and adjacent to the Rinconada fault in the San Antonio Hills bordering Lockwood Valley, offer an opportunity to evaluate the influence of Quaternary tectonic activity on alluvial processes. Existing geologic maps of the study area (Durham, 1964, 1965b; Dibblee, 1971a,b) have focused on pre-Quaternary rocks and structures; the older Quaternary alluvial surfaces have not been differentiated from one

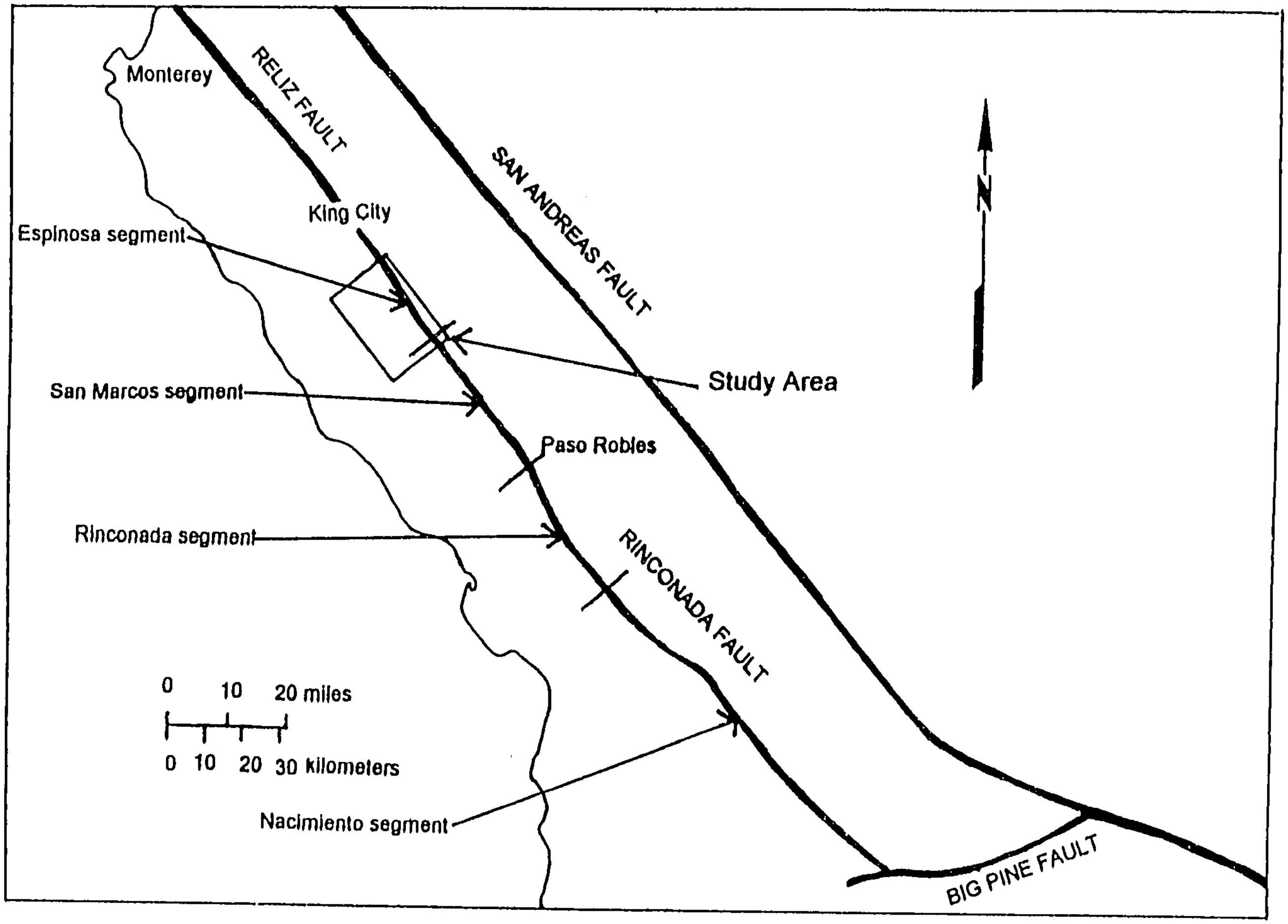

Figure 1. Rinconada fault segments (from Hart, 1985).

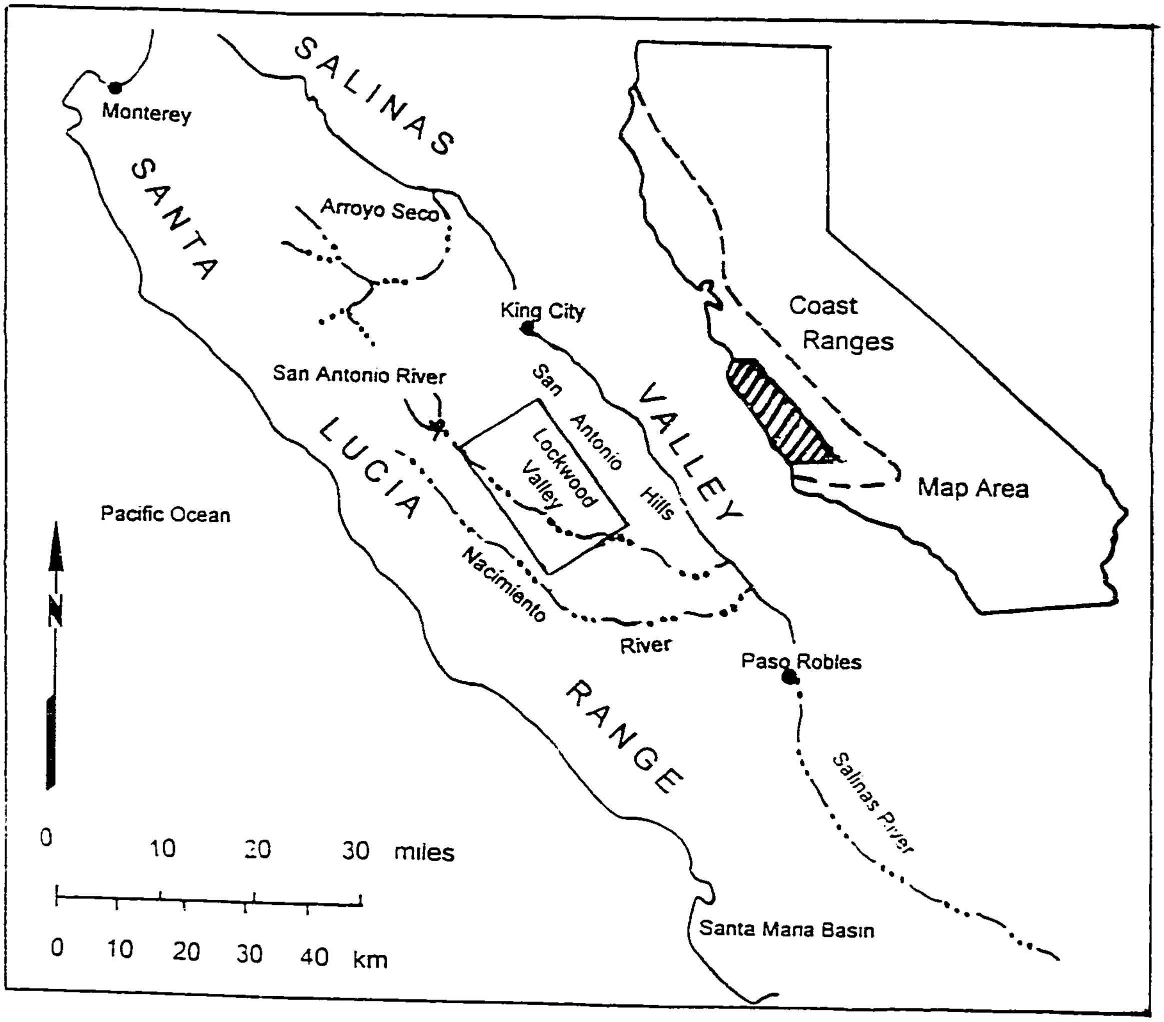

Figure 2. Index map showing location of study area.

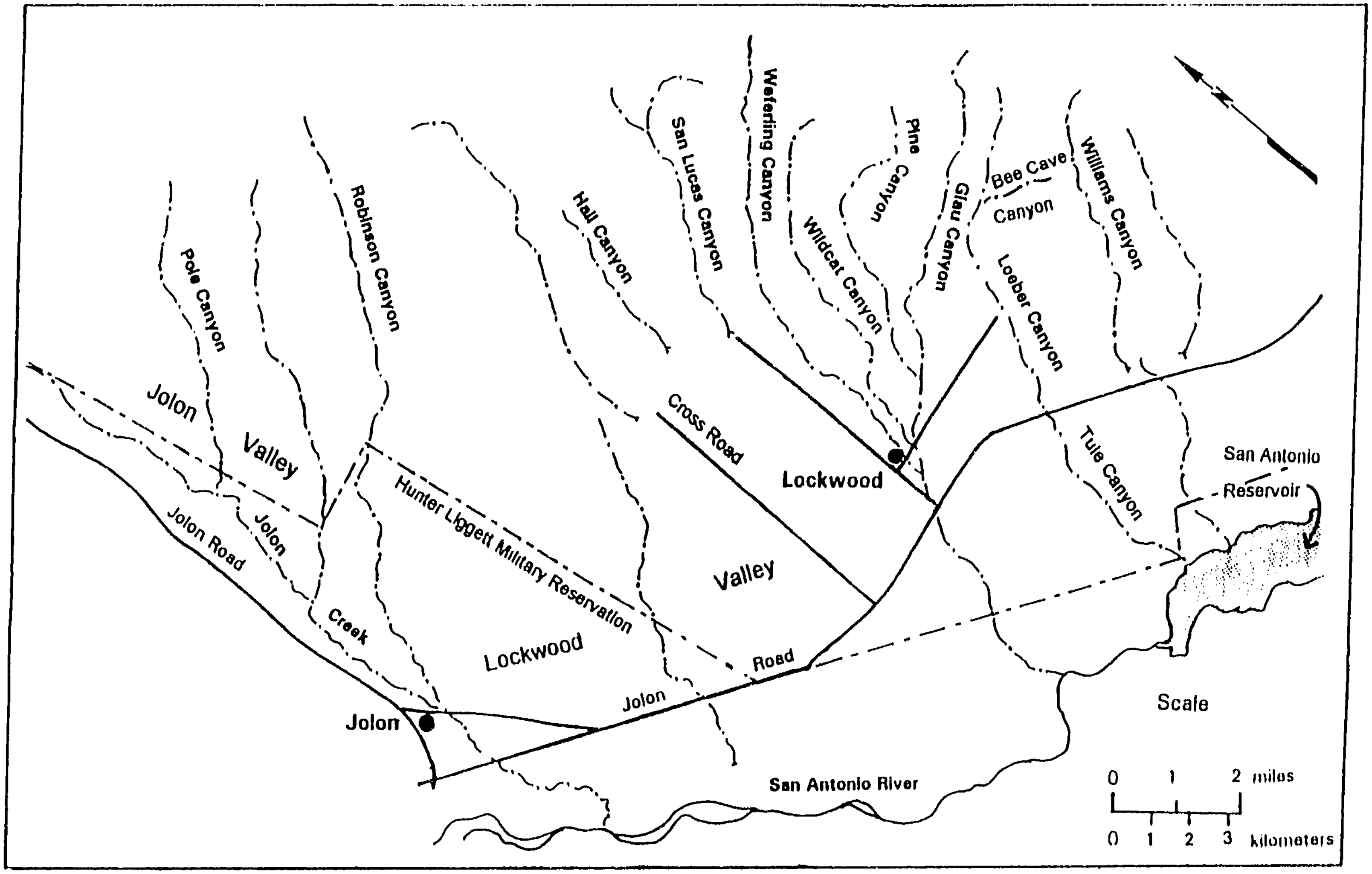

Figure 3. Index map of study area showing drainages (light lines), main roads (heavy lines), and towns (solid circles).

another, and authors have used varying criteria for distinguishing the Quaternary older alluvium from the Plio-Pleistocene Paso Robles Formation (Pike, 1925, 1926; Durham, 1964, 1965b). Previous investigations of the Rinconada fault have focused on surficial indicators of active faulting (Hart, 1985) and evidence of displacement of stratigraphic units in exposed sediment (Durham, 1964, 1965a,b; Dibblee, 1971a,b). Preliminary goals of this study therefore included detailed mapping of the older Quaternary alluvial surfaces in and near Lockwood and Jolon valleys, evaluating the relative ages of the surfaces by describing soil profiles and comparing with alluvial surfaces in the Salinas Valley, and refining earlier authors' distinctions between Quaternary alluvium and the Paso Robles Formation.

The larger goal of this study was to evaluate the effects of any Quaternary activity of the Rinconada and San Antonio faults on the Quaternary surfaces, including both tectonic influences on base-level processes, and post-depositional deformation. The study of tectonic influences on alluvial surfaces is appropriate for evaluating the extent and timing of vertical displacement on both surface and blind thrust faults (Bullard and Lettis, 1993). Although the Rinconada fault is known to be primarily a strike-slip fault, the apparent scarp in Pleistocene alluvium noted by Dibblee (1976) implies a vertical component of displacement. In addition, regional structures suggest that the San Antonio Hills are the product of a transpressive tectonic regime.

Location and Accessibility

Lockwood Valley is located near the southern end of the northern Santa Lucia Range of the central Coast Ranges of California, separated from the Salinas Valley by the low San Antonio Hills (Fig. 2). The Santa Lucia Range stretches along nearly 200 km of the central California coastline and extends about 40 km inland. In the northern part of the range, peaks are as high as 1,700 m; in the south, near the study area, the peaks are generally less than 1,000 m high. The San Antonio River, the major drainage of Lockwood Valley, flows toward the southeast along the southwestern side of the valley; near the lower end of the valley it passes through the San Antonio Reservoir (Fig. 3). Beyond the reservoir, it makes a sharp bend to the northeast and then joins the Salinas River about 15 km northeast of Paso Robles (Fig. 2).

A range of low hills extends from the east into the southeastern portion of Lockwood Valley in the vicinity of Tule Canyon, separating that portion of the valley from the San Antonio River (Fig. 3). The northeastern edge of Lockwood Valley curves toward the north, where it is aligned with the eastern edge of Jolon Valley, through which Jolon Creek flows southwestward to the San Antonio River (Fig. 3).

Temperatures in the study area are moderate throughout the year, with short, rainy winters and hot, dry summers. The area receives an average of 405 to 460 mm of rainfall annually, over 90% of it between November 30 and April 30 (Monterey County Planning Department, 1980). Much of the land in Lockwood and Jolon valleys and the larger tributary canyons has been cultivated; barley and wheat constitute the major crops. Annual grasses, scattered oaks, and chamise comprise most of the vegetation in areas that have not been cultivated. Figure 4 shows a typical view of the San Antonio Hills and southeastern Lockwood Valley. The coalescing Holocene fans, older fans, and/or pediments along the northeastern side of Lockwood Valley and the east side of Jolon Valley have generally been cultivated or used for grazing. The fans in the vicinity of Hall Canyon (Fig. 3) are subject to severe erosion, and in some cases the soils capping these are classified as xerorthents. Discontinuous gullies up to about 4 m deep have formed in many of the fans and canyon bottoms. No water was observed in any of the canyons during the field work for this study in the late spring, summer, and fall of 1995, although one landowner reported that water flows freely in Loeber Canyon during storms.

Jolon Road (Fig. 3) provides access to Lockwood and Jolon valleys from the Salinas Valley. Most of the study area is privately owned, with three or four large and numerous smaller landowners. The owners of a large ranch to the southeast of Williams Canyon do not allow researchers access to their land, nor was it possible to contact all of the smaller landowners who did not respond to written requests for access to their property. The areas to the south of Jolon Road and northeast of the village of Jolon (Fig. 3) lie within Hunter Liggett Military Reservation. At the time the field work for this study was performed, requests for access were referred to the reservation's environmental office and were subject to scheduling limitations. In addition, the author was allowed access to most areas of the reservation only when accompanied by staff of the environmental department.

Figure 4. Panoramic view of Lockwood Valley, taken from hill above Bee Cave Canyon, looking west. Quaternary alluvial surface between Glau and Loeber Canyons is in right center, with the Rinconada Fault running left to right across the far end of the surface. Lockwood Valley lies beyond the hills in the foreground; the northern Santa Lucia Range can be seen in the distance.

Methods

The surfaces were first delineated using 7.5-minute U.S.G.S. topographic quadrangles (U.S. Geological Survey, 1949) and aerial photographs, scale, 1:20,000 (U.S. Department of Agriculture, 1956); the geomorphic expressions of mapped faults and other photolineaments also were noted. The alluvium was then mapped in the field. Where soils were exposed naturally or in roadcuts, soil profiles were described using the parameters and format presented in Birkeland and others (1991). On the higher surfaces adjacent to the Rinconada fault, and in other locations where upper soil horizons were absent but outcrops of alluvium showed signs of weathering, weathering characteristics of the alluvium were described in detail.

It was not possible to determine absolute ages for the Quaternary surfaces. Relative ages were assigned on the basis of relative elevations above the modern drainages, soil development, and other weathering characteristics. The data were then compared with alluvial chronologies developed for the Salinas Valley (Dorhenwend, 1975; Tinsley, 1975), allowing tentative estimates of the ages of the Lockwood Valley surfaces.

In order to evaluate the effect of tectonics on the Quaternary surfaces, longitudinal profiles of the modern drainages and streams were constructed; profiles of the Quaternary surfaces were then projected orthogonally onto these stream profiles. The longitudinal profiles and field observations were combined to estimate the extent and timing of vertical deformation.

GEOLOGIC SETTING

Basement Rocks

The Sur-Nacimiento fault zone nearly bisects the Santa Lucia Range, separating rocks of the Franciscan Complex on the southwest from Salinian granitic and metamorphic basement on the northeast (Fig. 5). In the northern part of the range, which encompasses the upper reaches of the drainage basin of the San Antonio River, Salinian basement rocks crop out extensively. These include Mesozoic plutonic rocks that range from granite to diorite, and metamorphic rocks including quartz-feldspar gneiss, mica schist, feldspathic quartzite, and white marble (Dibblee, 1979). In the southern part of the range and in the study area, Eocene and younger sedimentary rocks, chiefly marine clastic rocks, cover the Salinian basement (Dohrenwend, 1975; Graham, 1978). Up to 650 m of Plio-Pleistocene and Quaternary alluvium fill the valley itself, and Plio-Pleistocene alluvial and lacustrine sediment crops out in low hills on the valley floor (Geotechnical Consultants, 1984).

Tertiary Marine Rocks

In the study area, Miocene and Pliocene marine sedimentary rocks (shown as "Tm" on Fig. 6) overlie the Salinian basement. In Lockwood Valley, the lower Miocene Vaqueros Sandstone, the Miocene Monterey Formation, and Pliocene marine sandstone form a section

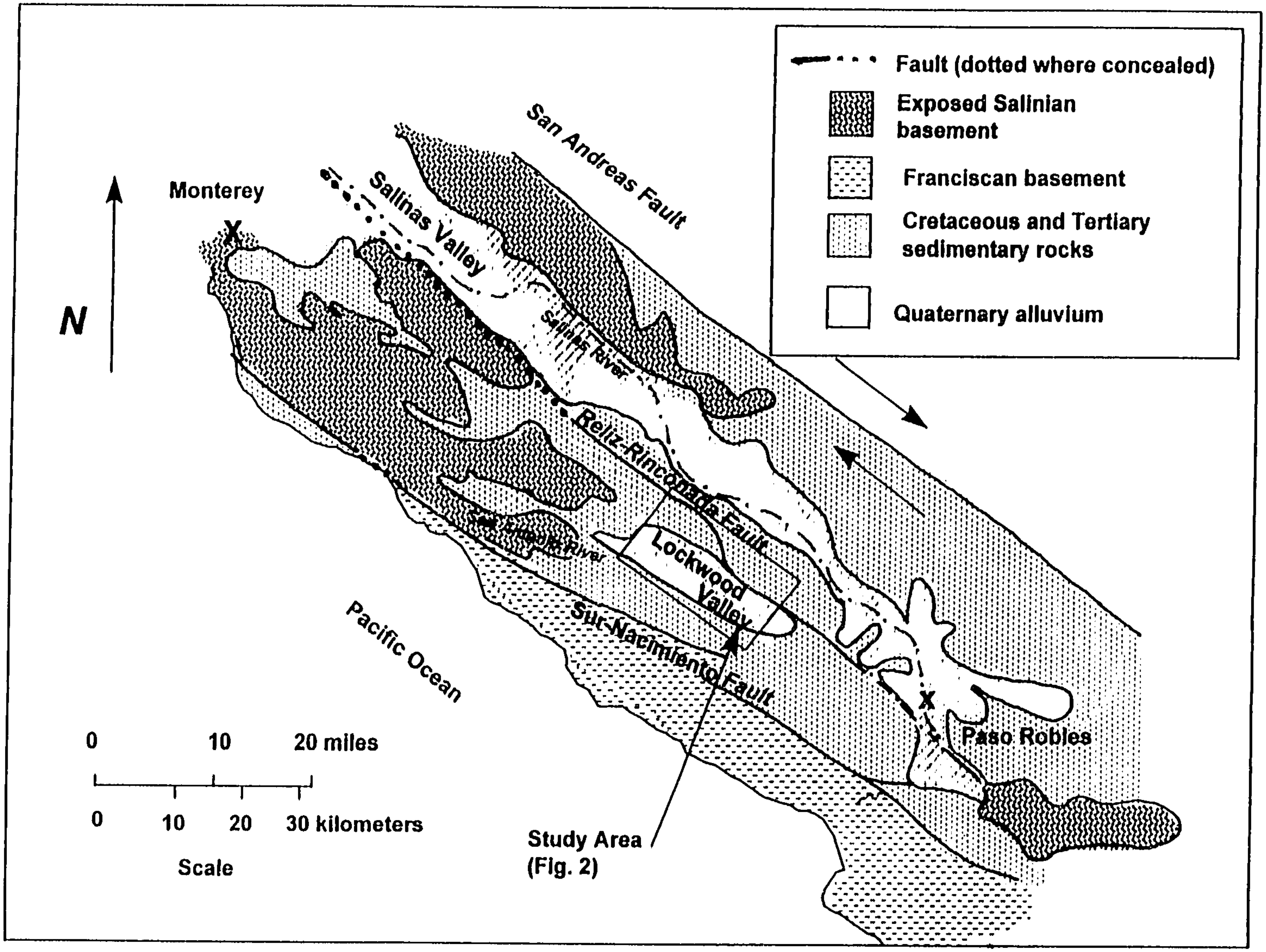

Figure 5. Regional geology (from Dibblee, 1979).

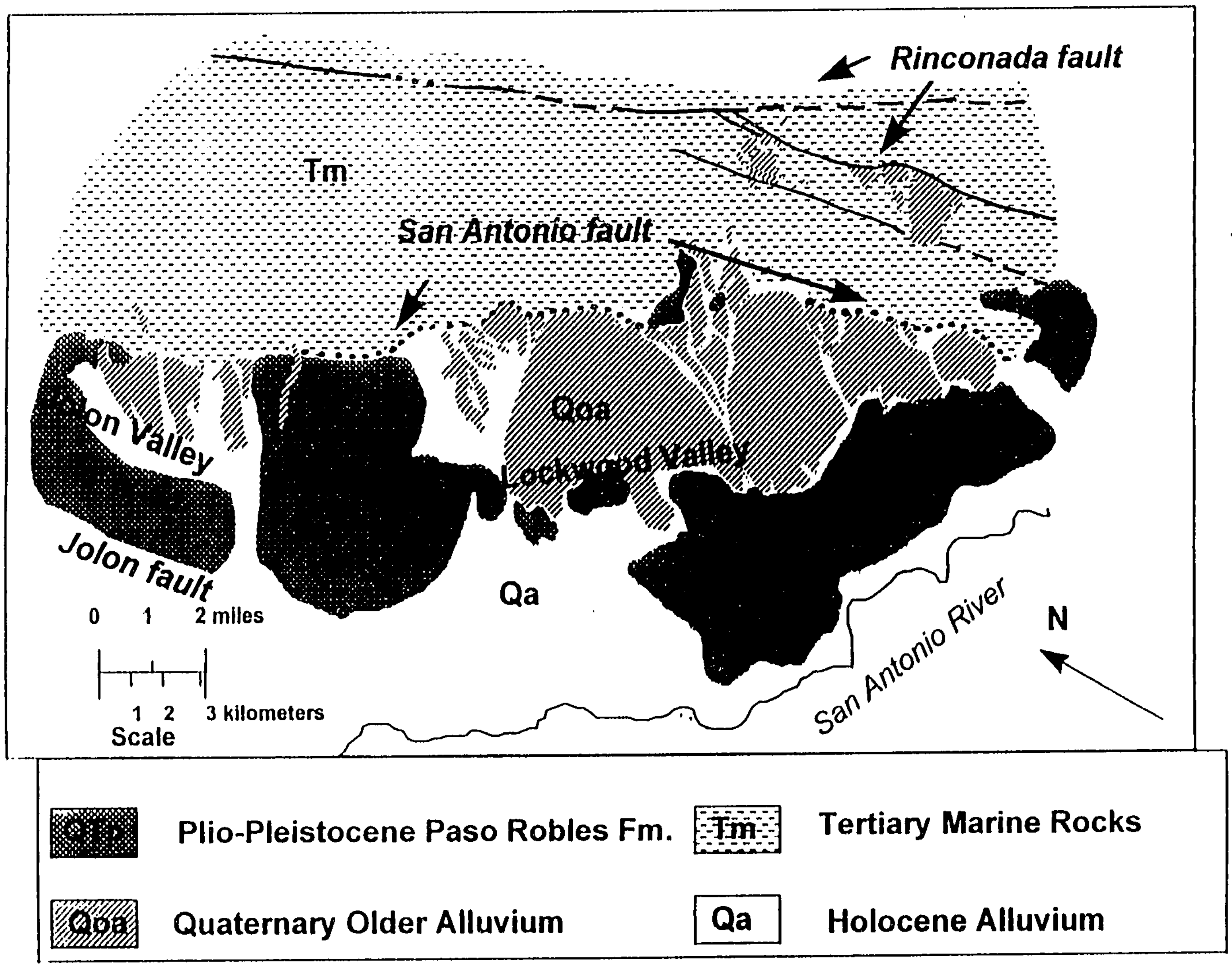

Figure 6. General geology of study area (from Dibblee, 1971a, 1971b, and Durham, 1964, 1965b).

that ranges from 600 to 1,500 m thick; in the San Antonio Hills east of the Rinconada fault the Monterey Formation alone is as much as 2,500 m thick (Dibblee, 1979).

The complete stratigraphic sequence of the Monterey Formation and related rocks is well developed in the Lockwood-Jolon area (Pisciotto and Garrison, 1981). This sequence includes a lower calcareous facies, a middle unit of phosphatic shale and mudstone, and an upper siliceous unit. Dibblee (1971a,b) shows only the siliceous upper Miocene member of the Monterey Formation exposed in drainages feeding the fans within the study area. These rocks include porcelanite and porcelaneous mudstone, well-cemented, non-calcareous mudstone, minor dolomitic beds, and minor light olive gray, brownish gray, or brownish black chert.

The hills underlain by the Monterey Formation are steep, rising to a maximum of about 490 m above Lockwood Valley. Major drainages are cut as much as 300 m below the ridgetops. Outcrops are scarce, as the rock is intensely fractured and easily eroded. Small debris flow scars are common on the slopes. Soils are typically clay loam 50 to 100 cm (20 to 40 inches) thick (U.S. Department of Agriculture, 1975a). South-facing slopes typically support sparse grass and scrub; north-facing slopes are more densely vegetated and commonly are covered with oaks.

Marine sandstone, diatomaceous mudstone, and silicic sandy siltstone of the Pliocene Pancho Rico Formation overlie the Monterey Formation and crop out in a discontinuous belt along the northeastern margin of Lockwood Valley and the eastern edge of Jolon Valley (included in unit "Tm," Fig. 6). The Pancho Rico Formation intertongues at the base with the

Monterey Formation, and there may be intertonguing nonmarine beds near the upper contact with the Paso Robles Formation.

Plio-Pleistocene and Quaternary Sediment

The Tertiary marine rocks are overlain by non-marine, Plio-Pleistocene sediment of the Paso Robles Formation (Unit "QTp" on Fig. 6). Alluvial and lacustrine sediment crops out in the low hills on the floor of Lockwood valley, and coalescing alluvial fans cover the northeast side of the valley. The valley is filled with up to 200 m of alluvium, including Plio-Pleistocene strata of the Paso Robles Formation and the Quaternary units that are the focus of this study. Previous authors (Pike, 1925, 1926; Durham, 1964, 1965b; Dibblee, 1971a,b) have not agreed on criteria for distinguishing between the Paso Robles Formation and Quaternary alluvium in the study area. Pike noted the predominance of igneous clasts in the Paso Robles Formation, whereas Durham described only porcelaneous rock and chert in the Paso Robles Formation and suggested that the only difference between the Paso Robles Formation and the Quaternary alluvium was that the latter was not deformed.

Tectonic Setting and Structures

In their overview of the tectonic setting of central coastal California, Clark and others (1994) attribute much of the present topographic relief of the central Coast Ranges to regional transpression that began in Pliocene time, apparently as a result of a component of convergence in the motion of the Pacific plate relative to the North American plate. Two types of Quaternary faults accommodate the uplift and deformation of the central Coast Ranges: the northwest-trending, predominantly strike-slip faults of the San Andreas fault system and west- to northwest-trending reverse and reverse-oblique faults. The major uplifts, troughs, and fold axes trend slightly west of northwest (Dibblee, 1976).

Between the 1920s and the 1960s, workers debated the timing of the Pliocene and Pleistocene uplift of the Santa Lucia Range (Reed, 1925; Taliaferro, 1943a; Snetsinger, 1962; Christensen, 1965). Most authors inferred that an episode of uplift in Pliocene time caused the widespread deposition of nonmarine sediment, known as the Paso Robles Formation in the Salinas Valley and in valleys within the Santa Lucia Range. Deformation of the Paso Robles Formation, which is folded broadly over the southern part of the range and sharply along the eastern side of the range (Christensen, 1965), constitutes the primary evidence for post-Pliocene uplift. Evidence for late Pleistocene and Holocene activity on the faults within the range is scanty, possibly because there are few deposits of late Quaternary sediment that might have recorded such movement (Clark and others, 1994).

Rinconada Fault

The Rinconada fault (sometimes, in conjunction with the Reliz fault, termed the Reliz-Rinconada fault) is thought to have played a key role in the uplift of the Santa Lucia Range. This interpretation of the Rinconada fault as a major Cenozoic tectonic feature originated with Dibblee (1976, p. 48), who argued that several faults previously considered to be separate, local faults in fact constituted a single, 200-km-long fault zone that he dubbed "the most extensive late Cenozoic transcurrent fault zone in the southern Coast Ranges west of the San Andreas fault."

The Nacimiento segment of the Rinconada fault forms the southwestern boundary of the Salinian block from the Big Pine fault, about 40 km northeast of Santa Barbara, to the vicinity of Paso Robles (Dibblee, 1976). The San Marcos segment (formerly known as the San Marcos fault) extends about 23 km northwest from Paso Robles to the San Antonio Reservoir; the Espinosa segment (formerly known as the Espinosa fault) traverses the San Antonio Hills obliquely between the Salinas and Lockwood valleys; and the Reliz fault runs along the western edge of the northern Salinas Valley (Fig. 2). Dibblee's argument that the segments define a single system was based primarily on their geographic alignment; no challenge to that interpretation has appeared in the published literature, and later authors have generally accepted his assessment.

Dibblee's structural interpretation of the Rinconada fault was essentially consistent with the consensus view that the Coast Range structures, including folds and thrust and reverse faults, are genetically related to large strike-slip movements on major faults (Clark and others, 1994). In a section across the Espinosa segment of the Rinconada fault, Dibblee (1976) showed thrust and reverse faults dipping toward the Rinconada fault from both sides.

Estimates of the amount and timing of right lateral displacement on the Rinconada-Reliz fault vary. Based on stratigraphic correlation and interpretation of paleogeography, Dibblee (1976) suggested a possible total offset of 60 km, including 23 to 56 km since early Miocene time. Graham (1976, 1978) argued for no more than 43 km of total displacement, including about 27 km since early Miocene time. Both accept Durham's (1965a) estimate of 18 km since the early Pliocene, most of which probably preceded deposition of the sediment of the Paso Robles Formation. The Paso Robles is the youngest formation definitely involved in movement along the Reliz-Rinconada fault (Tinsley, 1975).

As mapped by Dibblee (1971a,b), the Rinconada fault within the study area (a portion of the Espinosa segment) consists of three strands (Fig. 6). The central strand is Dibblee's main Rinconada fault strand and is associated with a steep gravity gradient (Dibblee, 1979). Dibblee tentatively showed the western strand as continuous with the San Antonio fault just southeast of the study area. The central and western strands join north of Lockwood Valley, near the head of San Lucas Canyon. The third, eastern strand, described by Durham (1965a, p. Q23) as "a zone of crushed and contorted rock 500 or more feet (150 m) wide," joins the main strand near Wildcat Canyon (Fig. 6). Each of these strands can be distinguished on topographic maps and aerial photos as a series of aligned drainages and saddles. The fault zone lies entirely within the Monterey Formation, except where it crosses Quaternary alluvium.

Dibblee (1976) cited evidence for Pleistocene activity on the Rinconada fault, including apparent vertical displacement of the Paso Robles Formation relative to the Miocene Monterey Formation on the San Marcos segment, possible elevation of Monterey shale against older alluvium near Lockwood Valley, and deflection of streams and canyons along the San Marcos and Espinosa segments. In an evaluation of the Rinconada fault, Hart (1985) focused on the San Marcos and Espinosa segments, stating that the remaining segments lacked clear geomorphic definition that might reflect recent activity. Hart found evidence of large-scale right-lateral displacement, including offset, beheaded, and otherwise disrupted drainages, primarily on the western strand and on the single strand northwest of Weferling Canyon. Hart also observed an apparent east-facing scarp truncating Pleistocene alluvial surfaces between Glau and Loeber canyons near Lockwood (Fig. 7). Hart did not, however, find evidence of faulting in alluvium exposed in gullies along the projected traces of the fault strands and noted than an old adobe structure within about 16 m (50 ft) of the western fault strand showed only minor stress cracks. He also noted the absence of the ephemeral, small-scale geomorphic features, such as sidehill benches, offset minor drainages, and small scarps, that typically are found along active strike-slip faults.

San Antonio Fault

South of Lockwood Valley, the San Antonio fault is the southwestern of two major traces of the San Marcos segment of the Rinconada fault (Fig. 1). Like the main trace, the San Antonio fault is vertical in most places, but locally it dips to the southwest or northeast (Dibblee, 1976). Northwest of the San Antonio dam, Dibblee noted an apparent fault contact between Monterey shale on the northeast and the Paso Robles Formation and Quaternary alluvium of Lockwood Valley on the southwest.

Dibblee (1971a) mapped the San Antonio fault bending northward into the San Antonio Hills near the southeastern end of Lockwood Valley (southeast of Williams Canyon), to join the western strand of the Rinconada fault, with a "minor thrust fault" splaying off to form the

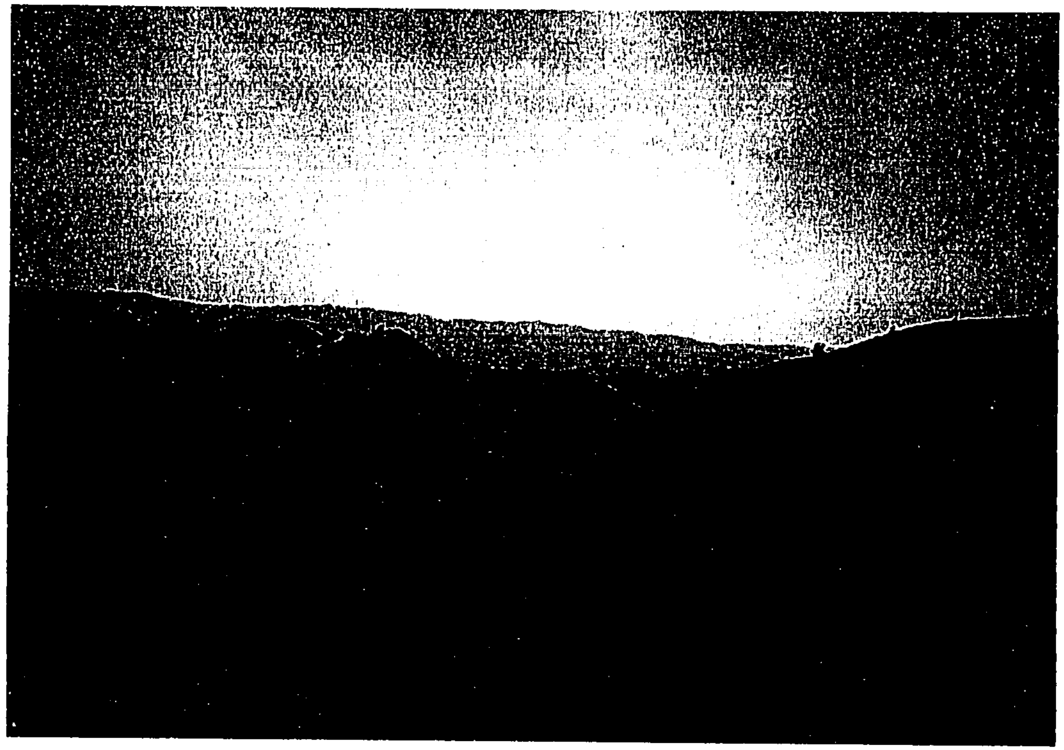

Figure 7. Scarp in Quaternary alluvium, between Glau and Loeber Canyons (Locality 23, Plate I). View to west; fault runs from left to right at the base of the low hill in the center of the photo.

northeastern boundary of Lockwood Valley. This study follows the nomenclature of Graham (1978) and Hart (1985), who both show the San Antonio fault continuing along the northeastern boundary of Lockwood Valley, where Dibblee indicated local thrust faults. Although the map of Dibblee (1971a) showed these unnamed local faults as buried, Dibblee (1979) reported evidence of possible fault contacts between Monterey shale and Quaternary alluvium in unspecified locations along the range front.

Durham (1965b) postulated that the system of faults along the northeastern boundary of Lockwood Valley (which this author is calling the San Antonio fault) was continuous with the fault zone forming the eastern border of Jolon Valley (Fig. 6). A cross-section constructed for a study of the hydrogeology of Fort Hunter Liggett Military Reservation (Fig. 3) shows a blind thrust fault within the Monterey Formation just east of Jolon Valley, with steeply folded beds of Tertiary marine sediment forming the boundary of a basin filled with about 450 to 650 m (1,500 to 2,000 feet) of Paso Robles sediment and a thin cover of Quaternary alluvium (Geotechnical Consultants, 1984). The authors of this study note that the shallow water-bearing deposits, which include the Paso Robles Formation and/or Quaternary alluvium, have been folded; the contact between these and the underlying Pancho Rico and Monterey formations is nearly vertical.

Jolon Fault

Durham (1965b) mapped a system of faults northwest of Jolon, forming the northeastern boundary of Lockwood Valley, which he called the Jolon fault (Fig. 6). Durham interpreted the Jolon fault as a major structural feature extending to the southeast under Lockwood Valley, where it is concealed by alluvium, and under the hills along the San Antonio River near the southeastern part of Lockwood Valley. As evidence for a fault in these hills, he noted an isolated outcrop of Monterey Formation near Tule Canyon that appears to be elevated anticlinally. Durham suggested that this fault, rather than the Espinosa fault (Dibblee's Espinosa segment of the Rinconada fault), formed the northwestern continuation of the San Marcos fault (Dibblee's San Marcos segment of the Rinconada fault). Dibblee (1976), however, discounted Durham's evidence for this argument and interpreted the Jolon fault as a local, 2-mile-long fault bounding the hills northwest of Jolon. Dibblee's (1971a) map shows this as a steep reverse fault with Monterey Formation on the northeast uplifted against Paso Robles Formation on the southwest.

Folds

The Tertiary marine rocks are broadly folded in Lockwood Valley along axes that trend generally northwest (Dibblee, 1979; Geotechnical Consultants, 1984). Involvement of the Paso Robles Formation in the folding is suggested by thinning of this formation over anticlinal structures (Geotechnical Consultants, 1984). Dibblee (1971a) also showed folds in Paso Robles sediment in Lockwood Valley. Beds of the Monterey Formation are intensely folded in the San Antonio Hills on both sides of the Rinconada fault (Dibblee, 1971a,b, 1979). Dibblee's maps show the folds trending slightly more east-west than the fault, and not crossing the fault.

PASO ROBLES FORMATION

Studies in the Salinas Valley

About 1,600 km^2 of continental sediment in the upper Salinas Valley (Fig. 2) have been assigned to the Paso Robles Formation by various researchers (e.g., Galehouse, 1967). Fairbanks (1898) named the formation for typical outcrops near Paso Robles, in the upper Salinas Valley. The Paso Robles Formation consists primarily of unconsolidated alluvial sand, gravel, silt, and clay, with some thin beds of lacustrine limestone (English, 1918; Taliaferro, 1943b; Galehouse, 1967). The total thickness is unknown; estimates range from 90 to 600 m (Galehouse, 1967). Studies of provenance and paleocurrent indicators suggest that, at the time of Paso Robles deposition, the Paso Robles basin drained southeastward into the San Joaquin Valley (Fig. 8). This drainage was defeated by uplift of the Temblor Range (Fig. 8) and southwestward tilting of the Gabilan Mesa (Galehouse, 1967; Dupré, 1991).

Dohrenwend (1975) described the Paso Robles sediment in the Salinas Valley south of Arroyo Seco (Fig. 8) as somewhat finer grained than that in the Paso Robles basin. His study of composition and paleocurrents indicated that drainage in the northern Salinas Valley during Paso Robles deposition resembled that of today, but that the Salinas Valley extended no further south than King City. His work and that of Tinsley (1975) suggest that the rocks mapped as Paso Robles Formation in the Salinas Valley were deposited in two separate basins.

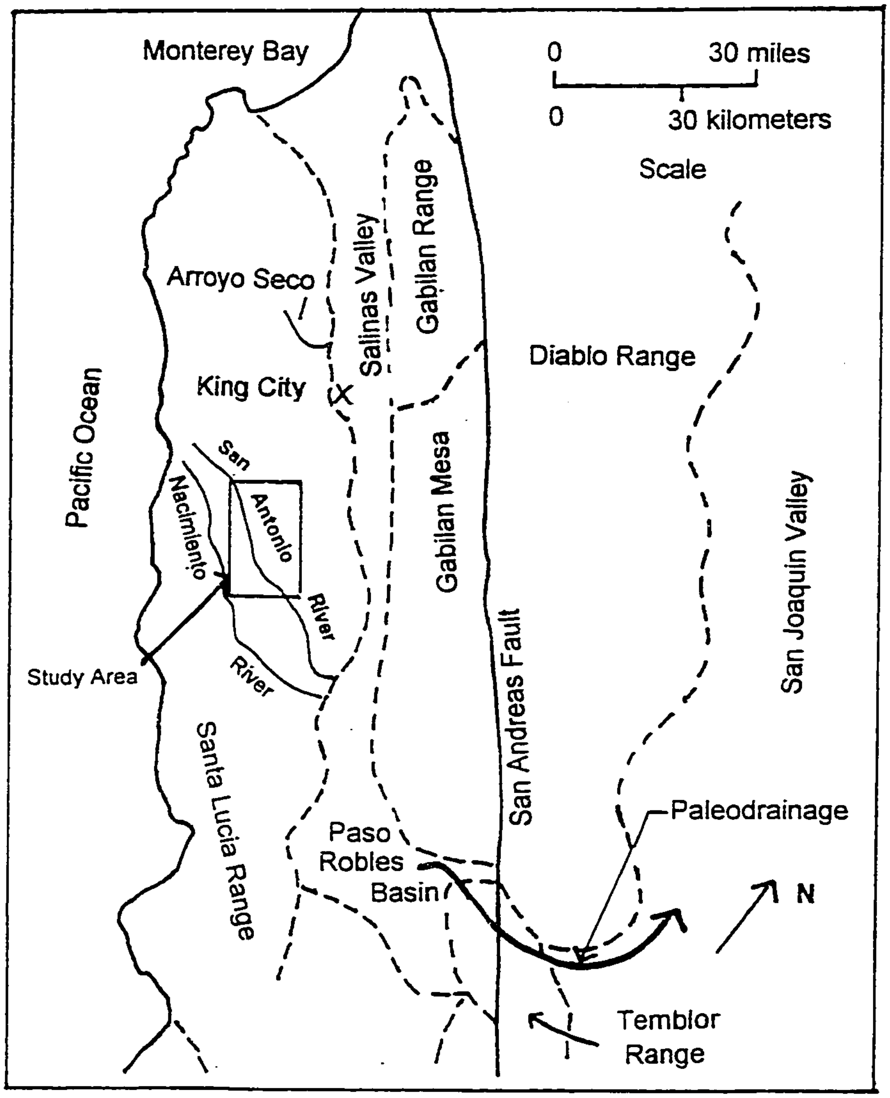

Figure 8. Physiographic features of the Salinas Valley region (after Galehouse, 1967).

The results of Galehouse's (1967) study imply a genetic relationship between the Plio-Pleistocene alluvium mapped in Lockwood and Jolon valleys and Paso Robles sediment in the Paso Robles basin (Fig. 8). The San Antonio and Nacimiento rivers apparently contributed Salinian basement clasts to the Paso Robles basin; these rivers probably were "major headwaters of the middle and late Pliocene drainage" (Galehouse, 1967, p. 974), and the upper end of the San Antonio River drainage must have been in the northern Santa Lucia Range, where Salinian basement rocks are exposed. Galehouse hypothesized that instead of bending to the northeast to enter the Salinas Valley, as it does today (Fig. 2), the San Antonio River continued generally southeastward into the Paso Robles basin. The defeat of Paso Robles drainage to the San Joaquin Valley may explain the presence of lake beds in the upper portion of the Paso Robles Formation. The San Antonio River, along with the Nacimiento River and other drainages in the upper Salinas Valley, subsequently must have been captured by the Salinas River.

Age of Paso Robles Formation

The age of the Paso Robles Formation has been a matter of some dispute. Fairbanks (1898), who named the Paso Robles Formation, considered it to be Pliocene in age. Later authors generally referred to it as Plio-Pleistocene, based in part on lithologic correlation with the San Benito gravels, the Tulare Formation, and the Paso Robles Formation in the Santa Maria basin to the south; paleontologic and radiometric evidence supports a late Pliocene to Pleistocene age for each of these (Galehouse, 1967). The Plio-Pleistocene age also was consistent with those authors' assumption that Paso Robles deposition was initiated as a result of a late Pliocene Coast Range orogeny.

Galehouse and Addicott (1973) found early Pliocene fossils in the Pancho Rico Formation, which conformably underlies and locally intertongues with the Paso Robles Formation. They concluded that most of the Paso Robles sediment in the Salinas Valley is middle to upper Pliocene. Tephra in the basal portion of the Paso Robles Formation in the northern Salinas Valley establish an age of at least 4.7 Ma, or early Pliocene, for this formation in that area (Sarna-Wojcicki, U.S. Geological Survey, oral communication, 1997).

Previous Work on Paso Robles Formation in Lockwood and Jolon Valleys

Pike (1925, 1926) described a unit he called the Jolon Formation unconformably overlying the Monterey Formation in Lockwood Valley, noting that it resembled the type section of the Paso Robles Formation, 80 km to the southeast. The Jolon Formation, which Pike interpreted as an old alluvial fan, consists of unconsolidated, generally unstratified gravel with minor sand; the clasts are mostly igneous, but diatomite fragments occur locally.

Durham's (1964, 1965b) description of the Paso Robles Formation in the Lockwood Valley area contrasts markedly with Pike's description of the Jolon Formation. Durham described the Paso Robles Formation as conglomerate, conglomeratic sandstone, sandstone, and mudstone, with large clasts of porcelaneous rock and chert of the types that occur in the Monterey Shale. He noted volcanic, granitic, and metamorphic clasts only south of the San Antonio River, outside the current study area. Durham described the mudstone as very pale orange, locally calcareous, massive or thick bedded, and containing scattered pebbles. He also tentatively assigned resistant limestone beds west of Tule Canyon, just north of the San Antonio River (Fig. 3), to the Paso Robles Formation.

Durham's criterion for distinguishing the Paso Robles Formation from Quaternary alluvium was that the latter was not deformed (Durham, 1964). Dibblee's (1971a,b) maps do not include detailed descriptions of units, and it is not clear on what basis he distinguished Paso Robles from Quaternary alluvium. Comparison of his map with observations made as part of the current study suggests that he included in the Paso Robles Formation not only sediment containing granitic clasts, but also alluvium derived exclusively from sedimentary rocks.

Durham (1964, 1965b) and Dibblee (1971a,b) mapped Paso Robles Formation at several localities within the study area. In the hills between the southern end of Lockwood Valley and the San Antonio River, where elevations are as much as 120 m above the valley floor, sediment mapped as Paso Robles Formation crop out nearly continuously (Fig. 6). This unit includes the limestone beds that Durham (1965b) questionably assigned to the Paso Robles Formation. In the hills west of Hall Canyon and north of the town of Jolon (Fig. 3), alluvium mapped by Dibblee (1971a,b) as Paso Robles Formation crops out extensively at elevations up to about 85 m above Jolon Creek and the nearby floor of Lockwood Valley. These hills are mostly capped by soils of the Pinnacles, Placentia, or Placentia-Arbuckle series, which form on alluvium derived from granitic and schistose rocks (U.S. Department of Agriculture, 1975a). Durham (1965b) and Dibblee (1971a) also mapped Paso Robles Formation on several low hills scattered throughout Lockwood Valley, up to about 30 m above the surface of the youngest alluvial fans. Discontinuous outcrops of Paso Robles Formation also have been mapped in the San Antonio Hills along the northeastern margin of Lockwood Valley, particularly near the mouths of Wildcat and Pine canyons (Fig. 3) and at the southeastern end of the valley (Fig. 6). Finally, Dibblee (1971a,b) mapped Paso Robles Formation on a series of low, rounded hills along the range front, intermingled with broad, gently sloping Quaternary alluvial surfaces, especially from the Hall Canyon area northwest to the eastern margin of Jolon Valley (Fig. 6). These hills are about 6 to 15 m higher than the Quaternary surfaces. Durham (1965b), however, mapped these as Quaternary older alluvium.

Field Observations of Paso Robles Formation

Of the five localities discussed in the preceding paragraph, the first three definitely pre-date the existing drainage system, as indicated by their relatively high elevations and the absence of preserved alluvial surfaces. They are therefore not considered in the following discussion. Limited observations of outcrops easily reached from public roads in the last two localities suggest that the sediment is well bedded, that granitic and other crystalline rocks make up more than 50 percent of the clasts, and that rounded granitic cobbles are abundant. In contrast, the field observations made as part of this study suggest that the clasts in outcrops of Quaternary gravel are all derived from sedimentary rocks, shale, porcelanite, and chert, and that they contain no granitic or other basement clasts.

It is possible that, although the bulk of the Paso Robles Formation in the Lockwood and Jolon areas was deposited by the San Antonio River, locally derived clasts were deposited on alluvial fans along the valley margins during Pliocene time, mixing or intertonguing at the distal ends of the fans with sediment of mixed granitic and sedimentary composition deposited by the San Antonio River. If so, one would expect a gradual compositional transition moving away from the range front, but this does not appear to be the case.

Near the southern end of Jolon Valley (Fig. 3), for example, an abrupt lateral transition from sediment derived exclusively from rocks of the Monterey Formation to sediment containing 30 to 75 percent basement and sandstone clasts is observed over about 100 m (Localities 47, 48, and 55, Plate I). However, the differences in the alluvial composition are reflected in the geomorphic characteristics of the surfaces: the gentler hills on the west, adjacent to and generally aligned with the Quaternary surfaces, are underlain by alluvium that is derived exclusively from the Monterey Formation, whereas the alluvium forming steeper hills to the east is of mixed sedimentary and crystalline composition.

The alluvium exposed in the low hills between Hall Canyon and the southern end of Jolon Valley (Fig. 3), mapped by Durham (1965b) and Dibblee (1971a,b) as Paso Robles Formation, is a poorly sorted gravel with subangular to rounded clasts up to about 12 cm (Localities 49, 51, 52, and 53, Plate I). The matrix is poorly sorted sand or coarse muddy sand. No bedding or alignment of flat clasts is apparent. In some outcrops, the clasts are floating in a muddy matrix.

No Salinian basement rocks are exposed in the hills on either side of Lockwood Valley or Jolon Valley. Therefore, the granitic clasts must have originally been transported from the upper reaches of the San Antonio River drainage, where basement rocks crop out extensively (Fig. 5). This observation appears consistent with Galehouse's (1967) conclusion that the San Antonio River was contributing basement clasts to the Paso Robles basin during Pliocene time. The presence of granitic clasts may be a key criterion by which to distinguish the Paso Robles from younger alluvial fan sediment in the study area. Outcrops previously mapped as Paso Robles Formation on lower surfaces are more difficult to distinguish from Quaternary alluvial surfaces. In these cases, Dibblee (1971a,b) seems to have differentiated Pliocene from Quaternary alluvium on the basis of subtle geomorphic variations.

The sediment exposed in the low hills between Hall Canyon and the southern end of Jolon Valley most resemble debris-flow deposits, as might be expected on an alluvial fan. This alluvium is distinguished from the nearby well-bedded alluvium with granitic clasts by its composition and lack of organized fabric (Localities 49, 51, and 52, Plate I). The Monterey-derived alluvium does not differ in any obvious ways from the alluvium forming the adjacent Quaternary surfaces. In one outcrop near Hall Canyon (Locality 46, Plate I), gently dipping sand and gravel are overlain by flat-lying beds of similar appearance and composition. Thus, it is possible that some of the sediment of local provenance northwest of Hall Canyon and mapped by Dibblee (1971a) and/or Durham (1965b) as Paso Robles Formation, actually is Quaternary alluvium.

QUATERNARY ALLUVIAL SURFACES

Four sets of Quaternary alluvial surfaces can be distinguished in the study area, apparently representing three or four separate periods of alluvial deposition (Fig. 9, Plate I, units Qf1, Qf2, Qf3, and Qf4). The characteristics used to define the four groups include the following: relative elevation above the modern drainages, relative steepness, degree of soil development and other weathering indicators, and degree of dissection. Relative elevation and steepness were determined on the basis of longitudinal profiles projected orthogonally onto profiles of modern drainages. To evaluate soil development, soil profiles were described in the field using natural or existing constructed exposures (Appendix A). Degree of dissection, based on qualitative observations of topographic maps and aerial photos, is the least reliable characteristic because some of the older surfaces are partially armored by some form of cement.

Distribution of Quaternary Alluvial Surfaces

Upstream of the range front, within the San Antonio Hills, Quaternary alluvial surfaces occur only in the vicinity of the central and western strands of the Rinconada fault, adjacent to Glau, Loeber, and Williams canyons (Fig. 3, Plate I). Along each of the straight segments of the range front on the northeastern side of Lockwood Valley, from the unnamed canyon at the southeastern end of the study area northwest to Glau Canyon, and at the mouth of San Lucas Canyon, relatively large, young fans have formed. Between these extensive surfaces are

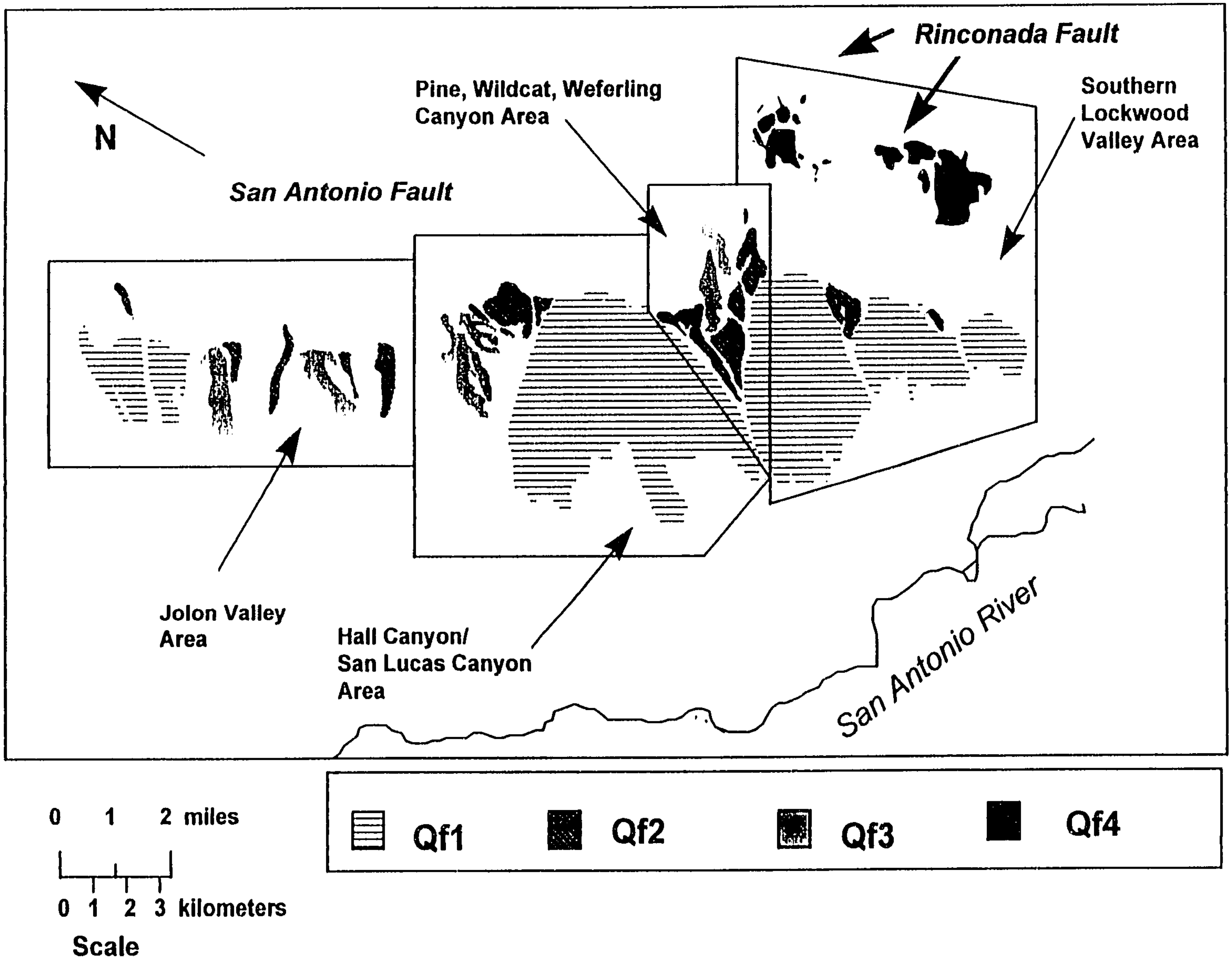

Figure 9. Map showing Quaternary alluvial surfaces, Lockwood and Jolon valleys.

smaller, dissected remnants of older surfaces, with complex clusters of dissected older surfaces at two points where the linearity of the range front is disrupted: near the mouths of Pine, Wildcat, and Weferling canyons; and in the Hall Canyon area. Quaternary alluvial surfaces cover much of Jolon Valley, and narrow terraces extend into Jolon Valley along Pole and Robinson canyons (Fig. 3, Plate I, Lines M-M'-M": and O-O'-O").

Quaternary Alluvium

Quaternary alluvium in the study area consists of gravel and sand, with minor silt and clay beds at some localities (Fig. 10). Where gravel alone is present, it ranges from matrix- to clast-supported. The clasts generally are very poorly sorted, with a maximum length of 5 to 10 cm. The matrix ranges from very poorly sorted, muddy fine sand to moderately sorted coarse sand. Bedding is uncommon in the gravel; where present, beds are 2 to 10 cm thick and in a few cases exhibit normal grading or cross-stratification. Alignment and imbrication of flat clasts are apparent in most exposures, but a few outcrops show no gross sedimentary structures. The gravel clasts range from angular to rounded; sand-sized clasts generally are angular.

Where the gravel is interbedded with sand and/or mud, the thickness of the beds ranges from 2 to 5 cm. The characteristics of the gravel beds are similar to those of the gravel unit described above. The sand beds are normally graded or cross-stratified at some localities. In rare cases, small channels up to about 30 cm wide are present. The gravel- and sand-sized

Figure 10. Typical Quaternary alluvium, west of Hall Canyon.

clasts scattered on the Quaternary surfaces are composed exclusively of tan to white shale, porcelanite, and olive chert.

Methods of Longitudinal Profile Construction

Longitudinal profiles were constructed of the mapped Quaternary alluvial surfaces. The first step in constructing the longitudinal profiles was to project the modern drainage elevations onto straight-line stream segments, thereby eliminating small-scale sinuosity. A straight line was then drawn longitudinally along each mapped alluvial surface, avoiding drainages and keeping the trend of the line as close as possible to that of the modern drainage profile line. The alluvial surface elevations (20-foot contours) were then projected orthogonally onto the stream profile lines.

This process introduces some unavoidable distortions. First, where the alluvial surface profile line is not parallel to the stream profile line, the relative steepness of the surface is exaggerated. Second, if a fault or other linear feature intersects the stream profile at some non-orthogonal angle, the fault will cross the drainage and the various alluvial surfaces at different points along the stream profile line. Finally, it was not always possible to assign each surface to its parent drainage. For example, the alluvium on the higher surfaces between Glau Canyon and Loeber Canyon (Localities 13, 14, and 22, Plate I) might have been deposited by either stream. The modern fan near the mouths of these two canyons might have been deposited by streams emerging from either canyon; it could also be the remains of coalescing fans from both drainages.

The projection method poses some additional problems when applied to alluvial fans because, on an active fan, the stream depositing sediment on or near the fan apex might die out at that point, whereas drainages heading on the fan erode material from the upper fan and deposit it further downfan or carry it off the fan (Denny, 1967). On fans where deposition is no longer taking place at the apex, the distributary channels may erode headward and may or may not be captured by the drainage emerging from the canyon. For example, the large Holocene fan on which active deposition appears to be taking place at the mouth of San Lucas Canyon (Fig. 3, Plate I) is dissected by the stream emerging from Weferling Canyon, near the southeastern side of the fan. Because the stream emerging from San Lucas Canyon dies out at the apex of the fan, it was not possible to show this fan using the method outlined above. One profile was constructed using Weferling Canyon, and a second profile was constructed showing the lower part of San Lucas Canyon and the fan as an extension of that drainage (Plate I, Line I-I'-I'' and Line H-H'-H'', profile kk-kk'). For this study, each alluvial surface was projected onto the profile of the nearest drainage; if adjacent to two separate drainages, it was projected onto both.

Profile Interpretation

The longitudinal profiles indicate that four distinct sets of surfaces are present (Plates II through V). The oldest group (unit Qf4 on Plates I and III and Fig. 9) is found only near the Rinconada fault in the San Antonio Hills in the southeastern portion of the study area. Most of these surfaces are about 15 to 40 m above the modern canyon floors, at elevations of 450 to

600 m. Their gradients are similar to or somewhat steeper than the modern drainages except near the western strand of the Rinconada fault, where they tend to be less steep than the modern drainage gradients. The surfaces in the second oldest group (unit Qf3) occur along the range front, primarily in the Hall Canyon and Jolon Valley areas. Some of the dissected surfaces in the Pine, Wildcat, and Weferling Canyon area may also belong to this group (Localities 32 and 33, Plate I). These (Qf3) surfaces are generally about 15 to 40 m above the modern drainages and display gradients similar to or slightly steeper than those of the modern streams. They appear to grade to a level above that of the modern drainage. The third oldest group (unit Qf2) includes small, highly dissected remnants scattered along the length of the Lockwood Valley range front. These are somewhat steeper than the modern drainages, about 10 to 40 m above the modern drainages at the range front, and appear to be graded to a base level below the modern streams. The youngest group of surfaces (unit Qf1 on Fig. 9 and Plates I through V) comprises the extensive fans along the relatively straight stretches of range front in Lockwood and Jolon valleys. These are generally about 6 to 10 m higher than the modern drainages but are as much as about 15 m higher than the drainages where they are entrenched near the range front. About the same slope as the modern drainages except where entrenched, they appear to grade to the same base level.

The distribution and characteristics of the four age-groups of alluvial surfaces differ from place to place within the study area. For descriptive purposes, the study area may be divided into four parts: southern Lockwood Valley from the southeastern end of the study area to Glau Canyon; the area near the mouths of Pine, Wildcat, and Weferling canyons; the Hall

Canyon area; and the Jolon Valley area (Fig. 9). A detailed discussion of the surfaces by area from south to north follows.

Southern Lockwood Valley

The alluvium near Glau, Loeber and Bee Cave canyons (Plate I) was mapped in the field. Because of limited access, field mapping of the area to the south and east of Williams Canyon (Fig. 3) was not possible, and the mapping of the alluvium in that area is based primarily on Dibblee's (1971a) map. However, the surfaces in that area are morphologically similar to those to the north and west of Williams Canyon, are similarly situated between two strands of the Rinconada fault, and have roughly comparable longitudinal profiles. Thus, the interpretation presented here may be extrapolated to that area. A few surfaces on which Dibblee shows Quaternary alluvium, but which are much higher and steeper than the Quaternary alluvial surfaces identified in the field, are shown on Plate I as questionably Quaternary alluvium (QP?).

Surfaces near the Rinconada Fault. The major distinctive feature of southern Lockwood Valley is the series of broad surfaces and scattered outcrops adjacent to the Rinconada fault in Glau, Loeber, Bee Cave, and Williams canyons (Qf4 on Fig. 9 and Plates I through III). The most extensive of the surfaces along the Rinconada fault zone in the Glau-Loeber canyon area between the two canyons, just northeast of the westernmost strand of the Rinconada fault (Plate II, Lines C-C'-C" and D-D'-D", profiles o-o', w-w', and x-x'), is 25 to 60 m above the floor of Loeber Canyon. Its slope is very slightly steeper than that of the modern Loeber Canyon. The contact between the alluvium and the underlying shale is exposed in a small drainage cut into the southeast side of the surface (Locality 19, Plate I); at that location, the alluvium is about 5 m thick. Dibblee (1971a) shows this surface extending as far upslope as the fault strand to the northeast, but field mapping performed for this study revealed no outcrops to support the extension of this surface beyond the break in slope at Locality 22 (Plate I), where a possible outcrop of weathered Monterey Formation was observed.

The large surface between Glau and Loeber canyons may once have extended at least as far northeast as the central fault strand, as suggested by small outcrops of rounded pebbles in a strong, pinkish cement exposed on the steep side of Loeber Canyon (Locality 18, Plate I). Alluvium also crops out northeast of the central fault strand on the steep slope above Loeber Canyon, just below a shallow bench (Locality 20, Plate I). About 30 m to the northeast and at the same elevation, is an outcrop of Monterey Formation. The two outcrops may be separated by a fault, but earlier workers (Durham, 1965a; Dibblee, 1971a) did not map a fault in the Tertiary rocks at this location. The alluvium may instead be the remains of old valley fill, most of which has been removed by subsequent downcutting of the stream. In profile, when plotted relative to the modern drainage (as point "m"), the bench at the top of the outcrop of alluvium appears to be continuous with the surface on the southwest side of the central fault strand (Plate II, Line C-C'-C", profiles m, n-n', and o-o').

The large surface between Glau and Loeber canyons is truncated on the southwest by an apparent fault scarp at the western fault strand (Locality 23, Plate I), as noted by Hart (1985).

The large surface between Glau and Loeber canyons is truncated on the southwest by an apparent fault scarp at the western fault strand (Locality 23, Plate I), as noted by Hart (1985). At this location, rocks of the Monterey Formation on the west are juxtaposed with Quaternary alluvium on the east. West of the scarp, a flat-topped hill, about 5 m higher than the surface east of the fault (Fig. 7), is capped by 1 to 2 m of weathered alluvium (mapped as Qf4) overlying rocks of the Monterey Formation (Locality 24, Plate I).

Also included among the surfaces near the Rinconada fault zone (Qf4) are two smaller surfaces on the northeast side of Glau Canyon, both roughly triangular in map view. These are capped by alluvial deposits at least 6 m thick (Localities 26, 27, and 28, Plate I). In profile, the westernmost of these is close to the profile of the large surface between Glau and Loeber canyons (Plate II, Line D-D'-D", profile w-w'). The profile of the eastern of the two triangular surfaces shows a similar elevation, but the profile lacks the convexity of the westernmost triangular surface and the surface between Glau and Loeber canyons (Plate II, Line D-D'-D", profile v-v').

Several small outcrops and remnants of alluvial surfaces on both sides of Bee Cave Canyon, a southeastern tributary of Loeber Canyon (Fig. 3), exhibit weathering characteristics similar to those found on the surfaces adjacent to Glau and Loeber canyons. On the north side of Bee Cave Canyon, a section of gravel about 4 m thick, with its base about 5 m above the floor of the modern canyon, is exposed below a bench too narrow to show on a longitudinal profile (Locality 9, Plate I). No outcrops appear on the brush-covered bench or on the ridge above it. Also on the north side of Bee Cave Canyon are small outcrops of what is apparently a strongly cemented alluvium, exposed in road surfaces up to about 7 m above the valley floor, and on the lower ends of ridges sloping toward the canyon floor (Localities 8 and 12, Plate I).

On the south side of Bee Cave Canyon, on narrow ridges 20 to 30 m above the canyon floor, two, more extensive exposures of alluvium are present (Localities 10 and 11, Plate I). The more southerly is east of the western fault strand, as mapped by Dibblee; the more northerly, higher one lies west of the fault. Dibblee (1971a) mapped alluvium on the higher slopes and ridges on both sides of Bee Cave Canyon and extending as far north as the central fault strand, at elevations up to about 150 m above the floor of Bee Cave Canyon. No outcrops of either alluvium or shale were observed above about 450 m during field mapping for the current study.

Like the surfaces near Glau and Loeber canyons, the surfaces near the Rinconada fault east of Williams Canyon are relatively undissected. Most of these are between 10 and 40 m above the modern drainage and have about the same slope, except near the westernmost strand of the Rinconada fault. However, the roughly triangular surface just east of Williams Canyon (Locality 6, Plate I) is much steeper and rises to about 80 m above the canyon floor (Plate III, Line B-B', profiles g-g' and h-h'). Because its slope and relative elevation are greater than those of any surfaces identified in the field as Quaternary alluvium, this may be an older surface; its identity is indicated as questionable (QP?) on Plate I.

Possibly associated with the surfaces near the Rinconada fault zone are outcrops of alluvial gravel exposed in three locations west of the Rinconada fault but still upstream from the range front. In Glau Canyon, a low ridge parallel to the drainage is capped by an outcrop of strongly cemented, pinkish-white to pinkish-gray gravel interbedded with sand (Locality 29, Plate I). In the lower reaches of Loeber Canyon, unconsolidated gravel and sand crop out in two locations (Localities 4 and 5, Plate I).

Range-front Surfaces. In addition to the surfaces near the Rinconada fault zone, two generations of alluvial fans appear along the range front in southern Lockwood Valley. The older fans (Qf2 on Plates I through V and Fig. 9) are relatively small, highly dissected, and generally steeper than the modern major drainages. These fans include two surfaces between Williams Canyon and the unnamed eastern Canyon, and a series of four surfaces between Williams and Loeber canyons (Figure 3). A large roadcut along Jolon Road, just north of the mouth of the unnamed canyon east of Williams Canyon, exposes a section about 6 to 10 m thick in one of these surfaces (Locality 1, Plate I). The alluvium here consists of well-bedded gravel and pebbly sand. The gravel clasts and sand-sized grains are predominantly fragments of shale and chert but include minor volcanic clasts.

Longitudinal profiles of these older (Qf2) range-front surfaces in southern Lockwood Valley are steeper than the modern drainages and intersect profiles of the Holocene (Qf1) fans (Plate II, Line C-C'-C", profiles q-q' and s-s', and Plate III, Line A-A', profile j-j' and Line B-B'-B", profile k-k'). The relative steepness varies and the fan elevations above the modern drainage at the range front range from 10 to 40 m.

The youngest range-front fans in southern Lockwood Valley (Qf1 on Fig. 9 and Plates I through V) vary in size, becoming smaller and generally steeper from north to south along the entire length of the valley as it narrows. The distal edges of these fans are indistinctly defined; on aerial photographs they appear to have partially buried the low hills to the south. These fans are very slightly steeper than the modern drainages. Over most of their length they are about 6 to 10 m higher, and they are as much as about 15 m higher where they are entrenched near the range front. The easternmost fan, which emanates from an unnamed canyon east of Williams Canyon, is only slightly entrenched (about 6 m) near the fanhead; the drainage emerging from the canyon dies out near the range front (Plate III, Line A-A', profile i-i'). The Williams Canyon fan is entrenched to a depth of about 12 m for most of its length, except where the profile line crosses a shallow drainage (Plate III, Line B-B'-B", profile l-l').

The young fan between Glau and Loeber canyons is entrenched about 15 m near the fanhead by Glau Canyon and Loeber canyons, and is partly dissected by a shallow drainage originating in hills underlain by Paso Robles Formation just east of the range front (Plate II, Line C-C'-C", profile r-r' and Line D-D'-D", profile aa-aa'). Dissection explains most of the deviations of the longitudinal profiles from a smooth concave shape. The profile line closest to Loeber Canyon (Plate II, Line C-C'-C", profile r-r') also shows a greater amount of entrenchment between the 1020- and 1080-foot contours, along a relatively steep stretch of the drainage.

Pine, Wildcat and Weferling Canyons

The surfaces near the Rinconada fault do not extend northwest into the vicinity of Pine, Wildcat, and Weferling canyons. However, surfaces that appear to correlate with each of the two generations of range-front fans in southern Lockwood Valley (Qf1 and Qf2) appear in this area. In addition, several less easily classified surfaces are found here, including some that share certain characteristics with a third, older group of range-front surfaces found in Hall Canyon (Qf3 on Plate I), but that may not be Quaternary.

The largest of the dissected alluvial surfaces near the mouths of Pine, Wildcat, and Weferling canyons appear to be remnants of a Holocene fan (Plates I and IV, Lines G-G'-G" and H-H'-H", profiles ii-ii' and jj-jj'). In profile, these generally follow the slopes of Wildcat and Weferling canyons; they are entrenched to about 12 m near their upstream ends, and appear to grade to the same base level as the modern drainages.

Between Pine Canyon and Glau Canyon, three higher surfaces slope more steeply than the youngest (Qf1) surfaces (Plates I, III, and IV, Lines D-D'-D" and F-F'-F", profiles bb-bb', cc-cc', and dd-dd'). These are apparently older remnants and may correlate with the older group of range-front surfaces (Qf2) in southern Lockwood Valley (Plate II, Line C-C'-C", profiles q-q' and s-s', and Plate III, Line A-A', profile j-j', and Line B-B'-B", profile k-k'). The profiles do not form a smooth, continuous line, possibly due to dissection and/or the variations in the trends of the profile lines.

Also tentatively identified on Plates I and IV as Qf2 because of its similarity to the older range-front surfaces in southern Lockwood Valley is a small fan sloping down to the floor of

Pine Canyon from a hill on the west that is underlain, according to Dibblee (1971a), by Paso Robles Formation (Line F-F'-F", profile gg-gg'). No outcrops appear on the fan, but the ground surface, exposed beneath sparse vegetation, appears almost white, suggesting the absence of a well-oxidized soil.

Among the questionable Quaternary surfaces is a ridge on the east side of Pine Canyon. The alluvium underlying the ridge is exposed in roadcuts at the base of the ridge and near its upper surface (Localities 32 and 33, Plate I). In profile, this surface steps down and then levels out, terminating at its lower end at a knob near the mouth of the canyon, where the map of Dibblee (1971a) shows Paso Robles Formation (Plate IV, Line F-F'-F", profiles ee-ee' and ff-ff'). The upper segment of the ridge (profile ee-ee') is probably a remnant of a pre-Quaternary surface. In profile, the lower segment of the ridge (ff-ff') appears to correlate with the surface on the east side of Wildcat Canyon (Plate IV, Lines F-F'-F" and G-G'-G", profile hh-hh'), whose profile is nearly horizontal but diverges from the modern drainage at its downstream end, where it is about 30 m above the floor of Wildcat Canyon.

San Lucas and Hall Canyon Areas

Three generations of Quaternary alluvial surfaces can be distinguished in the San Lucas and Hall canyon areas. The oldest surfaces in this area are broad, steep-sided surfaces on both sides of Hall Canyon that appear to grade to a level higher than the modern Lockwood Valley floor (Qf3 on Fig. 9 and Plate I). The second group consists of several small, highly dissected fan remnants steeper than the modern drainages, between San Lucas and Hall canyons.

Finally, the youngest surface is the large Holocene (Qf1) fan at the mouth of San Lucas Canyon.

The surfaces in the first group (Qf3 on Fig. 9 and Plate I; Plate V, Line K-K', profiles, rr-rr', ss-ss', vv-vv', ww-ww', and xx-xx') are generally 15 to 40 m above the modern drainage, and have about the same slope or are slightly steeper. They appear to grade to a level above that of the modern Hall Canyon. Near the eastern (upstream) ends of these surfaces, on both sides of Hall Canyon, are knobs topped with boulders of strongly cemented gravel (Localities 41 and 42, Plate I).

Typical of these Qf3 surfaces is the broad surface extending for about 1,500 m along the western side of Hall Canyon (Plate V, Line K-K', profile ww-ww'-ww''; Fig. 11). The only extensive exposure of the alluvium underlying this surface is a roadcut outcrop on Cross Road (Figs. 3, 12, Locality 46, Plate I), where an angular unconformity between two alluvial units is exposed. The lower unit dips about 15 degrees toward the south. Both upper and lower units consist of unconsolidated, interbedded gravel and mud. Vertical and horizontal cracks in the lower unit are filled with a brown sediment, weathered to pale gray along the edges of the cracks; the vertical cracks terminate at the unconformity. The gravel is entirely derived from siliceous sedimentary rocks, and contains no granitic or volcanic clasts. All the other exposures beneath this surface are small and/or partially obscured by erosion, making it impossible to measure bedding attitudes.

The second group of surfaces in the San Lucas and Hall canyon area includes at least two highly dissected fans east of Hall Canyon and that are possibly of different ages (Localities

Figure 11. Quaternary alluvial surface west of Hall Canyon, view to west.

Figure 12. Angular unconformity west of Hall Canyon, east side of Cross Road (Locality 46, Plate I). The unconformity is at the base of the gravel at the top of the photo, with prominent channeling. Sediment-filled horizontal cracks are shown near the bottom of the photo. The 15-degree dip of the lower unit is not evident at this scale.

34-39, Plate I; Plate V, Lines J-J' and K-K', profiles mm-mm', nn-nn', oo-oo', pp-pp', and qq-qq'), and several low, finger-like extensions of the dissected fans. Surfaces in this group have profiles that are steeper than the modern drainages and are apparently graded to a lower base level, a pattern similar to that shown by the dissected range-front (Qf2) surfaces in southern Lockwood Valley (Plate II, Line C-C'-C", profiles q-q' and s-s', and Plate III, Line A-A', profile j-j' and Line B-B'-B", profile k-k').

Remnants of the eastern, and possibly older, of the two fans east of Hall Canyon are found on both sides of the unnamed canyon between Hall Canyon and San Lucas Canyon (Localities 34, 35, 36, and 37, Plate I). A roadcut in this surface, southwest of the mapped fault, exposes very pale brown (10YR 8/4), strongly cemented pebbly mudstone and conglomerate (Locality 47, Plate I). Vertical cracks in this unit, filled with a darker brown sediment that is weathered to white along the crack edges, are similar to those observed in the unit below the angular unconformity west of Hall Canyon (Locality 46, Plate I). In profile, the remnants of this fan are steeper than the modern drainage but flatten toward their distal ends (Plate V, Line J-J', profiles mm-mm' and nn-nn'). The change in gradient occurs near the San Antonio fault as mapped by Dibblee (1971a).

The second and possibly younger of the two dissected fans lies between Hall Canyon and the unnamed canyon to the east (Plate I, Lines J-J' and K-K'). In a roadcut outcrop, the light brownish gray (10YR6/2) gravel is uncemented to weakly cemented (Locality 39, Plate I). Most of the clasts are light gray to white, though a few are weathered to dark red or dark orange. In profile, this fan is steeper than modern Hall Canyon and apparently graded to a lower base level.

Several low, finger-like surfaces at the lower ends of the dissected fans (Plate V, Line K-K', profiles tt-tt' and uu-uu') are gentler in slope than the two dissected fans, though still sloping more steeply than the modern drainage. These may be remnants of a fan that buried the lower ends of the two dissected fans and which was later mostly buried by the younger San Lucas Canyon fan.

The profile of the large Holocene fan at the mouth of San Lucas Canyon is continuous with that of the canyon floor. The absence of dissection and fanhead entrenchment suggests active deposition on the fanhead . The longitudinal profile of the fan is slightly convex near the fanhead, but very slightly concave in the lower portion (Plate V, Line I-I'-I'').

Dibblee (1971a) mapped both Quaternary alluvium and Paso Robles Formation on the gently sloping (Qf3) surfaces adjacent to Hall Canyon, apparently indicating that Quaternary deposits overlie the Paso Robles Formation and that the unit below the unconformity described above (Locality 46, Plate I) is Paso Robles Formation. If this is true, then the lithology of the alluvial clasts does not provide a way to distinguish the Paso Robles Formation from Quaternary alluvium in this area. The more strongly cemented and thus possibly older alluvium appears to be limited to the knobs closer to the range front and may be Paso Robles Formation; however, the unit below the angular unconformity was not cemented. Given these uncertainties, any attempt to distinguish between Paso Robles Formation and Quaternary alluvium in the Hall Canyon area must be tentative.

The vertical cracks in alluvium capping one of the nearby highly dissected (Qf2) fans, resembling the cracks in the unit below the angular unconformity at Cross Road, may be evidence that the upper unit (Quaternary alluvium) has been eroded at this location, exposing an older unit, possibly Paso Robles sediment. Dibblee's (1971a) map shows the buried range-front fault crossing this surface. North of the mapped fault, the contact between the alluvium and Monterey Formation is exposed in a small canyon (Locality 34, Plate I), supporting Dibblee's interpretation of the location of the buried fault contact between Paso Robles Formation and Tertiary marine rocks.

Jolon Valley Area

Distinguishing the Paso Robles Formation from Quaternary alluvium is also difficult in the area northwest of Hall Canyon, where the Quaternary alluvial surfaces give way to a series of extensively dissected ridges extending about 800 to 1,500 m from the range front, and in Jolon Valley. In addition, several less dissected surfaces share some characteristics of the alluvial surfaces in Lockwood Valley, including a broad, gently sloping surface at the mouth of the unnamed canyon between Robinson Canyon and Pole Canyon that resembles the surfaces on both sides of Hall Canyon (Qf3); stream terraces adjacent to Robinson and Pole canyons and two fan remnants near Pole Canyon that may be correlated with the small, highly dissected (Qf2) range-front surfaces in Lockwood Valley; and one fan of probable Holocene age adjacent to Pole Canyon.

According to the maps of Durham (1965b) and Dibblee (1971a), the highly dissected hills northwest of Hall Canyon are underlain by Paso Robles Formation. Alluvium observed in outcrops in these hills appears to be derived exclusively from siliceous rocks of the Monterey Formation (Localities 49, 51, 52, and 53, Plate I). The uniform composition of the clasts in these outcrops contrasts sharply with the mixed sedimentary, granitic, and metamorphic composition of the Paso Robles sediment cropping out in the hills to the west and southwest (Localities 47, 48, and 55, Plate I). The apparently abrupt lateral change in composition suggests that the dissected ridges consisting Monterey Formation detritus may be Quaternary surfaces. However, the unit below the unconformity in the Hall Canyon area discussed in the previous section (Locality 46, Plate I), which was mapped as Paso Robles Formation by Durham (1965b) and Dibblee (1971a), was also derived from the Monterey Formation. Without more detailed study of the stratigraphy of the Paso Robles sediment, the age of much of the alluvium northwest of Hall Canyon remains uncertain.

A few surfaces in this area do seem to correlate with the Quaternary surfaces in Lockwood Valley. First, a relatively extensive surface that extends for about 1.6 km from the unnamed canyon between Robinson Canyon and Pole Canyon (Plate V, Line N-N', profile aaa-aaa') is similar to the oldest range-front surfaces (Qf3) in the Hall Canyon area. No outcrops appear on the surface, but detritus on the surface includes pieces of strongly cemented, reddish brown to light brown (5YR5/4 to 7.5YR6/4) gravel. A gully at the lower end of this surface exposes very pale brown, weakly cemented, shale-derived alluvium, capped by about 1.5 m of loose, well bedded alluvium. Bedding is not distinct enough to determine exact attitudes, but the lower unit appears to be flat-lying or dipping a few degrees to the north. Cobble- to boulder-sized clasts in the bottom of the gully include well rounded granitic and metamorphic rocks, probably eroded from the gravels that underlie the hills to the south. In profile, this surface is about 15 to 20 m above the modern drainage. It slopes very gently and is roughly parallel to the modern drainage, with a break in the slope about halfway down.

Two drainages in the Jolon Valley area, Robinson Canyon and Pole Canyon, feature stream terraces; in each case the upper end is upstream of the range front (Plates I and V, Line M-M', profile yy-yy', and Line O-O', profile bbb-bbb'). In contrast with all other alluvial surfaces in the study area, each of these two surfaces is parallel to a single stream and shows no evidence of a fan shape and thus can properly be called a terrace. Because of limited access, the Robinson Canyon surface was not mapped in the field. This terrace is about 12 m above the modern drainage for most of its length, but upstream of the range front it steepens slightly, rising to about 25 m above the modern drainage (Plate V, Line M-M', profile yy-yy'). Judging by its relative elevation and steepness, this terrace may be correlated with the dissected older range-front surfaces in Lockwood Valley (Qf2).

The Pole Canyon terrace slopes steeply from about 25 m above the modern drainage to the level of the modern drainage, near the mouth of the canyon (Plate V, Line O-O', profile bbb-bbb'). The entire thickness of the alluvium is exposed near the lower end of the ridge, where an angular unconformity is exposed at the base of the ridge (Locality 56, Plate I). The underlying unit is a steeply dipping shale mapped by Durham (1964) as Pancho Rico Formation. The alluvium is not cemented and shows no color change with depth. Like the

Robinson Canyon terrace, the Pole Canyon terrace may be tentatively correlated with the dissected older fans in Lockwood Valley (Qf2), based on the elevation of the upstream end of the terrace. The steepness of the slope distinguishes the Pole Canyon terrace from the oldest range-front surfaces (Qf3), such as that along the west side of Hall Canyon (Plate V, Line K-K', profile ww-ww'-ww'').

Two fan remnants southeast of the mouth of Pole Canyon are about 10 m above the modern drainage and have about the same slope (Plate V, Line O-O', profiles ccc-ccc' and ddd-ddd'). A third surface, northwest of the mouth of Pole Canyon, is about 5 m above the modern drainage, also with about the same slope (Plate V, Line O-O', profile eee-eee'). All three surfaces appear to grade to the same base level as the modern drainage. No outcrops are exposed beneath these surfaces. Because of their relatively high elevation, the surfaces southeast of Pole Canyon are tentatively shown on Plate I as correlative with the Pole Canyon and Robinson Canyon terraces and with the older dissected fans in Lockwood Valley (Qf2). The surface to the northwest of Pole Canyon is most similar to the youngest fans in Lockwood Valley (Qf1).

Soils and Weathering

Numerous models, both qualitative and quantitative, exist for developing and evaluating soil chronosequences. Generally, these studies document increases with age in clay content, thickness and extent of clay films, soil structure, and sequioxides for a variety of parent materials (Harden, 1982; Harden and Taylor, 1982; Merritts and others, 1991). For this study, the criteria and format presented by Birkeland and others (1991) were used to describe soil profiles (App. A). The descriptive criteria included depth and thickness of each horizon, moist and dry color, structure, percent gravel, wet and dry consistence, and clay films. Because fresh exposures, particularly of complete profiles, are rare, data were not collected for all mapped surfaces. In addition, many of the surfaces, particularly in the Hall Canyon area and in Jolon Valley, appear to have been stripped of the upper soil horizons; exposures in these areas typically do not show variation of the descriptive characteristics by depth.

Mapped USDA Soil Series

The Soil Survey of Monterey County (U.S. Department of Agriculture, 1975a) shows the alluvial surfaces in the study area as capped by soils of the Lockwood, Chamise, and Arbuckle series, with small areas capped by soils of the Placentia series and, in a few areas near Hall Canyon, by xerorthents. Appendix B presents summaries of the USDA's representative profiles for the three most widespread soil series, which are described in the soil survey. The representative profile of the Arbuckle soil series described in the USDA soil survey is located in the study area, on the Holocene fan between Glau and Loeber canyons (NW 1/4, NW 1/4, S.13, T.23S, R.8E). The USDA's representative profiles for the Lockwood, Chamise, and Placentia series are outside the study area.

All four of these soil series belong to the general category of xeralfs (most of which were formerly classified as non-calcic brown soils), which make up a large percentage of soils in the valleys and foothills of California (U.S. Department of Agriculture, 1975b). According to the USDA, xeralfs are mostly confined to older alluvial surfaces and the lower reaches of foothills, on slopes between 2% and 30%. The characteristics shared by these soils include low organic matter due to limited vegetation, poorly developed surface soil structures, and pale, yellowish or brown surface horizons (Harradine, 1963).

Lockwood soils are found on surfaces underlain by alluvium derived from siliceous shale whereas soils of the Arbuckle series formed in semi-consolidated alluvium derived from igneous and sedimentary rocks (U.S. Department of Agriculture, 1975a). Chamise soils formed on high terraces in alluvium derived from shale. Placentia soils typically are formed in alluvium derived from granitic and schistose rocks on old alluvial fans and terraces.

Based on the descriptions and representative profiles in the soil survey (App. B), Lockwood series exhibit the least development of sesquioxides (as indicated by color), the smallest increase in clay with depth, and the fewest clay films. Arbuckle soils show intermediate development of sesquioxides, increase in clay with depth, and clay films. Chamise and Placentia soils show the most extensive development, but Placentia soils cannot be compared directly with the other series because they are formed on alluvium that is derived from granitic rather than sedimentary rocks. Comparison of the USDA's representative profiles suggests that the characteristics that show the most variation among the four series are color and development of clay films. The increase in clay content with depth as measured by moist and dry consistence is slightly more pronounced in the more developed soils, but structure does not appear to undergo significant development in these soils.

The four soil series mapped in the field area by the U.S. Department of Agriculture soil survey do not represent a clear age progression. In the southern part of Lockwood Valley, Arbuckle and Lockwood soils are both mapped on the Holocene fans (Qf1 on Fig. 9 and Plates I through V). Lockwood soils are also mapped on most of the canyon floors and in drainages within the valley, but Arbuckle soils are mapped on the floor of Williams Canyon. The soils capping the surfaces near the Rinconada fault zone (Qf4 on Fig. 9 and Plates I through III) are mapped as Arbuckle soils east of Williams Canyon and Lockwood soils between Glau and Loeber canyons. Soils on the small dissected range-front fans (Qf2 on Fig. 9 and Plates I through V) are generally mapped as Lockwood and Arbuckle soils. In the Hall Canyon area, Chamise and Arbuckle soils predominate on the older Quaternary surfaces (Qf3 on Fig. 9 and Plates I through V), Lockwood soils in the drainages, and Lockwood and Arbuckle soils on the Holocene fans (Qf1). Similarly, in Jolon Valley, Chamise soils are shown on all the older alluvial surfaces (Qf2 and Qf3), Lockwood soils in the drainages, and Lockwood and Arbuckle soils on the younger fans. In sum, the mapped soil series delineate the alluvial surfaces, but they only broadly differentiate the surfaces by age.

Soil Profiles

For this study, 11 partial or complete soil profiles on natural or existing man-made exposures were described (App. A). Reliance on hand excavation and existing exposures limited the thickness of the exposures. The maximum depth of the profiles described for this study was 230 cm; only three were deeper than 150 cm; four were between 100 and 150 cm deep. Although the bases of some were not excavated, it is likely that the seven profiles deeper than 100 cm were deep enough to include the horizon with maximum red color and maximum percentage of clay. Table 1 summarizes the seven deepest profiles, and complete descriptions of all 11 soil profiles observed during field mapping for this study are included in Appendix A.

No consistent pattern emerges from the soil profile data. Although the soil with the reddest horizon (5YR 5-4/4 dry) was one of two soil profiles on the surfaces near the Rinconada fault zone (Locality 28, Plate I; soil profile #3), which are probably the oldest surfaces studied, the remaining soils do not appear to show evidence of rubification with age. The maximum red encountered in the other soil profile on a Rinconada fault zone surface was 10YR 5/3 to 7.5YR 4/4 (Locality 13, Plate I; soil profile #1). The only soil exposed on one of the oldest range-front surfaces (Qf3 on Fig. 9 and Plates I, IV, and V) is the remnant on the gravel unit above the angular unconformity on Cross Road, west of Hall Canyon (Locality 46, Plate I). This is loose and has a color of 7.5YR 6/4. Two soil profiles described on the highly dissected range-front surfaces (Qf2 on Fig. 9 and Plates I through V) have maximum red colors of 7.5YR 5/4 and 10YR 5/3-7.5YR 5/4 (Localities 30 and 38, Plate I; soil profiles #6 and #7). Two soil profiles were described for Holocene fans (Qf1 on Fig. 9 and Plates I through V); these have maximum red colors of 7.5YR 6-5/4 and 10YR 5/4 (Localities 3 and 31, Plate I; soil profiles #4 and #5). Thus, although the reddest soil is found on one of the oldest surfaces, the soil colors do not vary consistently with the probable relative ages of the surfaces.

Table 1: Summary of Soil Profiles in Field Area

Locality (Plate I)	Soil Profile # (App.A)	Thickness of Exposure (cm)	Maximum Red Color	Structure	Moist Consistence	Dry Consistence	Clay Films	Mapped USDA Soil Series	Age Group of Surface
13	1	110	10YR 5/3-7.5YR 4/4	moderate, angular blocky	sticky, plastic	very hard	few distinct bridges	Lockwood	Qf4
28	3	117	5YR 5-4/5	moderate, angular blocky	sticky, slightly plastic	soft/slightly hard	many prominent pores	Lockwood	Qf4
3	4	180	7.5YR 6-5/4	moderate, angular blocky	slightly sticky, not plastic	hard	distinct coats, few pores	Arbuckle	Qf1
31	5	180	10YR 5/4	moderate, angular blocky	very sticky, plastic	soft/slightly hard	common, distinct coats and bridges	Lockwood	Qf1
30	6	230	7.5YR 5/4	moderate, angular blocky	sticky, slightly plastic	soft/slightly hard	may prominent bridges, coats, and pores	Arbuckle	Qf2
38	7	113	10YR 5/3-7.5YR 4/4	moderate, angular blocky	very sticky, plastic	slightly hard	many prominent coats and bridges	Chamise	Qf2
46	11	*	7.5YR 6/4	*	very sticky, very plastic	loose	none	Arbuckle	Qf3

Note: *= evaluated only for maximum red color and consistence

Similarly, no trend is evident in structure, consistence, or clay films (Table 1). All the soils had moderately developed, angular blocky structures. Moist consistence ranges from slightly sticky and not plastic to very sticky and very plastic, and shows no correlation with the apparent age of the surface. Distinct to prominent clay films were described for soils on all four groups of surfaces. Erosion of the upper soil horizons from some of the older surfaces may explain why the soils do not show the expected variation with age.

Case Hardening

Although the soil profiles in the field area do not show clear variation with age, the oldest soils, which are developed in gravel on the (Qf4) surfaces near the Rinconada fault in the Glau-Loeber canyon area (Localities 10, 11, 18, 20, 23, 24, 26, 27, and 28, Plate I), exhibit evidence of more extensive weathering than soils on the other groups of surfaces. The steep exposures of alluvium in the major drainages and on some of the gently sloping upper surfaces are coated with a strong, non-calcareous cement sufficiently indurated to form ledges (Fig. 13). The cemented gravel cannot be broken with the hands but can easily be broken with a hammer, and the cement breaks down in water. This is case-hardening rather than a duripan horizon, because it appears only on exposed terrace edges rather than as a horizontal layer extending into buried parts of the soil profile. Ledge-forming outcrops of gravel occur up to about 7 m below the surfaces (for example, Locality 27, Plate I). The cementation extends only a few centimeters inward; beneath the surface, in small hollows in the sides of the surfaces and on fresh exposures, the soil is not cemented. The hardened surfaces also are

Figure 13. Case hardening on alluvial surface near Rinconada fault zone (Locality 20, Plate I). The upper surface and steep sides of the overhanging ledge are strongly cemented. The well-bedded gravel in the hollow beneath the overhang is loose.

redder than the inner material and usually are redder than the soil exposed in roadcuts and erosion gullies on these surfaces. The color of the case-hardened surfaces (Localities 10, 11, 20, 23, 24, 26, 27, 28, and 29, Plate I) ranges from 5YR 5/6 to 5YR 4/4 (dry); fresh material exposed beneath the case hardening is generally 7.5YR 5.4 to 10YR 8/3 (dry). Color and texture vary, but not systematically with depth as would be expected in a truly pedogenic cementation. The cementation also appears to have disrupted depositional structures such as bedding, perhaps by filling cracks.

The cemented surfaces described here probably are not indurated well enough to be silcrete, in which the cement is formed of quartz or opal and does not break down in water. Silcretes form only when precipitation of silica is favored over that of clay minerals or other silicates, and they have not been described in the western U.S. (Summerfield, 1983). Moody and Graham (1997), however, have described opaline silica cementation in soils at south-facing edges of a dissected marine terrace on the central California coast.

The case hardening observed in the study area also appears to bear some resemblance to the calcium carbonate cementation on the surfaces of steep, unvegetated outcrops of alluvium and colluvium described by Lattman (1973) and Funk (1979). Lattman (1973) hypothesized that the case hardening is formed by solution of calcareous fines by surface water and subsequent redeposition as cement. The cementation decreases inward and occurs on horizontal or gently sloping surfaces where calcic horizons are exposed. A hard cement can form in this way within a few years and is developed particularly on the sides of modern drainages. Lattman considered case hardening to be non-pedogenic because it appears to be formed by processes occurring at the surface rather than within the soil. Similar processes may have operated in the highly siliceous alluvium in the Lockwood Valley area.

The oldest range-front surfaces (Qf3 on Fig. 9 and Plates I, IV, and V) do not exhibit the case hardening described above. However, remnants of weathered material were found in several locations on these surfaces. These remnants include a loose (uncemented), light-brown (7.5 YR 6/4, dry) soil that caps the alluvial unit above the unconformity exposed in a roadcut on Cross Road (Locality 46, Plate I). The lower unit shows little sign of accumulation of sesquioxides or cementation. In other exposures on this surface, the reddish soil capping the upper unit is absent and the color is consistently light brownish gray to light yellowish brown (10 YR 6/2-4/2). The alluvium exposed in these outcrops ranges from weakly to strongly cemented. The absence of a well-developed soil on parts of the Qf3 surfaces indicates that the Quaternary alluvium has partially eroded.

Strongly cemented sand and gravel found near the northeastern ends of several surfaces in the Qf3 group (Localities 42, 44, 45, and 54, Plate I) generally are pale pink to pale tan, compared with the darker red of the case-hardened surfaces in the Rinconada fault zone. The only exception is the surface near the mouth of the unnamed canyon between Robinson and Pole canyons (Locality 54, Plate I); some of the cobbles and boulders of well-cemented alluvium on this surface are similar in color (5YR 5/4 to 7.5YR 6/4) to those of the case-hardened surfaces near the Rinconada fault zone. Direct comparison with the weathering pattern on the surfaces near the Rinconada fault zone may not be appropriate, because soil formation and case hardening may be affected by the permeability of the underlying bedrock.

The surfaces near the Rinconada fault zone are underlain by intensely fractured shale; the older range-front surfaces in the Hall Canyon and Jolon Valley areas are underlain by sand and gravel of the Paso Robles Formation. The problem is complicated by the possibility that the well cemented, tan to pale pink conglomerate actually is the underlying Paso Robles Formation. Alluvium cropping out west of Hall Canyon (Localities 51, 52, and 53, Plate I) and mapped as Paso Robles Formation by Durham (1965b) and Dibblee (1971a) is strongly cemented and white to very pale brown (10YR 8/2).

The small, highly dissected range-front surfaces (unit Qf2 on Fig. 9 and Plates I through V) are not extensively weathered. Sediment exposed in a roadcut just north of the mouth of the unnamed canyon east of Williams Canyon (Locality 1, Plate I) generally is unconsolidated, but locally is weakly to strongly cemented, especially where finer grained. From a distance, the top 3 m appear redder than the lower beds, but closer inspection reveals no difference in cementation or texture. The color of the matrix of both upper and lower sections is very pale brown (10YR 7/3). The only difference between the two sections is in the weathering of the shale clasts; in the lower portion these are mostly white to light gray, with yellowing of about 10 percent of their surfaces, whereas in the upper portion, 60 to 70 percent of the surfaces of the shale clasts are yellow in color (10YR 7/6, dry).

Summary of Quaternary Alluvial Surfaces

The terraces in the Rinconada fault zone (Qf4 on Plates I through III) are probably the oldest of the Quaternary alluvial surfaces in the study area. The case hardening exhibited by these surfaces is evidence of extensive weathering, and they are relatively high (15 to 40 m) above the modern drainages. The two different elevation groups within Qf4 may represent two different periods of deposition, or the difference in elevation may be due to erosion; the lower surfaces lack the upper soil horizons and are capped by the case-hardened surface (Plates II and III, Lines A-A'-A" through E-E'-E", profiles b-b', c-c', p-p', and v-v').

Although the relative elevations (about 15 to 40 m above the modern drainages) of the oldest range-front surfaces in the Hall Canyon area and Jolon Valley (Qf3 on Fig. 9 and Plates I through V) are similar to those of the Qf4 surfaces near the Rinconada fault zone , the Qf3 surfaces generally lack signs of extensive weathering and do not exhibit the case hardening typical of the Qf4 surfaces. The remnants of weathered material found in several locations on the Hall Canyon surfaces, however, suggest that the general absence of well-developed soils and other signs of weathering may not accurately reflect the ages of the surfaces. Overall, no single pattern of weathering on the Qf3 surfaces emerges, but it seems plausible to conclude that they are about the same age as or somewhat younger than the Qf4 surfaces near the Rinconada fault zone.

The Qf3 surfaces are distinguished by their profiles (Plate V, Line K-K', profiles vv-vv', ww-ww'-ww", xx-xx', Line N-N', profile aaa-aaa', and possibly Plate IV, Line F-F'-F" and G-G'-G", profiles ff-ff' and hh-hh'). They have about the same slope as the modern drainages or are slightly steeper and appear to grade to a higher base level than the modern drainages and the younger Qf2 and Qf1 surfaces.

The small, highly dissected range-front surfaces and the Pole Canyon and Robinson Canyon terraces (Qf2 on Fig. 9 and Plates I through V) are inferred to be younger than the Rinconada fault zone surfaces (Qf4) and the oldest range-front surfaces (Qf3), based on their relative elevations above the modern drainages and the absence of signs of extensive weathering, including cementation, case hardening, or well-developed soils. The relatively low elevations, gentle slopes, and absence of dissection are evidence that the large range-front surfaces (Qf1 on Fig. 9 and Plates I through V) comprise the youngest of the four groups of surfaces.

Absolute Ages of the Quaternary Surfaces

Surfaces in the Salinas Valley

Although direct dating of the alluvial surfaces in the field area was not feasible, rough estimates of the ages were made by correlation with two chronologies developed for the Salinas Valley. Dohrenwend (1975) described terraces on both the east and west sides of the Salinas Valley, from Arroyo Seco on the north to the Paso Robles basin on the south (Fig. 8). The soils on the west side were formed on alluvium derived from the Monterey Formation and may thus be compared with soils examined for the current study. Some of the surfaces on the west side are capped by soils of the Chamise and Lockwood series, both also found in the Lockwood and Jolon Valley area. The soils on the east side of the Salinas Valley were formed mainly on terraces derived from the Pancho Rico and Paso Robles formations, and are not directly comparable to those in the study area.

Tinsley (1975) tentatively correlated alluvial fans and Salinas River terraces north of Arroyo Seco with the surfaces described by Dohrenwend. His correlation was complicated, however, by the discontinuity in the terraces near Arroyo Seco which coincides with a lithologic boundary in the bedrock between predominantly granitic and metamorphic rocks on the north and predominantly siliceous sedimentary rocks on the south. Tinsley (1975) obtained radiocarbon ages for Holocene terraces and fans, but he and Dohrenwend (1975) both estimated the ages of the older surfaces by correlating with an alluvial chronology developed for the eastern San Joaquin Valley.

Dohrenwend (1975) and Tinsley (1975) identified four age groups of surfaces (Table 2). The oldest surfaces, Tinsley's Gloria fan system and Dohrenwend's Gloria-Pinnacles terraces, are capped by maximally developed soils. Tinsley noted that a duripan in these soils commonly crops out as ledges and at some localities has prevented dissection of the older deposits; at many sites the A and B horizons have been stripped away. According to Dohrenwend, the Gloria-Pinnacles surfaces are difficult to correlate and probably represent more than one terrace level. He estimated their age as greater than 125,000 years, based on comparison with eastern San Joaquin Valley deposits; Tinsley estimated that the Gloria fan system was 300,000 to 400,000 years old.

The Placentia-Chamise terrace south of Arroyo Seco, and the Placentia tributary fan deposits and Antioch terraces of the northern Salinas Valley are younger than the Gloria-Pinnacles surfaces are. The Placentia-Chamise terrace is 30 to 100 m above the present Salinas Valley floor; the soils are maximally developed xeralfs ("non-calcic brown soils")

Table 2: Correlation of Alluvial Surfaces in Lockwood and Jolon Valleys with Salinas Valley Alluvial Chronologies

Alluvial surfaces of the central Salinas Valley-Gabilan Mesa area (Dohrenwend, 1975)		Alluvial deposits of the northern Salinas Valley (Tinsley (1975)		Alluvial surfaces of Lockwood and Jolon Valleys (this report)		Estimated Age (years)
Surface	**Soil Series**	**Surface**	**Soil Series**	**Surface**	**Soil Series**	
Salinas-Docus surface	Salinas, Docus, Mocho, Sorrento, Cropley, Lockwood, Garey	Metz and Salinas terraces; Arroyo Seco	Metz, Chualar, Arroyo Seco, Tujunga, Hanford	Qf1	Lockwood, Arbuckle	Holocene (<10,000)
Chualar-Rincon terrace	Rincon, Chualar, Lockwood, Atwater, Garey	Chualar fan system	Chualar	Qf2	Lockwood, Chamise	late Pleistocene (20,000- 100,000)
Placentia-Chamise terrace	Placentia, Placentia-Arbuckle, Chamise, Snelling, Parkfield, Atwater	Antioch terrace; Placentia fan system	Antioch, Placentia	Qf3	Chamise	100,000- 200,000
Gloria-Pinnacles	Gloria, Pinnacles	Gloria fan system	Gloria	Qf4	Lockwood, Arbuckle	300,000- 400,000

with prominent red-brown B horizons (Tinsley, 1975). In one location near Chualar, according to Tinsley (1975), Placentia deposits overlie a Gloria soil. The Placentia-Chamise and Antioch terraces are extensively preserved, in contrast with the Gloria-Pinnacles surfaces. The Antioch terrace, which appears to be younger than the Placentia fans, may be graded to the Isotope Stage 5 marine terrace in the Monterey Bay area; Dohrenwend (1975) and Tinsley (1975) thus estimated that the surfaces are between 100,000 and 200,000 years old.

The third youngest group of surfaces includes the Chualar fans in the northern Salinas Valley and the Chualar-Rincon terrace south of Arroyo Seco. These are the most extensive surfaces; the Chualar-Rincon terrace is almost continuous along the length of the Salinas River, about 20 to 70 m above the present channel, and can be followed along the major tributaries. The Chualar fans and Chualar-Rincon terraces are capped by moderately developed soils, including Lockwood soils, and are estimated to be less than 100,000 years old.

The youngest group of surfaces includes Tinsley's (1975) Arroyo Seco terraces and deposits, which are associated with active fans and interfinger with the Metz and Salinas floodplain deposits of the Salinas River. These are correlated with the Salinas-Docus, Salinas, and Metz terraces south of Arroyo Seco. The soils are undeveloped to minimal (some are Lockwood soils); the Salinas terrace, 1 to 5 m above the present channel, is inundated in extreme flood events, and the Metz terrace, 1 to 2 m above the present channel, is flooded every 5-9 years. A radiocarbon date of 1,900 years confirms a Holocene age for the Salinas terrace.

Correlation of Salinas Valley Surfaces with Surfaces in the Study Area

It is likely that the alluvial cycles in the Salinas Valley generally parallel those in the Lockwood Valley area, because the elevation of the Salinas River determines the base level for the San Antonio River and the climatic influences on the two areas are similar. Dohrenwend's (1975) and Tinsley's (1975) descriptions of the degree of soil development may also be compared to characteristics of soils capping the alluvial surfaces of Lockwood and Jolon valleys. Although the northern Salinas Valley alluvium is derived primarily from granitic and metamorphic rocks, the alluvium on the western side of the Salinas Valley south of Arroyo Seco, in Dohrenwend's study area, is derived mostly from Monterey Formation.

Based on both field and USDA (1975a) soil descriptions, the four groups of alluvial surfaces in the Jolon and Lockwood valleys have been correlated with the four broad groups of Salinas Valley surfaces, providing rough estimates of the ages of the surfaces in the study area. The oldest Lockwood Valley surfaces, the Qf4 surfaces near the Rinconada fault, may be correlated with the Gloria-Pinnacles terraces south of Arroyo Seco and the Gloria fan system in the northern Salinas Valley, with an estimated age of 300,000 to 400,000 years. The ledge-forming outcrops observed on the Rinconada fault zone surfaces in the Glau-Loeber canyon area, as in the Gloria fans in the Salinas Valley, are evidence of extensive weathering.

Based on the presence of Chamise soils (USDA, 1975a), the oldest range-front surfaces of this study (Qf3 on Fig. 9 and Plates I, IV, and V), most extensive near Hall Canyon, are probably correlative with the Placentia-Chamise terrace in the Salinas Valley south of Arroyo Seco and the Antioch terrace-Placentia fan system of the northern Salinas Valley and therefore may be about 100,000 to 200,000 years old. Soil series and weathering characteristics of the small, highly dissected (Qf2) fans of Lockwood and Jolon valleys do not correlate directly with those of any of the Salinas Valley surfaces. However, the intermediate age of the Qf2 fans in the study area, younger than the Qf3 surfaces but older than the Holocene fans, suggests that they may be of the same age as the Chualar-Rincon terrace south of Arroyo Seco and the Chualar fan system in the northern Salinas Valley. These are late Pleistocene, or less than 100,000 years old. Based on relative elevation and lack of dissection, the youngest fans in Lockwood Valley are probably roughly correlative with the Holocene terraces in the Salinas Valley.

Tectonic Deformation of Alluvial Surfaces

Tectonic activity can affect longitudinal profiles of alluvial surfaces in several ways. First, some researchers have described post-depositional deformation of older alluvial surfaces, generally convexities in surfaces assumed to have originally been concave, and interpreted them as anticlinal folds produced by blind thrust faults (Bull, 1984; Sowers and others, 1992; Hitchcock and others, 1994). Local convexities in a modern stream profile, when associated with zones of lineaments, mapped fault traces, and terrace convexities, may also be indicators of active tectonic processes (Hitchcock and others, 1994). Tectonic activity can also shape the longitudinal profiles of alluvial surfaces by raising or lowering the base level of a stream, thus affecting the relative steepness and elevation of a series of surfaces. It can be difficult or impossible, however, to distinguish tectonic causes of base level change from other causes, such as climatic change and human activity.

Tectonic processes that change relative base level affect alluvial fans in complex ways (Bull 1961, 1964a,b, 1984; Denny, 1967; Bull and McFadden, 1977; Rockwell and others, 1984). Bull and McFadden (1977), and Bull (1984) proposed a system for evaluating the tectonic activity along range-bounding faults in arid regions based on the interaction of the three base-level-controlling processes: relative uplift, stream-channel downcutting within the mountains, and piedmont aggradation and degradation. According to this analysis, the uplift rate must be equal to or greater than the sum of the channel downcutting and piedmont degradation in order for active deposition of sediment on the fanhead to continue (Fig. 14). Fanhead entrenchment will develop if channel downcutting in the mountains exceeds the rate of uplift or if aggradation of alluvial fan deposits steepens the fan faster than the uplift rate increases the steepness of the stream in the mountains.

Thus, in Bull's (1984) system, fans on "highly active" range fronts are not entrenched; "moderately active" range fronts have entrenched fans; and inactive mountain fronts, where fluvial erosion dominates, generally have dissected or undissected pediments. Bull and McFadden (1977) noted, however, that the latter may have characteristics of active mountain fronts. Range-front sinuosity also is an indicator of the level of tectonic activity: sinuosity is low for highly active range fronts because fault processes dominate over erosion, and it is high for inactive range fronts where erosion tends to obscure the linear expression of the fault.

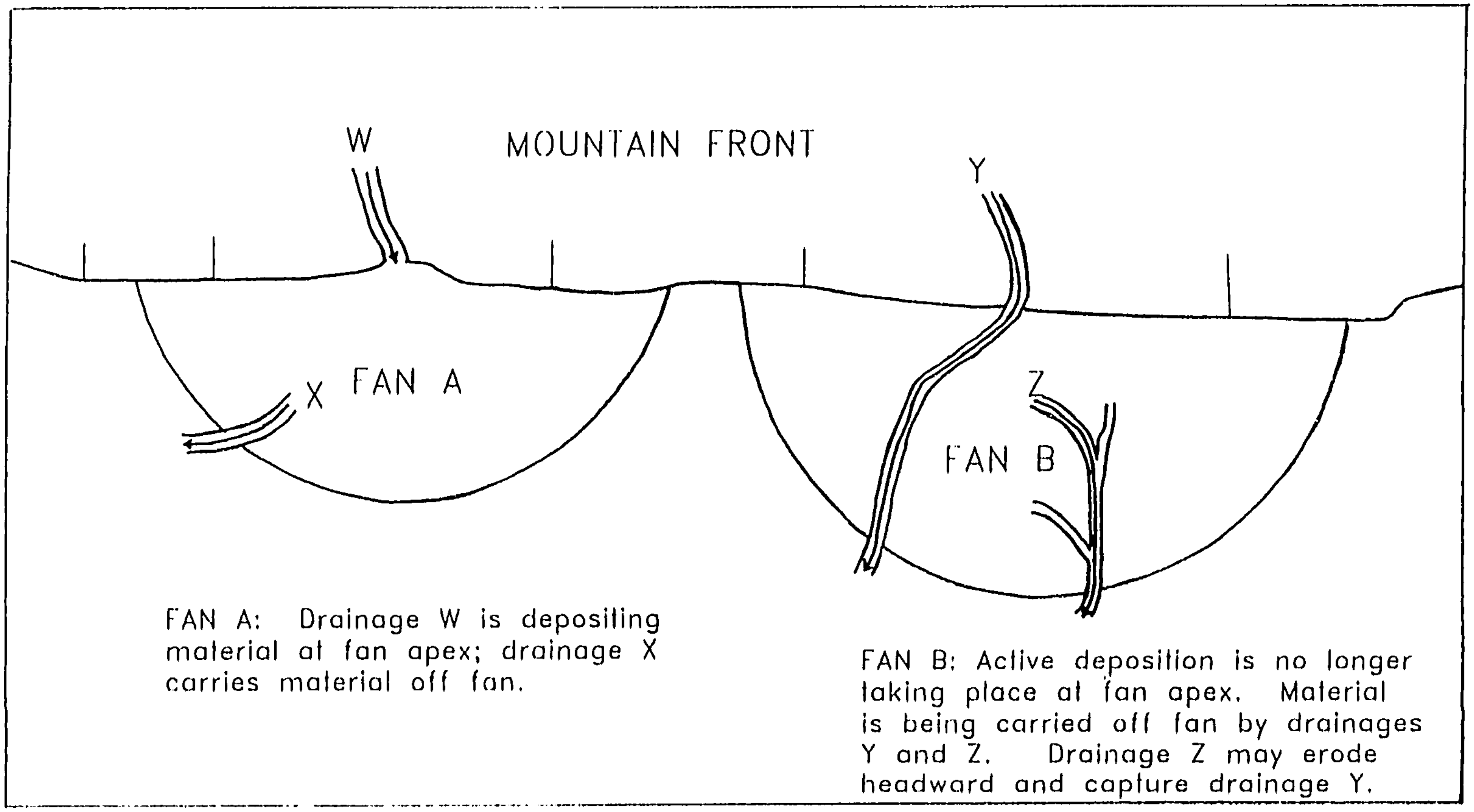

Figure 14. Schematic diagram of alluvial fan drainage (modified from Denny, 1967).

Another potential effect of tectonic activity on the depositional processes on alluvial fans is fan segmentation (Bull, 1964a,b). This develops when accelerated downcutting associated with uplift in the mountains increases the steepness of the fan deposits. The newer deposits are built out onto an older, more gently sloping depositional surface. Bull hypothesized that fans with increasingly steep, younger fans toward the range front will result from intermittent uplift with the axis just above the fan apex. An area of tectonic uplift several miles upstream of the fan apex would produce the opposite pattern, with progressively gentler gradients and deposition farther from the range front. This is because the uplift is attenuated with distance from the axis, and channel downcutting exceeds the small amount of uplift immediately upstream from the fan's apex. Climatic effects also can cause fan segmentation, but progressive steepening and progressively younger segments toward the apex produces thick valley fills upstream from the fan. Entrenchment could result from regional (i.e., climate-linked) base-level changes, which would steepen stream gradients, but these would also prevent deposition on the fan and thus might be distinguished from the local effects of fault activity.

Geomorphic Expression of Faults

As noted by previous workers (Dibblee, 1976; Hart, 1985) and mentioned above, most of the larger drainages flowing into southern Lockwood Valley, including Williams, Loeber, Pine, Wildcat, Weferling, and San Lucas canyons, are all either deflected or have linear tributaries along the western strand of the Rinconada fault (Plate I, Lines B-B'-B", C-C'-C", D-D'-D", F-F'-F", G-G'-G", H-H'-H", and I-I'). Of these canyons, only Pine and Wildcat canyons have small tributary drainages that run along the central fault strand. To the north of San Lucas Canyon, where only one strand of the Rinconada fault is mapped, the fault is generally marked by linear drainages.

The geomorphic expression of the San Antonio fault (Dibblee's "minor thrust faults") in the study area varies. From the southern end of Lockwood Valley to Loeber Canyon the fault runs along a linear, sharply defined range front (Fig. 6, Plate I). Dibblee's (1971a) map shows a discontinuity in the fault between the mouths of Loeber and Weferling canyons, where several dissected alluvial surfaces break the linear range front (Plate I). A short, straight, clearly defined topographic break extends along the range front between Weferling and San Lucas canyons, but northwest of San Lucas Canyon Dibblee's fault crosses several dissected, older alluvial surfaces. Northwest from Hall Canyon, the mapped fault runs discontinuously through a series of aligned saddles and drainages that cut older alluvial surfaces and low hills underlain by Paso Robles sediment where they meet the range front. Dibblee does not show the fault continuing into Jolon Valley, but the east side of this valley has a linear, steep range front.

Tectonic Activity Implied by Longitudinal Profiles

Southern Lockwood Valley

As noted earlier, older surfaces near the Rinconada fault (Qf4) are confined almost exclusively to the area between the central and western traces, suggesting that they may have formed as a result of movement on the fault. Relative downdropping of the block between the two faults or vertical movement on the western strand may have led to aggradation between the two strands. It is likely, then, that at least one trace of the fault was active during the period during which these surfaces were formed, probably at least 300,00 to 400,000 years ago.

Profiles of the lower group of Qf4 surfaces near the Rinconada fault zone (Plate II, Line C-C'-C", profile p-p', and Line D-D'-D", profile v-v'; and Plate III, Line A-A', profiles b-b' and c-c') are generally parallel to the stream profiles, with the exception of one surface adjacent to the unnamed eastern canyon, which diverges near the western fault trace (Plate III, Line A-A', profile c-c'). This divergence also is the most consistent pattern in the higher group of Qf4 profiles (Plate II, Line D-D'-D", profiles w-w', x-x', and y-y' and Plate III, Line A-A', profiles e-e' and f-f'). The surfaces in Bee Cave Canyon show the same divergence, assuming the original continuity of the two outcrops whose profiles are represented (Plate II, Line E-E", Profiles t-t' and u-u').

The most convincing evidence for post-depositional deformation of the Qf4 surfaces is the scarp in the alluvial surface between Glau and Loeber canyons (Fig. 3), which shows the typical flattening at the fault (Plate II, Line D-D'-D", profiles w-w' and x-x'). It is not possible to use the profile to estimate the amount of vertical displacement, because the relatively uplifted surface west of the fault (profile x-x') has a thinner alluvial cover than the surface to the east of the fault (profile w-w'), and the base of the alluvium is not exposed immediately the east of the fault. Based on the thickness of the alluvium farther to the east, where the contact with the underlying Monterey Formation is exposed in a drainage (Locality 19, Plate I), the displacement appears to be about 3 to 6 m.

Between the two fault strands, the older, higher group of Rinconada fault zone profiles (Qf4) does not exhibit a clear pattern. Some are markedly convex (Plate II, Line D-D'-D", profiles y-y' and w-w'), but others are smoothly concave and slightly steeper than the stream profile except for a slight convexity near the eastern fault trace (Plate II, Line C-C'-C", profiles m-m', n-n', and o-o'). In the unnamed eastern canyon, a-a' also is slightly convex between the two fault traces (Plate III, Line A-A', profile a-a'). These convexities may reflect gentle anticlinal folding but more likely are erosional artifacts. In the few exposures where bedding can be measured, the attitudes are horizontal, which is inconsistent with folding.

The greater steepness of the range-front surfaces of intermediate age (Qf2) in southern Lockwood Valley, compared with the youngest fans (Qf1) and the modern drainages, is evidence of a change in base level since late Pleistocene time, when these surfaces were probably formed (Plate II, Line C-C'-C", profiles q-q', s-s', and Line D-D'-D", Line bb-bb', cc-cc', and dd-dd'; and Plate III, line B-B'-B", profile k-k'). This pattern could be the result of vertical slip along the range-front fault.

In general, profiles of the Holocene fans in southern Lockwood Valley are gently concave; each of these fans, with the exception of the fan emanating from the unnamed eastern canyon (Plate III, Line A-A", profile i-i'), is entrenched near the fanhead. As discussed above, fanhead entrenchment may be a sign of a moderately active range front as defined by Bull and McFadden (1977), or it may result from rainfall variations over several decades (Bull, 1964b).

Weaver and Schumm (1974) also have suggested that entrenchment is an inherent process in the natural development of an alluvial fan and may not imply tectonic activity, climatic change, or human activity.

The break in slope in the profile of the Holocene fan below the unnamed eastern canyon is an artifact of the broad drainage adjacent to the fan profile line (Plate II, Line A-A', profile i-i'). The younger fan emerging from Williams Canyon diverges from the modern stream profile line at two points, one where the stream bends sharply so that the drainage is perpendicular to the stream profile line, the other where the fan profile line crosses a drainage (Plate III, Line B-B'-B", profile l-l'). Two profiles of the large younger fan between Glau and Loeber canyons are gently undulating, probably due to slight dissection of the fan (Plate II, Line C-C'-C", profile r-r', and Line D-D'-D", profile aa-aa'). Thus, there is no evidence for post-depositional tectonic deformation of these young surfaces.

Pine, Wildcat, and Weferling Canyon Area

The linearity of the range front is interrupted between Glau and Wildcat canyons (Fig. 6 and Plate I), where the range front fault appears to form a left stepover. According to Bull and McFadden's (1977) model, the sinuosity of the range front at this point is inconsistent with active faulting along the range front. Profiles of the range-front surfaces near Pine, Wildcat, and Weferling canyons present a pattern similar to that in southern Lockwood Valley, with the same implication of some tectonic activity since the late Pleistocene. The youngest fan is smoothly concave and diverges from the modern drainage only near the fanhead (Plate IV, Lines G-G'-G" and H-H'-H'', profiles ii-ii' and jj-jj'-jj").

San Lucas and Hall Canyon Areas

Active deposition appears to be taking place near the head of the fan at the mouth of San Lucas Canyon. The profile of the fan is relatively flat at the fanhead, compared with the drainage within the canyon and the lower portion of the fan (Plate V, Line I-I'-I"). Because there is no evidence for active uplift along the range-front, Bull's (1984) model suggests that fan aggradation exceeds stream downcutting. Thus, the morphology of the San Lucas Canyon fan is probably the result of an excess of sediment supply, perhaps due to local agricultural practices or to specific geologic materials. Closed depressions in the canyon are probably the result of recent debris flows and landslides (Hart, 1985), which may also partly explain the excess supply of sediment.

In the Hall Canyon area, the oldest range-front surfaces (Qf3) appear to grade to a higher base level than the modern drainages but present no consistent pattern of post-depositional deformation. As in the areas to the south, profiles of the late-Pleistocene (Qf2) surfaces are steeper than those of the modern drainages (Plate V, Lines J-J' and K-K', profiles mm-mm', nn-nn', oo-oo', pp-pp', and qq-qq'). Steepening of the late Pleistocene surfaces but not the older surfaces suggests that the steepening is related to climatic or tectonic processes affecting the steepness of the depositional surface rather than to post-depositional tectonic deformation of the surfaces. Dibblee's (1971a) map shows a fault buried beneath the probable late

Pleistocene alluvial surfaces between San Lucas Canyon and Hall Canyon. Two profiles do show steepening just upslope from the fault (Plate V, Line J-J', profiles mm-mm' and nn-nn'), perhaps due to tectonic deformation. No photolineaments are evident on the aerial photos along the trend of the fault and no scarp was observed during field mapping; if the fault has slipped recently, evidence has been obscured by cultivation or natural erosion or both.

Jolon Valley

Dibblee (1971a,b) showed the San Antonio fault continuing northwest from Lockwood Valley to the southern end of Jolon Valley, with Monterey Formation on the northeast and Paso Robles Formation on the southwest. Like the similar (Qf3) surfaces in the Hall Canyon area, the broad surface adjacent to the unnamed canyon between Robinson and Pole canyons grades to a higher base level than the modern drainage, again suggesting relative downdropping of the valley or some base level change downstream since the deposition of the alluvium capping the surface (Plate V, Line N-N', profile aaa-aaa').

The Robinson Canyon terrace (Qf2), mapped as Quaternary alluvium by Dibblee (1971b), has a smoothly concave profile, diverging from the stream profile upstream of the fault (Plate V, Line M-M'-M", profile yy-yy'-yy"). The Pole Canyon terrace (Qf2) exhibits a similar profile, although it slopes more steeply, from a knob about 25 m above the canyon floor to the level of the Holocene fan near the mouth of the canyon (Plate V, Line O-O', profile bbb-bbb') The profiles of these two terraces thus indicate greater downcutting east of the fault than west of the fault since deposition of the terrace deposits. This differential downcutting may be the result of uplift along the fault and suggests that the range-front fault may continue as far north as Pole Canyon.

Like the Holocene fans in Lockwood Valley, the younger Pole Canyon fan is smoothly concave. It is slightly entrenched near the fanhead and shows no signs of post-depositional deformation (Plate V, Line O-O', profile eee-eee'). The apparently older, southeastern, Pole Canyon fan also is smoothly concave; unlike the probable late Pleistocene fans in Lockwood Valley it has about the same slope as the modern drainage (Plate V, Line O-O', profiles ccc-ccc' and ddd-ddd').

Discussion

The profiles and field characteristics of the alluvial surfaces near the Rinconada fault (Qf4) provide strong evidence that early Pleistocene vertical displacement occurred on the Rinconada fault, continuing long enough to produce about 3 to 6 m of vertical offset on an early Pleistocene alluvial surface. No younger surfaces exist in the vicinity of the Rinconada fault to evaluate slip since the early Pleistocene. The results of this study support Hart's (1985) conclusion that evidence for more recent movement on the fault is lacking.

Uplift along the range-front fault may also have caused the 15 to 40 m of channel downcutting that has occurred since the surfaces near the Rinconada fault zone were formed. However, profiles of the alluvial surfaces in the Hall Canyon area suggest that the surface of Lockwood Valley was formerly about 20 m above the elevation of the modern valley floor. The surfaces near the Rinconada fault zone (Qf4) therefore might have been graded to that higher base level. The subsequent capture of the San Antonio River drainage by the Salinas River implied by Galehouse's (1967) interpretation of the paleogeographic history of the Paso Robles basin may have triggered the base level change for the streams in the study area. It is possible that this capture initiated significant downcutting extending as far upstream as Lockwood and Jolon valleys.

There is also evidence of Pleistocene vertical displacement along the range-front faults in Lockwood and Jolon valleys. First, the relatively steep slopes of the late Pleistocene surfaces (Qf2) suggest that uplift of the source area has occurred since their formation, although the influence of Pleistocene climate is unknown. Second, the late Pleistocene surfaces near Hall Canyon appear to be deformed. Third, the greater amount of downcutting east of the fault in Pole and Robinson canyons suggests uplift of the range front since deposition of these late Pleistocene surfaces.

According to Bull and McFadden's (1977) model, the Lockwood Valley range front is not in the "highly active" category. Streams are not actively downcutting upstream of the fault and the fanheads are entrenched. The upper fans erode and deposition occurs on the lower fan. Longitudinal profiles of the Holocene fans in Lockwood and Jolon valleys do not show any evidence of post-depositional deformation. The only geomorphic feature suggestive of active faulting is the linearity of the range front from the southern end of Lockwood Valley to Glau Canyon.

This study did not reveal evidence for late Pleistocene or Holocene activity on the Rinconada fault. However, no surfaces younger than Qf4 (about 300,000 to 400,000 years) cross any of the traces of the fault, so deformation of alluvial surfaces is not a definitive way to evaluate the history of this fault. Further, the methods employed in this study did not allow estimation of strike slip. Generally, however, Dibblee's suggestion that Quaternary alluvium is involved in the range-front faulting is supported by this study. Field observations suggests that some of the deposits identified by previous researchers as Paso Robles Formation may be Quaternary alluvium; however, it remains difficult to distinguish the two. A detailed study of the Paso Robles Formation in Lockwood and Jolon valleys and its relationship to related deposits in the Salinas Valley would be useful in evaluating the Pleistocene tectonic history of the area.

CONCLUSION

Four distinct age groups of alluvial surfaces are present in Lockwood and Jolon valleys. The oldest surfaces (Qf4) in the study area, confined to the Rinconada fault zone near the southeastern end of Lockwood Valley, are 15 to 40 m above the modern drainages and slope more steeply. A distinctive non-calcareous case hardening developed on the Qf4 surfaces attests to their extensive weathering. The second oldest group of surfaces (Qf3) is found primarily in the Hall Canyon area and in Jolon Valley; a few surfaces in the Pine, Wildcat, and Weferling canyon areas may also belong to this group. The Qf3 surfaces are broad and steep-sided, 15 to 40 m above the modern drainages, and about the same slope or slightly steeper. The Qf3 surfaces are graded to a higher base level than the modern drainages. The absence of case hardening on the Qf3 surfaces distinguishes them from the Qf4 surfaces near the Rinconada fault zone.

The third group of surfaces (Qf2) is found throughout the study area. It includes small, highly dissected fan remnants adjacent to the range front in Lockwood Valley, and two stream terraces in the Jolon Valley area. These surfaces are about 10 to 40 m above the modern drainages near the range front and slope more steeply. They are graded to base levels below present streams. The final group of surfaces (Qf1) includes the large range-front fans found throughout the study area. These are generally about 6 to 10 m higher than and about the same slope as the modern drainages. Several fans are entrenched to depths up to 15 m near the range front.

Soil profiles described for this study did not yield clear information about relative ages of the surfaces, at least in part because the upper soil horizons have been eroded from a number of the surfaces. Relative ages were therefore determined from other indicators of weathering, relative elevation, and steepness. The case hardening on the surfaces near the Rinconada fault zone indicates extensive weathering not found elsewhere in the study area and supports the interpretation that these are the oldest surfaces. Although the broad, relatively flat surfaces in Hall Canyon and Jolon Valley (Qf3) lack case hardening, extensive weathering may be indicated by the strongly cemented boulders near their upper ends and a remnant of a relatively red soil on the unit above an angular unconformity in an outcrop on the surface along the northwest side of Hall Canyon. Profiles showing that the Hall Canyon surfaces are graded to a level above the modern valley floor also suggest that this group of surfaces is relatively old compared with the other surfaces along the range front. The relative steepness and extensive dissection of the small fan remnants and stream terraces (Qf2) indicate that these surfaces are older than the large Holocene fans (Qf1).

Although independent evidence for absolute ages of the alluvial surfaces in the study area is lacking, correlation with Salinas Valley surfaces suggests ages of about 300,000 to 400,000 years for the surfaces near the Rinconada fault zone, about 100,000 to 200,000 years for the Hall Canyon-Jolon Valley surfaces that are graded to a higher base level than the modern valley floor (Qf3), and 20,000 to 100,000 years for the small highly dissected range-front surfaces (Qf2). The large, young fans (Qf1) are Holocene, or less than 10,000 years old.

Field observations and longitudinal profiles provide several types of evidence of post-depositional deformation of the alluvial surfaces and base-level changes that may or may not have been tectonically induced. The profiles of the surfaces near the Rinconada fault zone diverge from the profiles of the modern drainages near the western trace of the Rinconada fault, where a scarp in one of these surfaces is apparent in the field. The elevation of these surfaces above the modern drainages also indicates 15 to 40 m of channel downcutting since the surfaces were formed.

The profiles of the second oldest (Qf3) surfaces show no evidence of post-depositional deformation, but the fact that the surfaces are graded to a level above the modern valley suggests a relative lowering of the floor of Lockwood Valley since the surfaces were formed. A later base level change is also suggested by the steepness of the late Pleistocene (Qf2) surfaces. A break in slope in one of the Qf2 surfaces coincides with the range-front fault and thus is the only evidence of post-depositional deformation of either Qf2 or Qf3 surfaces.

The results of this study provide evidence for at least 5 m of vertical slip on the Rinconada fault zone since the early Pleistocene. The timing of this slip, however, remains uncertain. The apparent lowering of the relative level of Lockwood Valley is most likely due to regional base-level changes rather than local tectonic activity. However, the apparent deformation of late Pleistocene (Qf2) alluvial surfaces along the range-front fault suggests that relative uplift of the San Antonio Hills along the range-front fault explains the relative steepness of these surfaces. Most of the Holocene (QF1) fans are entrenched; the entrenchment may result from tectonic process, but may have been caused by result of hydrologic change and/or other local factors influencing sediment supply, or the natural evolution of the fans. Overall, this study provides strong evidence of long-term Quaternary tectonic deformation in Lockwood Valley.

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APPENDIX A

Soil Profiles

Appendix A summarizes the soil data collected in the field for this study. The parameters and soil horizon nomenclature used in the soil profiles are described in Birkeland, Machette, and Haller (1991).

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence Wet	Consistence Moist	Consistence Dry	Texture	Clay Films
Soil Profile #1, Locality 13 (Plate I)									
0-12	Ap	--/10YR 4/2	single grain, very fine, granular	~10	slightly sticky, slightly plastic	--	soft	sandy clay load	none
12-33	Bt1	--/10YR 6/2	weak, fine, angular blocky	~10	sticky, plastic	--	soft	clay loam	few, faint coats
33-100	Bt2	--/10YR 6-7/2	moderate, medium, angular blocky	~25	sticky, plastic	firm	hard	clay loam	very few/few, distinct coats
100+	IIBt3	--/10YR5/3	massive, granular	>75	sticky, plastic	firm	very hard	clay loam	few, distinct bridges
Soil Profile #2, Locality 22 (Plate I)									
0-7	A	--/10YR 5-6/3	massive, granular	~25	sticky, plastic	firm	loose/ soft	clay loam	none
7-30	Bt1	--/10YR 5/3	weak, medium, granular	10-25	sticky, slightly plastic	friable/ firm	slightly hard	sandy clay loam	very few faint coats
30-50	Bt2	--/75.YR 6/2	weak, coarse, granular	~25	sticky/very sticky, slightly plastic	friable	slightly hard/hard	sandy clay loam	common, distinct ped faces
50-58	Bt2	--/7.5YR 6/2	massive, fine to medium, granular	25-50	sticky, plastic	friable	loose /soft	sandy clay loam	very few, faint coats
58+	IIBt3	--/7.5YR 6/2	weak, coarse, granular	50-75	very sticky, plastic	firm	soft	sandy clay loam	few, faint coats

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence			Texture	Clay Films
					Wet	Moist	Dry		
Soil Profile #3, Locality 28 (Plate I)									
0-14	A	--/10YR 6/2	moderate, medium, granular	~25	slightly sticky, not plastic	friable	soft	sandy loam	none
14-27	Bt1	--/7.5YR 5-4/4	weak, fine, angular blocky	~25	slightly sticky/sticky, not plastic	friable	soft	sandy loam	few faint coats
27-63	Bt2	--/5-7.5YR 4/4	moderate, medium-coarse,angular blocky	~25	sticky, slightly plastic	firm	soft/ slightly hard	sandy clay loam	many, prominent pores
63-117+	Bt3	--/5YR 5-4/4	moderate, medium-coarse, angular blocky	~30	sticky, slightly plastic	friable	soft	sandy clay loam	many, prominent pores

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence			Texture	Clay Films
					Wet	Moist	Dry		
Soil Profile #4, Locality 3 (Plate I)									
0-35	Ap	--/10YR 6/2	massive/single grain, coarse, granular	~25	sticky, slightly plastic	friable/ firm	soft	sandy clay loam	none
35-52	Bt1	--/7.5YR 6/4	weak, coarse, granular	~40	very sticky, slightly plastic	firm	soft/ slightly hard	sandy clay loam	many distinct bridges
52-99	Bt2	--/7.5YR 6-5/4	moderate, coarse, angular blocky	~30	very sticky, very plastic	firm	hard	clay loam	common distinct pores and coats
99-140	Bt3	--/7.5YR 6/4	moderate, coarse, angular blocky	~40	sticky, plastic	firm	slightly hard/hard	clay loam	many prominent coats/bridges
140-180+	Bt4	--/7.5YR 6/4	weak, massive, angular blocky	~25	sticky, plastic	firm	slightly hard	sandy clay loam	many distinct coats and bridges

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence			Texture	Clay Films
					Wet	Moist	Dry		
Soil Profile #5, Locality 31 (Plate I)									
0-20	Ap	10YR 4/2 / 10YR 6/2	weak-moderate, fine, subangular blocky	~10	sticky, plastic	firm	soft	clay loam	none
20-40	A2	10YR 5/4 / 10YR 6/2	moderate, medium, angular blocky	~10	sticky, slightly plastic	very friable	slightly hard	sandy clay loam	common, distinct bridges, coats
40-100	IIBt2	10YR 5/6 / 10YR 6/2	weak, medium, angular blocky	~75	sticky, not plastic	very friable	soft/ slightly hard	sandy clay loam	may distinct bridges,coats
100-150	IIBt3	10YR 5/6 / 10YR 5/4	weak, very fine, subangular blocky	~75	slightly sticky, not plastic	loose	soft to slightly hard	sandy clay loam	common, distinct bridges, coats
150-180+	IIC	10YR 5/6 / 10YR 6/3	massive	~50	slightly sticky, not plastic	very friable	--	--	none

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence			Texture	Clay Films
					Wet	Moist	Dry		
Soil Profile #6, Locality 30 (Plate I)									
1-10	Ap	10YR 4/4/ 10YR 5/3	single grain, massive	~25	sticky, plastic	firm	soft	sandy clay loam	none
10-30	B1	7.5YR 4/4 / 10-7.5YR 5/4	weak, coarse, angular blocky	10-25	very sticky, plastic	firm	soft	clay loam	few, faint coats, bridges
30-60	Bt2	7.5YR 4/4/ 7.5YR 5/4	moderate, coarse, angular blocky	~10	very sticky, plastic	firm	slightly hard	clay loam	few, faint coats, bridges
60-106	Bt3	7.5YR 4/4/ 7 .5YR 5/4	weak-moderate, coarse, angular blocky	~25	very sticky, plastic	firm	soft/ slightly hard	clay loam	many, distinct coats, bridges
106-180	IIBt4	7.5YR 5/4/ 7.5YR 5/4	weak, coarse, angular blocky	25-50	very sticky, plastic	friable/ firm	soft/ slightly hard	sandy clay loam	many prominent coats, bridges
180-230+	IIIC	10YR5/4/ 10YR 7/2	weak, fine, angular blocky	~50	sticky, slightly plastic	--	soft/ slightly hard	sandy clay loam	common, distinct bridges, coats

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence Wet	Moist	Dry	Texture	Clay Films
				Soil Profile #7, Locality 38 (Plate I)					
0-10	Ap	10YR 3/4/ 10YR 5/2	single grain, coarse	~25	sticky, plastic	firm	soft	sandy clay loam	none
10-22	B1	10YR 3/4/ 10YR 5/2	weak, medium, angular blocky	~25	very sticky, slightly plastic	firm	soft	sandy clay loam	none
22-92	Bt2	10YR 3/4/ 10YR 5/3	weak, medium, angular blocky	~25	very sticky, slightly plastic	friable	soft	sandy clay loam	common, faint bridges, coats
92-113+	Bt3	7.5YR 4/2/ 10YR-7.5YR 5/3	moderate, coarse, angular blocky	~10	sticky, plastic	friable	slightly hard	sandy clay loam	many, prominent coats, bridges
				Soil Profile #8, Locality 36 (Plate I)					
0-14	Ap	10YR 3/3/ 10YR 5/2	massive, coarse, granular	~10	slightly stickly, very slightly plastic	friable	soft	loam	none
14-28	Bt1	10YR 3/3-4/ 10YR 4/2	massive, medium to coarse, granular	10-25	sticky/very sticky, slightly plastic	friable	soft	sandy clay loam	none
28-44+	IIBt2	7.5YR 4/2/ 7.5YR 4/2	moderate, coarse, angular blocky	~50	very sticky, very plastic	firm/very firm	soft/ slightly hard	common, prominent bridges, coats	

Depth (cm)	Horizon	Color Moist/Dry	Structure	% Gravel	Consistence Wet	Consistence Moist	Consistence Dry	Texture	Clay Films
Soil Profile #9, Locality 2 (Plate I)									
0-21	Ap	10YR 3/3-4/ 10YR 5/2	weak, coarse, subangular blocky	~10	slightly sticky, slightly plastic	very friable	soft	loam	none
21-50	Bt1	10YR 4/3/ 10YR 6/2	weak, coarse, subangular blocky	~25	slightly sticky/sticky, plastic	friable	soft/ slightly hard	loam	few faint coats, bridges
50-70+	Bt2	10YR 4/4/ 7.5YR 6/2	weak, coarse, angular blocky	~10	very sticky, plastic	firm	soft/ slightly hard	clay loam	many distint bridges, coats
Soil Profile #10, Locality 43 (Plate I)									
0-20	Ap	10YR 3/4/ 10YR 6/2	weak, coarse, subangular blocky	~10	sticky, plastic	firm	soft/ slightly hard	clay loam	none
20-74+	B	10YR 4/4/ 10YR 5/3	moderate, coarse, subangular blocky	10-25	slightly sticky, not plastic	friable/ firm	slightly hard/hard	sandy clay loam	many prominent bridges, coats, pores
Soil Profile #11, Locality 46 (Plate I)									
*	Bt	7.5YR /4	*	>10	very sticky, very plastic	loose	soft	clay loam	none

Note: * = Single sample at roadcut, evaluated only for color and consistence.

APPENDIX B

Mapped USDA Soil Series (USDA, 1975a)

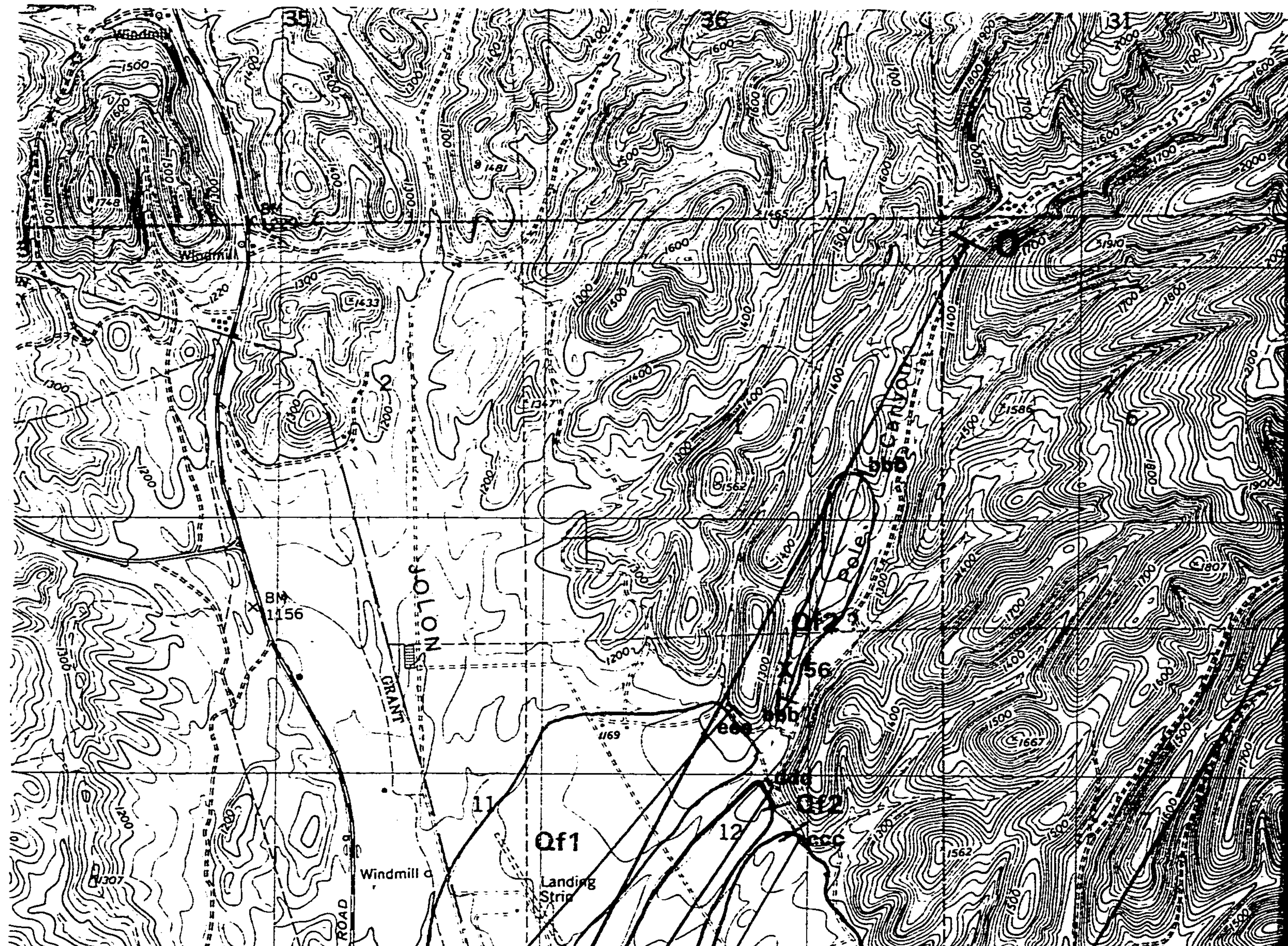
Appendix B summarizes representative profiles described in the soil survey of Monterey County, California, for the three most widespread soil series found on Quaternary alluvial surfaces in the study area. Two of these profiles were described by the USDA outside of the study area; the representative of the Arbuckle soil series was described by the USDA at a location within the study area, on the Holocene fan between Glau and Loeber canyons.

Horizon	Depth (cm)	Percent Gravel	Color (dry; moist)	Moist Consistence	Dry Consistence	Structure	Clay Films
Arbuckle Series, NW1/4, NW1/4, S.13, T.23S, R.8E (USDA, 1975a)							
Ap	0-20	15	10YR 6/2; 10YR 4/2	sticky, slightly plastic	hard	massive	none
A12	20-43	15	10YR 6/2; 10YR 4/2	sticky, plastic	hard	weak, medium, subangular blocky	none
B1t	43-71	25	10YR 6/3; 10YR 4/3	sticky, plastic	hard	massive	common, thin, pores and bridges
B21t	71-94	25	7.5YR 6/4; 7.5YR 4/4	sticky, plastic	very hard	massive	common, moderately thick, pores and bridges
B22t	94-117	25	7.5YR 6/4; 7.5YR 4/4	sticky, plastic	very hard	massive	common, moderately thick, pores and bridges
IIC	117-152	50	7.5YR 7/4; 7.5YR 5/4	sticky, slightly plastic	hard	massive	none

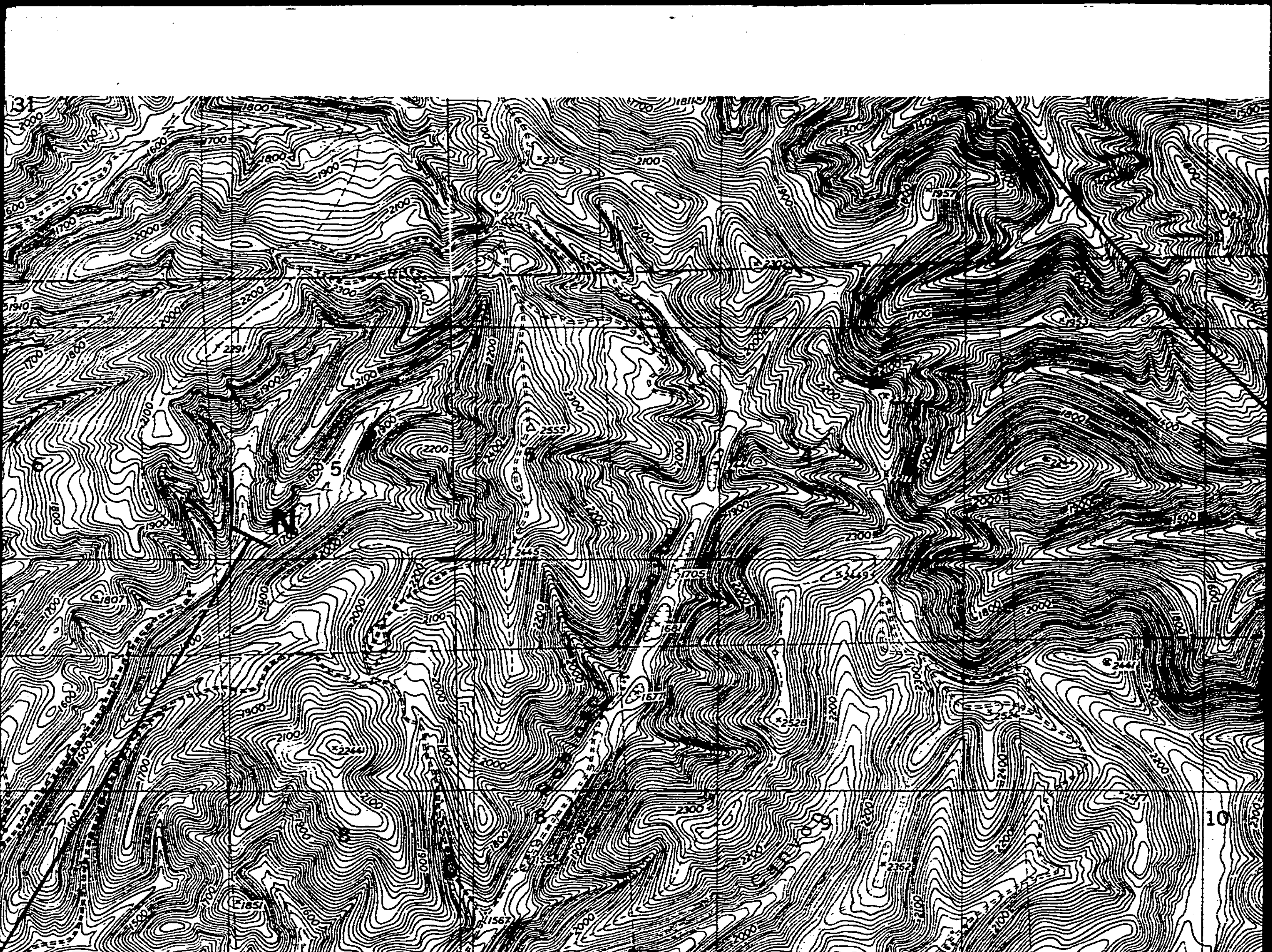
Horizon	Depth (cm)	Percent Gravel	Color (dry; moist)	Moist Consistence	Dry Consistence	Structure	Clay Films
Lockwood Series, ~7 miles west of King City on Central Avenue (USDA, 1975a)							
Ap1	0-8	15	10YR 5/1; 10YR 3/2	slightly sticky, slightly plastic	slightly hard	moderate, subangular blocky	none
Ap2	15189	10	10YR 5/1; 10YR 2/2	slightly sticky, slightly plastic	slightly hard	weak, angular blocky, to moderate, granular	none
A13	41-66	10	10YR 5/1; 10YR 2/2	slightly sticky, slightly plastic	slightly hard	strong, granular	none
B1	66-102	25	10YR 5/1; 10YR 3/2	slightly sticky, slightly plastic	soft	moderate, granular	none
B21t	102-145	30	10YR 5/3; 10YR 4/4	sticky, plastic	slightly hard	massive	continuous thin, few moderately thick bridges
B22t*	145-208	30	10YR 5/3; 10YR 4/3	sticky, plastic	slightly hard	massive	continuous thin, few moderately thick bridges
IIC	208-218	varies, up to 60%	10YR 6/3; 10YR 4/3	slightly sticky, slightly plastic	slightly hard	massive	few thin pores

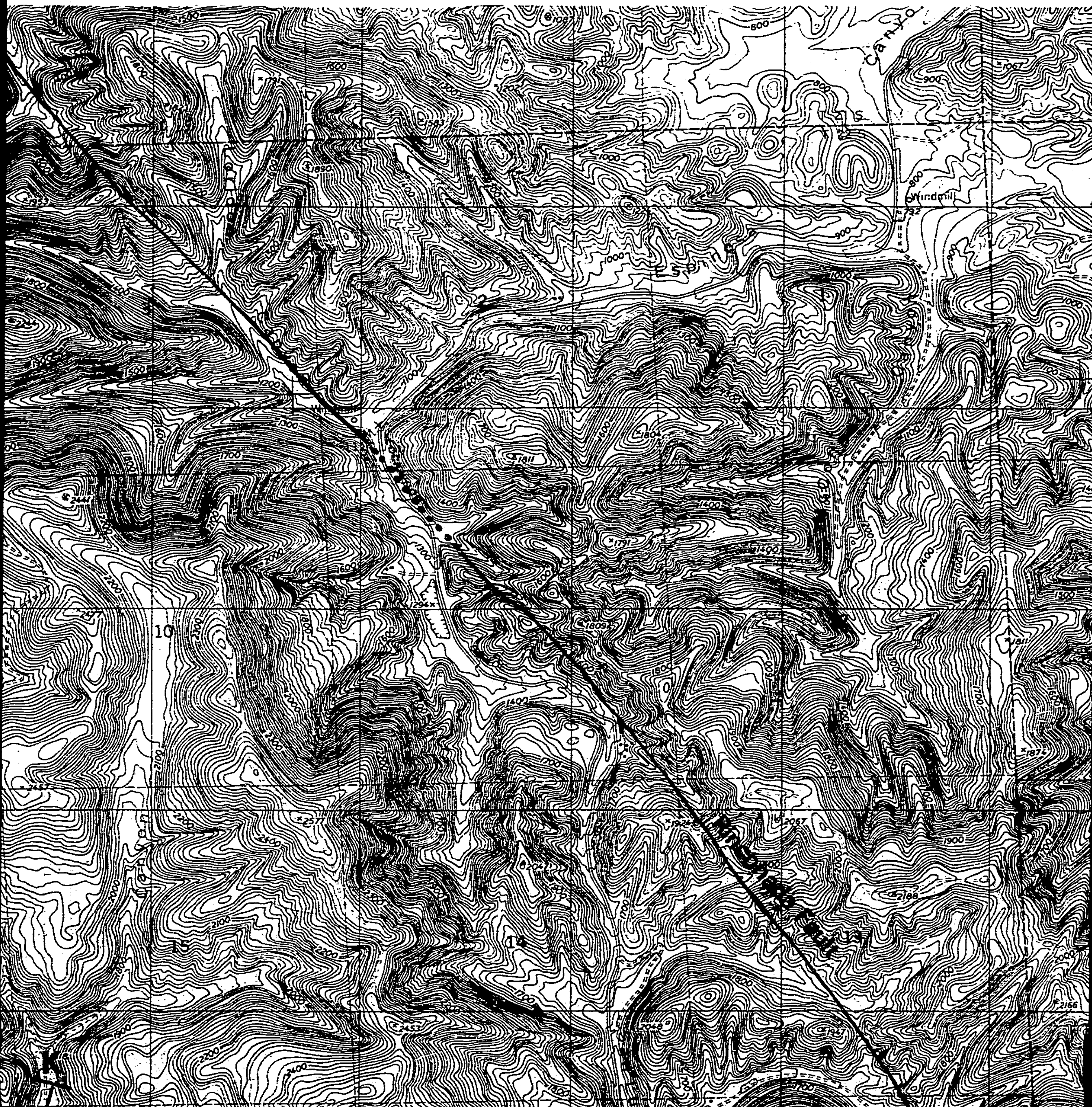
* Below 102 cm, Bt is weakly cemented in some places

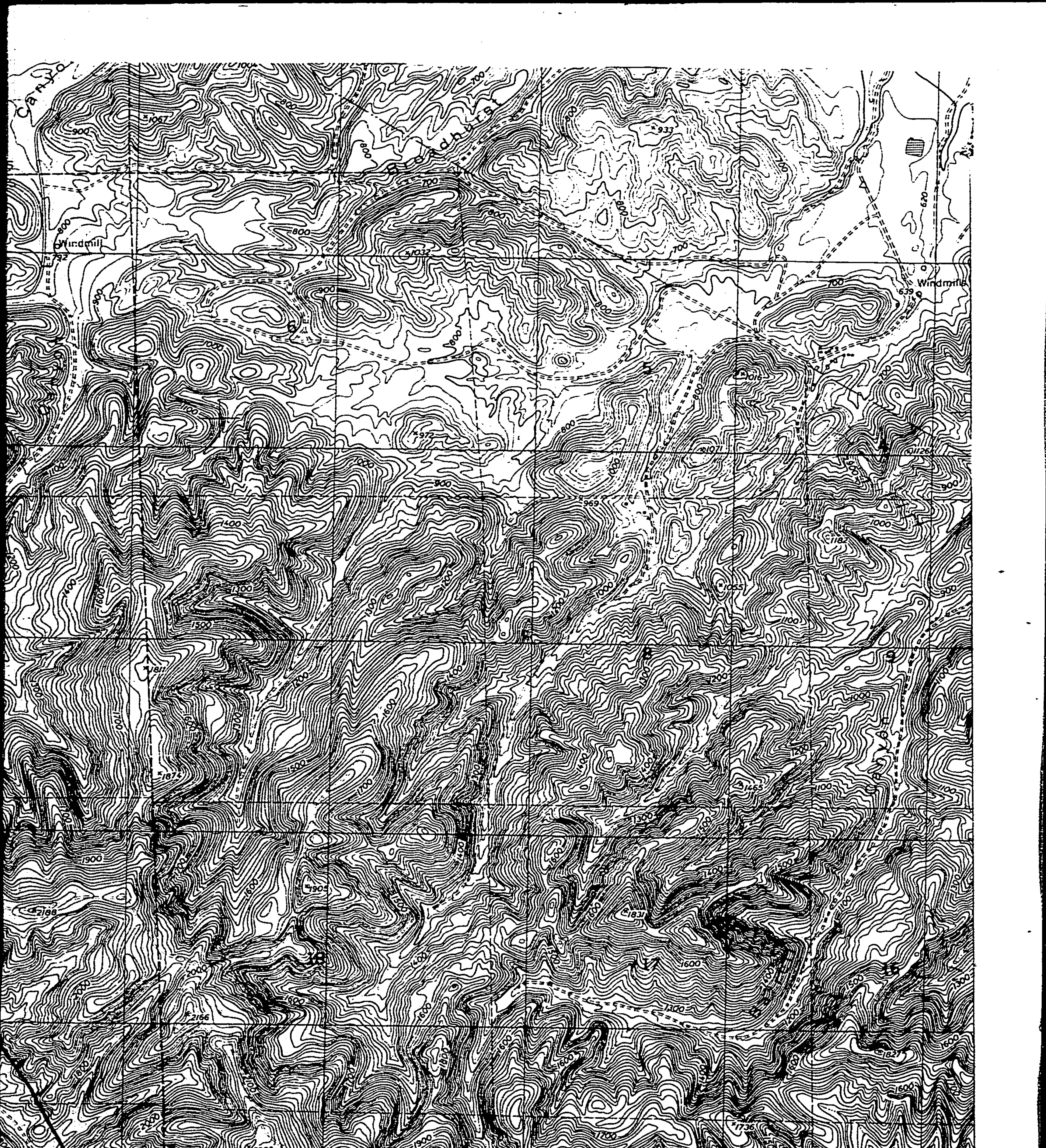
Horizon	Depth (cm)	Percent Gravel	Color (dry; moist)	Moist Consistence	Dry Consistence	Structure	Clay Films
Chamise Series, ~4 miles NW of King City, NE1/2, SE1/4,S.34, .19S, R.7E (USDA, 1975a)							
A11	0-10	25	10YR 5/2; 10YR 3/2	slightly sticky, plastic	slightly hard	weak, subangular blocky	none
A12	10-46	20	10YR 5/2; 10YR 3/2	slightly sticky, plastic	slightly hard	moderate, subangular, blocky	none
A2	46-48	20	10YR 6/3; 10YR 3/3	sticky, plastic	slightly hard	moderate, granular	none
B21t	48-74	65	10YR 5/3; 7.5YR 3/2	sticky, plastic	hard	massive	common moderately thick, in pores
B22t	74-102	55	10YR 3/2-10YR3/3; 5YR 3/2	very sticky, very plastic	very hard	massive	many moderately thick, in pores
IIC	102-152	15	10YR 6/4; 10YR 4/4	not sticky, not plastic	slightly hard	massive	few thick, pores

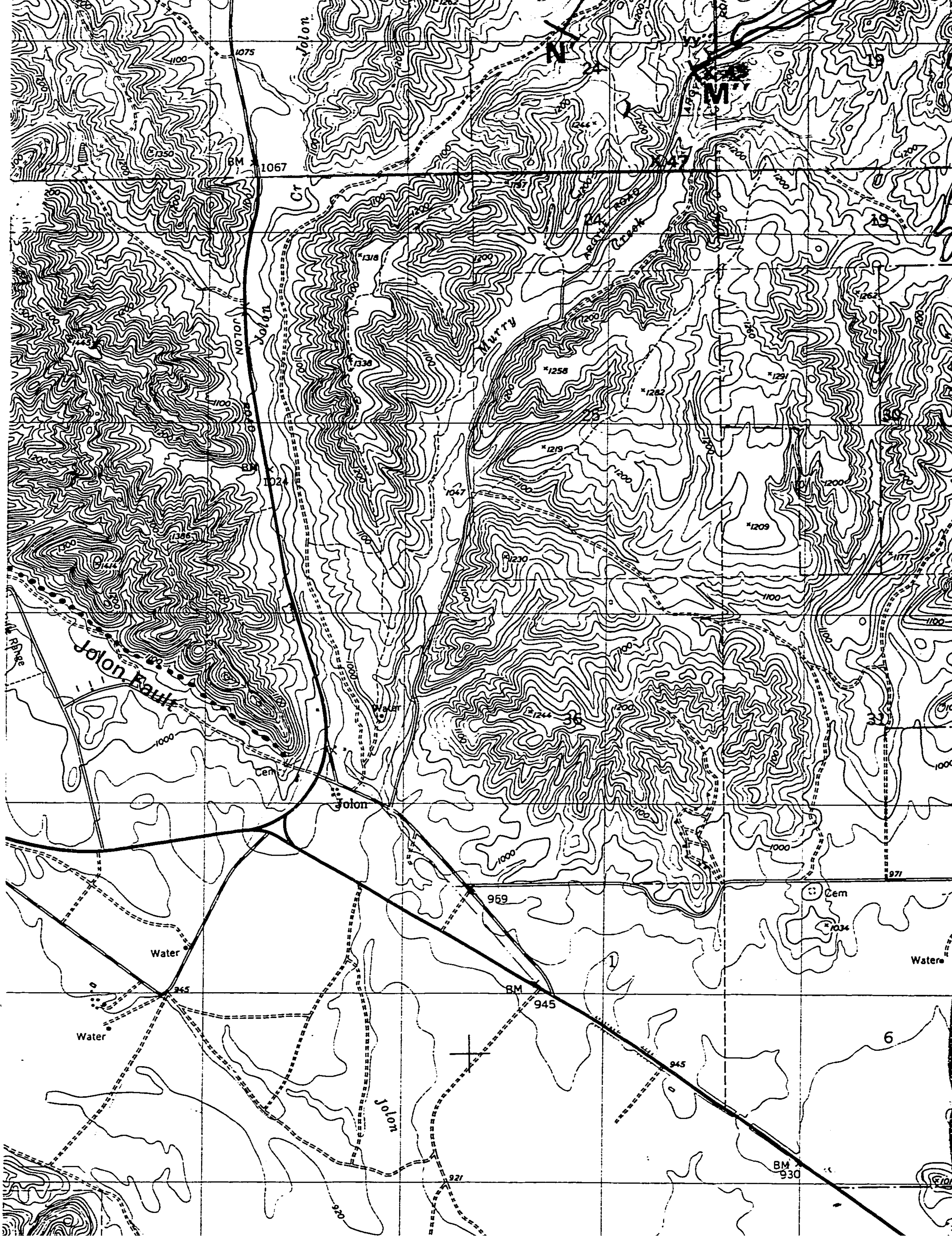


35
36
31
Windmill
JOLON
GRANT
ROAD
VALLEY
BOUNDARY
Pole
Canyon
Jolon
Creek
Qf1
Qf2
Qf3
Landing Strip
BM 1156
BM 1105
BM 1091
O'
N'
X 55
X 56
X 54
X 52
X 51
X 50
X 49
bbb
ccc
ddd
eee
aaa
zz
yy
Ruins

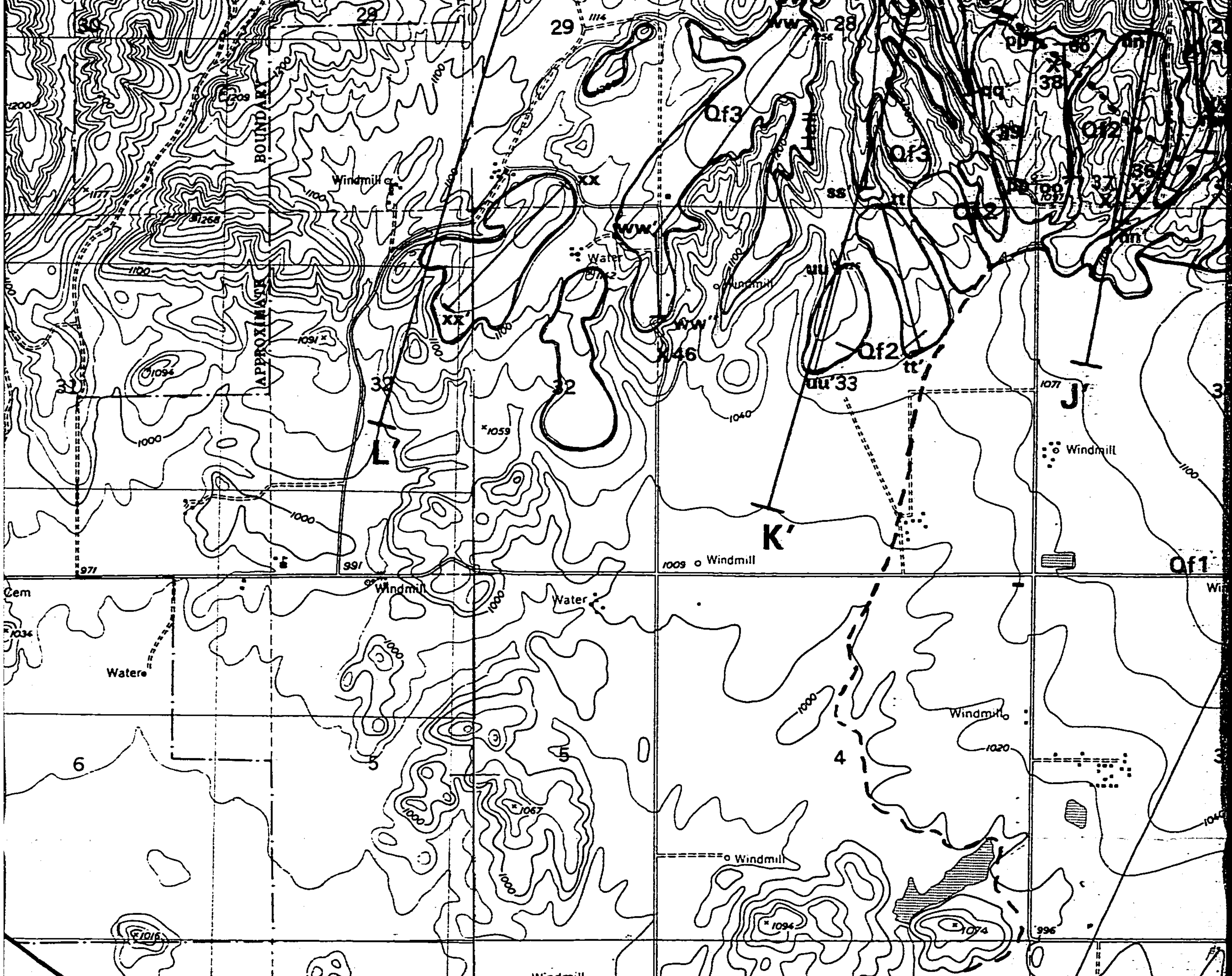

N
M
L
K
Qf2
Qf3


Windmill

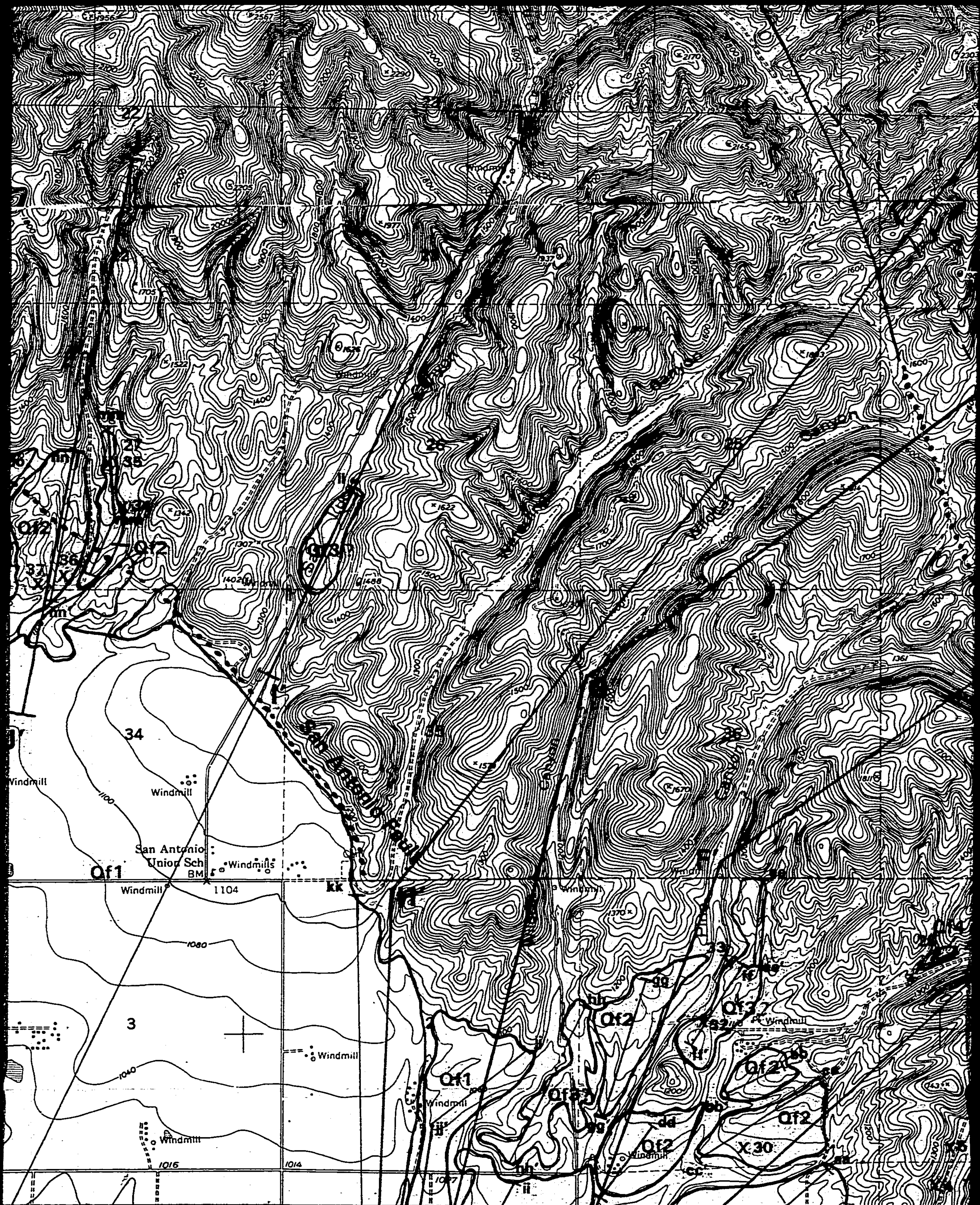

Windmill
Windmills



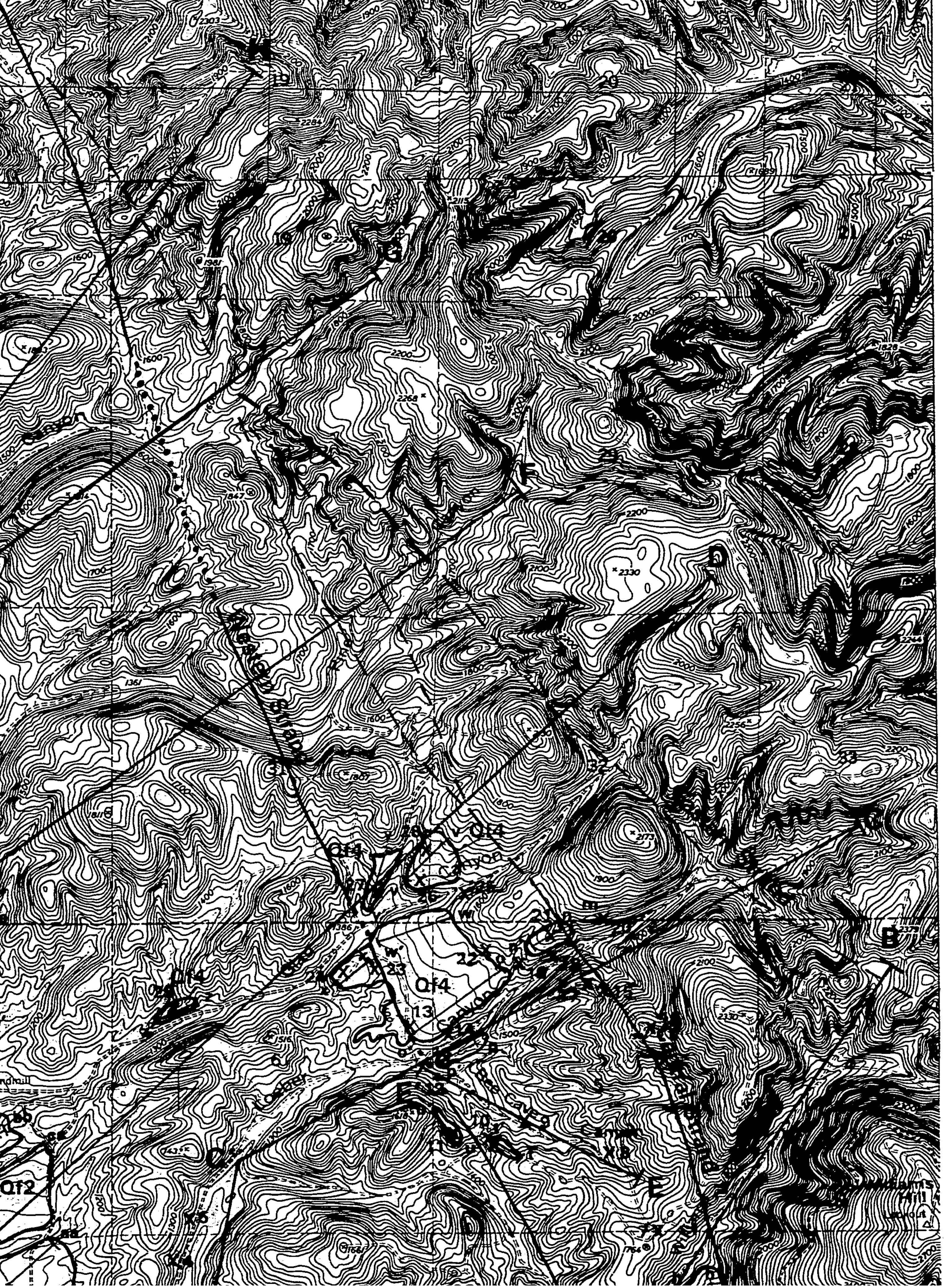
N
M
24
19
BM 1067
Jolon
Jolon Cr
Murry
Creek
JOLON ROAD
25
30
BM 1024
1047
1100
1200
Jolon Fault
36
31
Water
Cem
Jolon
1000
969
971
Cem
1034
Water
945
Water
1
BM 945
6
945
Jolon
BM 930
921
920



APPROXIMATE
BOUNDARY
Windmill
Water
Cem
Qf1
Qf2
Qf3
K'
L'
J'



San Antonio fault
San Antonio
Union Sch
BM
1104
Windmill
Windmills
Qf1
Qf2
Qf3 ?
Qf3 ?
34
3
35
26
25
22
Canyon
kk
1080
1040
1016
1014
1100
X 30



Qf4
Qf2
Canyon

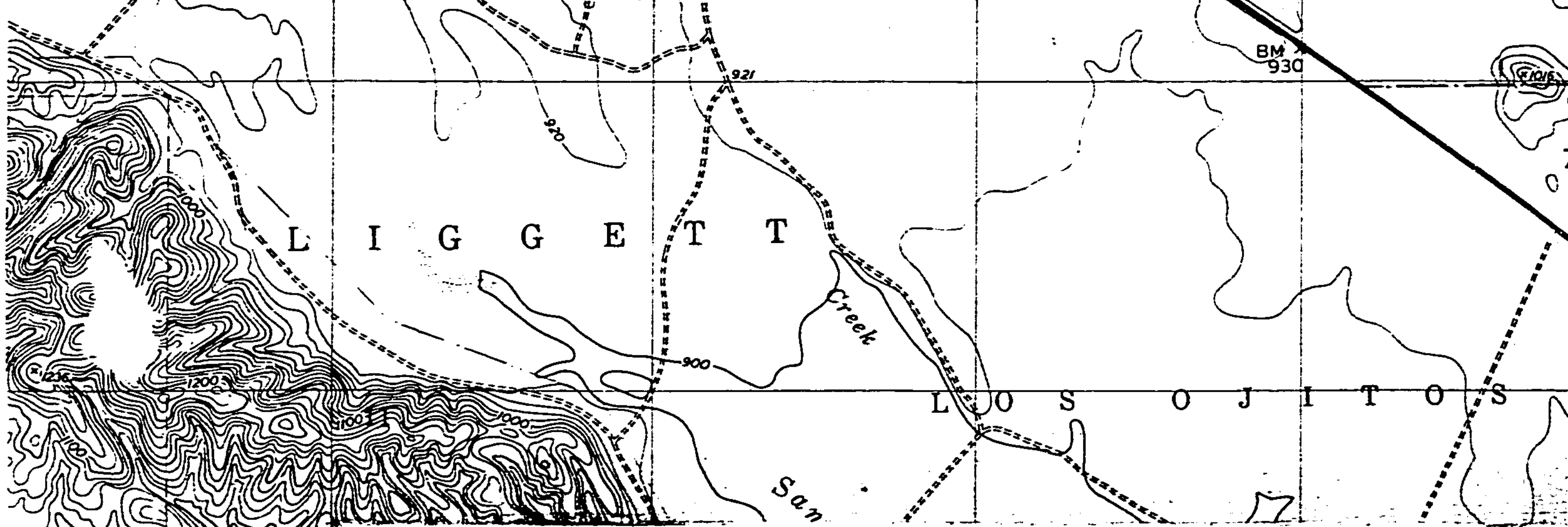


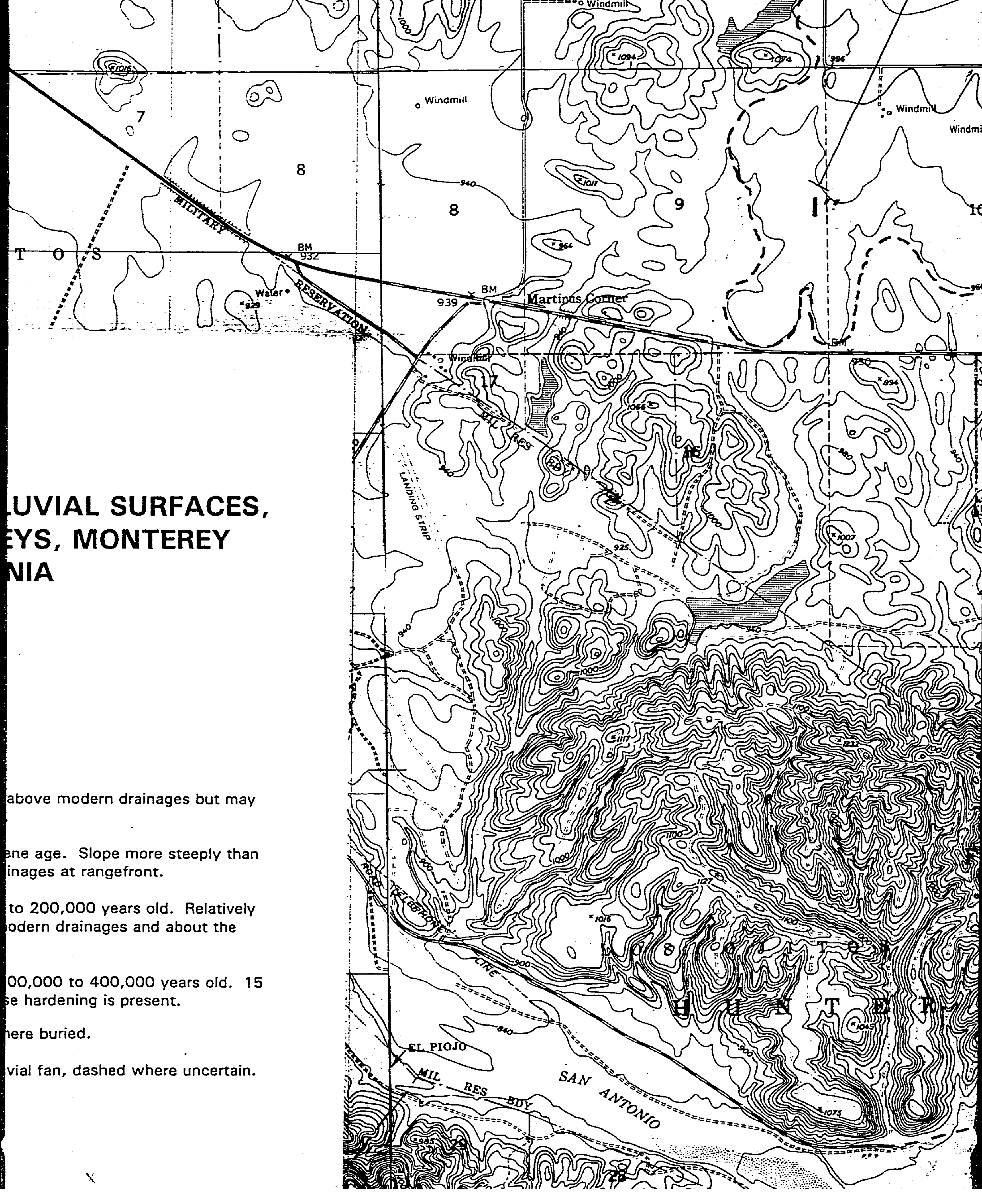
PLATE I

MAP SHOWING QUATERNARY ALLUVIAL SU
LOCKWOOD AND JOLON VALLEYS, MON
COUNTY, CALIFORNIA

EXPLANATION

Quaternary Alluvial Surfaces

Qf1	**Qf1** Holocene alluvial fans. Generally 6 to 10 m above modern dr be entrenched to as much as 15 m at rangefront.
Qf2	**Qf2** Well-dissected fans of probable late Pleistocene age. Slope m modern drainages; 10 to 40 m above modern drainages at rangefr
Qf3	**Qf3** Rangefront surfaces approximately 100,000 to 200,000 yea flat-topped and steep sided; 15 to 40 m above modern drainages same slope.
Qf4	**Qf4** Oldest Quaternary surfaces, approximately 300,000 to 400,0 to 40 m above modern canyon floors; locally, case hardening is p
━━━ ━ ━ • •	Fault, dashed where uncertain, dotted where buried.
——— — —	Approximate boundary of Quaternary alluvial fan, dashed
X 24	Field Site
H ├──┤ H′	Stream profile line
a ├──┤ a′	Alluvial surface profile line



LUVIAL SURFACES, EYS, MONTEREY NIA

above modern drainages but may

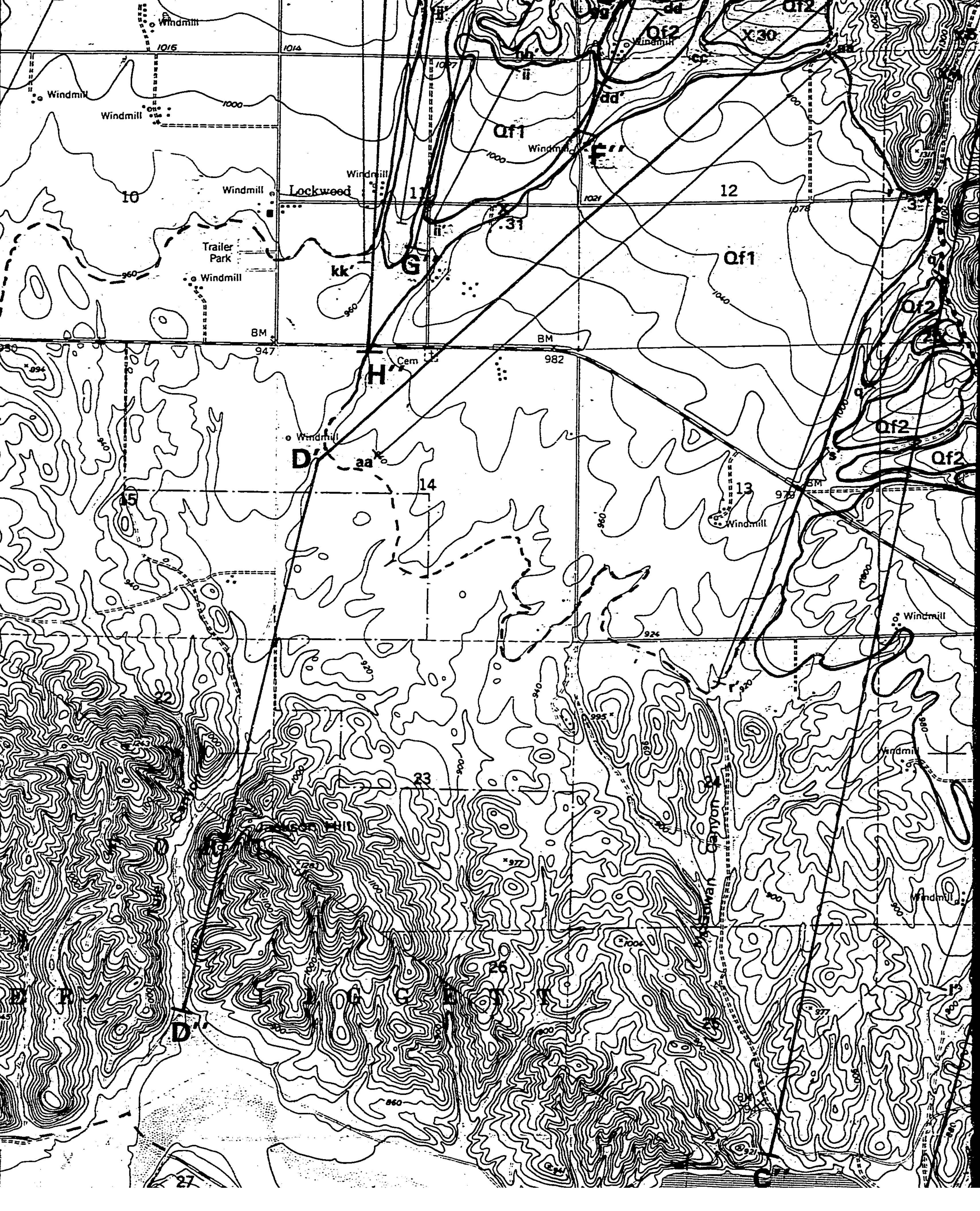
ene age. Slope more steeply than inages at rangefront.

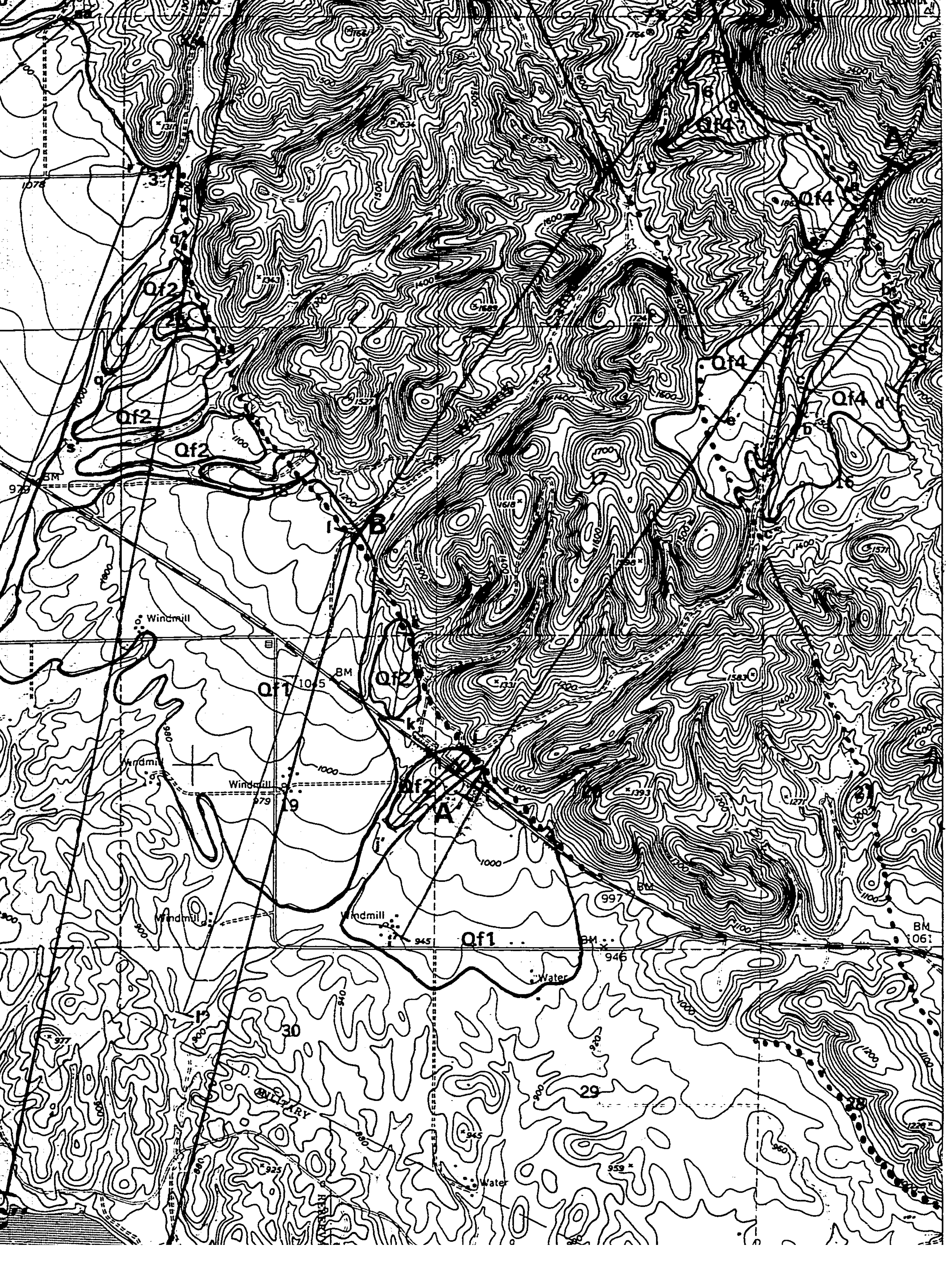
to 200,000 years old. Relatively odern drainages and about the

00,000 to 400,000 years old. 15 se hardening is present.

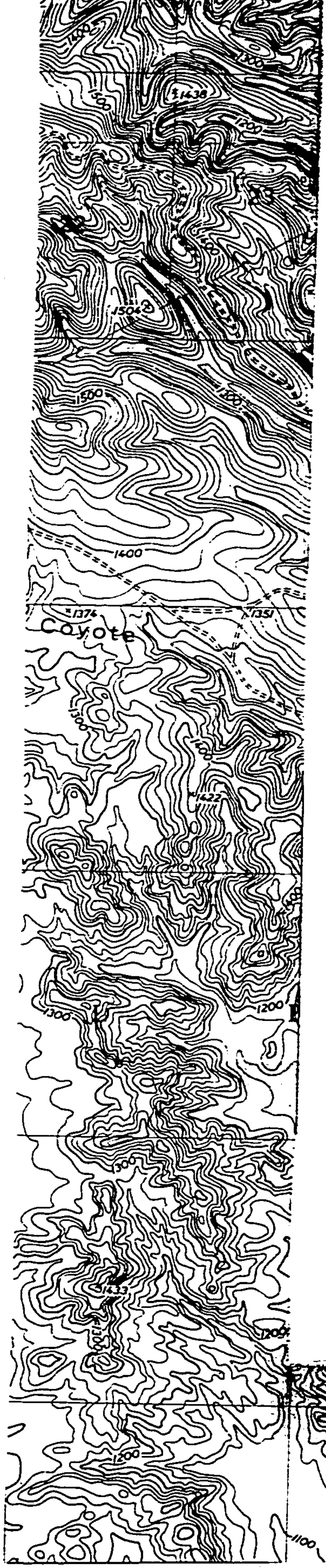
here buried.

vial fan, dashed where uncertain.


Windmill
Lockwood
Trailer Park
Qf1
Qf2
10
11
12
13
14
15
22
23
24
25
26
27
BM 947
BM 982
Cem
D'
D''
H'
G'
F'
C'
aa
kk'
Canyon
L I G G E T T


Qf2
Qf2
Qf2
Qf2
Qf1
Qf1
Qf2
Qf2
Qf4
Qf4
Qf4
Qf4
A
A'
B
B'
Windmill
Windmill
Windmill
Windmill
Windmill
Water
Water
BM
MILITARY
19
30
29
28
17
16
21
20

COUNTY, CALIFORNIA



EXPLANATION

Quaternary Alluvial Surfaces

Qf1	**Qf1** Holocene alluvial fans. Generally 6 to 10 m above modern dr be entrenched to as much as 15 m at rangefront.
Qf2	**Qf2** Well-dissected fans of probable late Pleistocene age. Slope m modern drainages; 10 to 40 m above modern drainages at rangefr
Qf3	**Qf3** Rangefront surfaces approximately 100,000 to 200,000 year flat-topped and steep sided; 15 to 40 m above modern drainages same slope.
Qf4	**Qf4** Oldest Quaternary surfaces, approximately 300,000 to 400,0 to 40 m above modern canyon floors; locally, case hardening is pr

Fault, dashed where uncertain, dotted where buried.

Approximate boundary of Quaternary alluvial fan, dashed v

X 24 Field Site

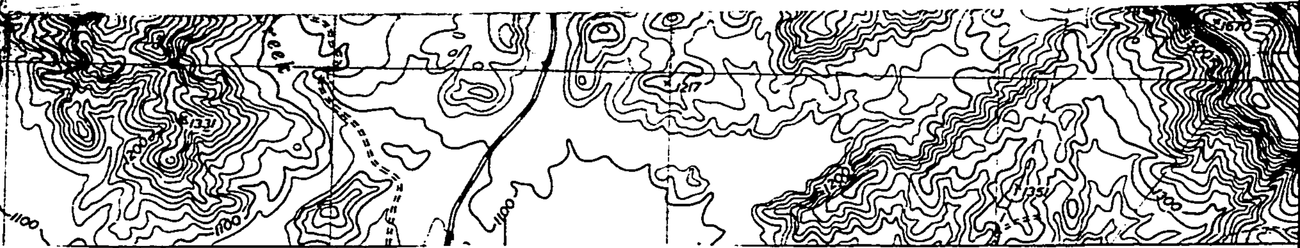
H H′ Stream profile line

a a′ Alluvial surface profile line

Base Maps: U.S. Geological Survey, Topographic maps of 7.5-minute quadrangle California (1949, photorevised 1984), Jolon, California (1949), and Williams Cany (1949, photorevised 1979): scale 1:24,000.

SCALE: 1:24,000

Alisa Klaus
San Jose State University
1999



LEYS, MONTEREY
RNIA

m above modern drainages but may
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ocene age. Slope more steeply than
drainages at rangefront.

00 to 200,000 years old. Relatively
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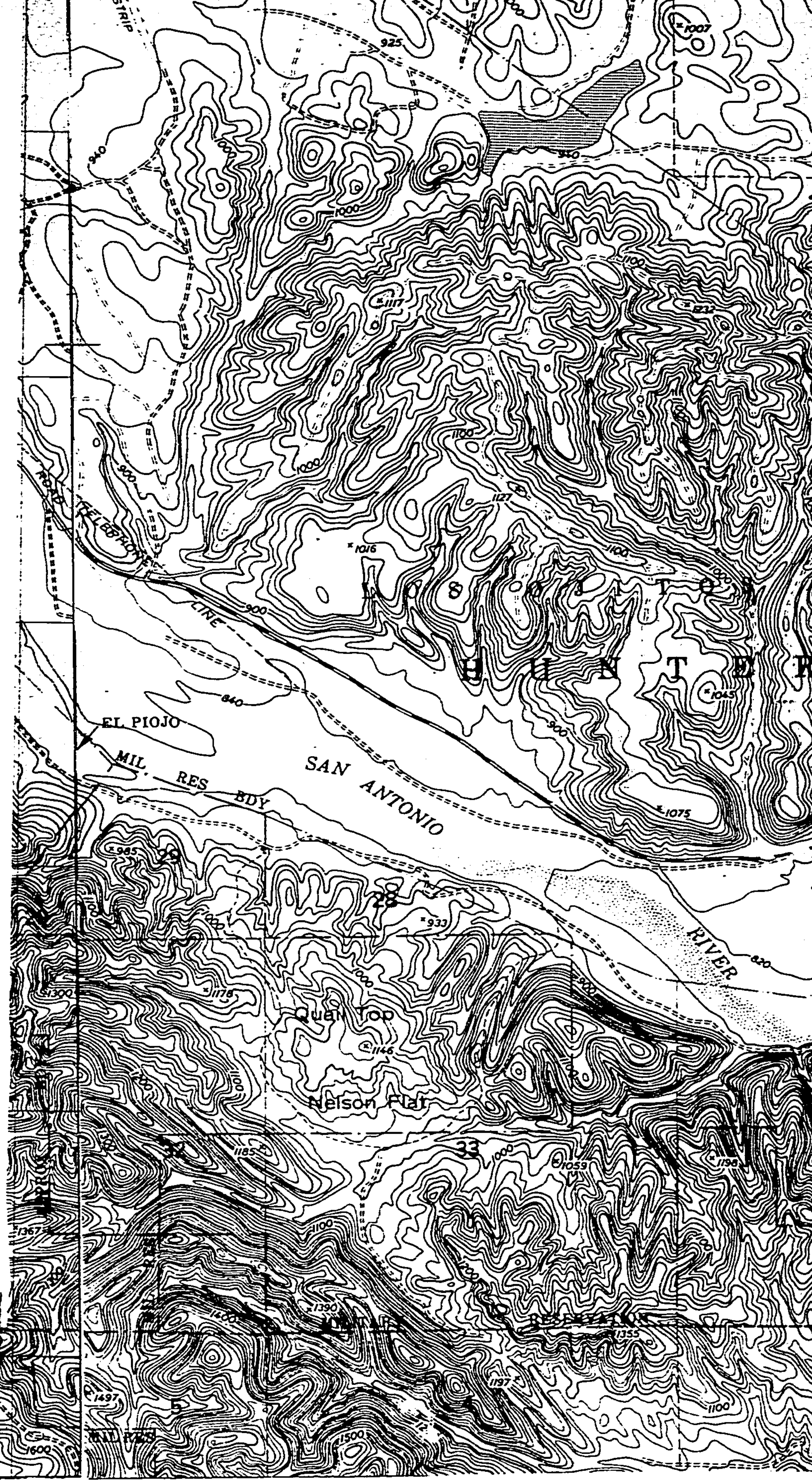
y 300,000 to 400,000 years old. 15
case hardening is present.

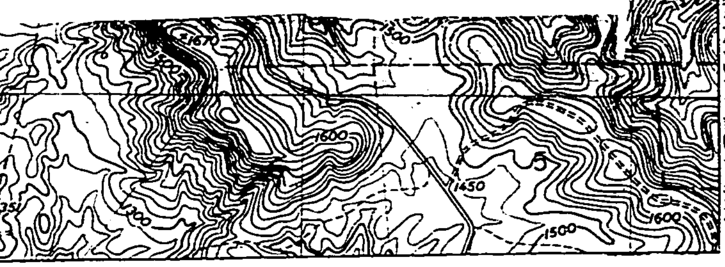
where buried.

alluvial fan, dashed where uncertain.

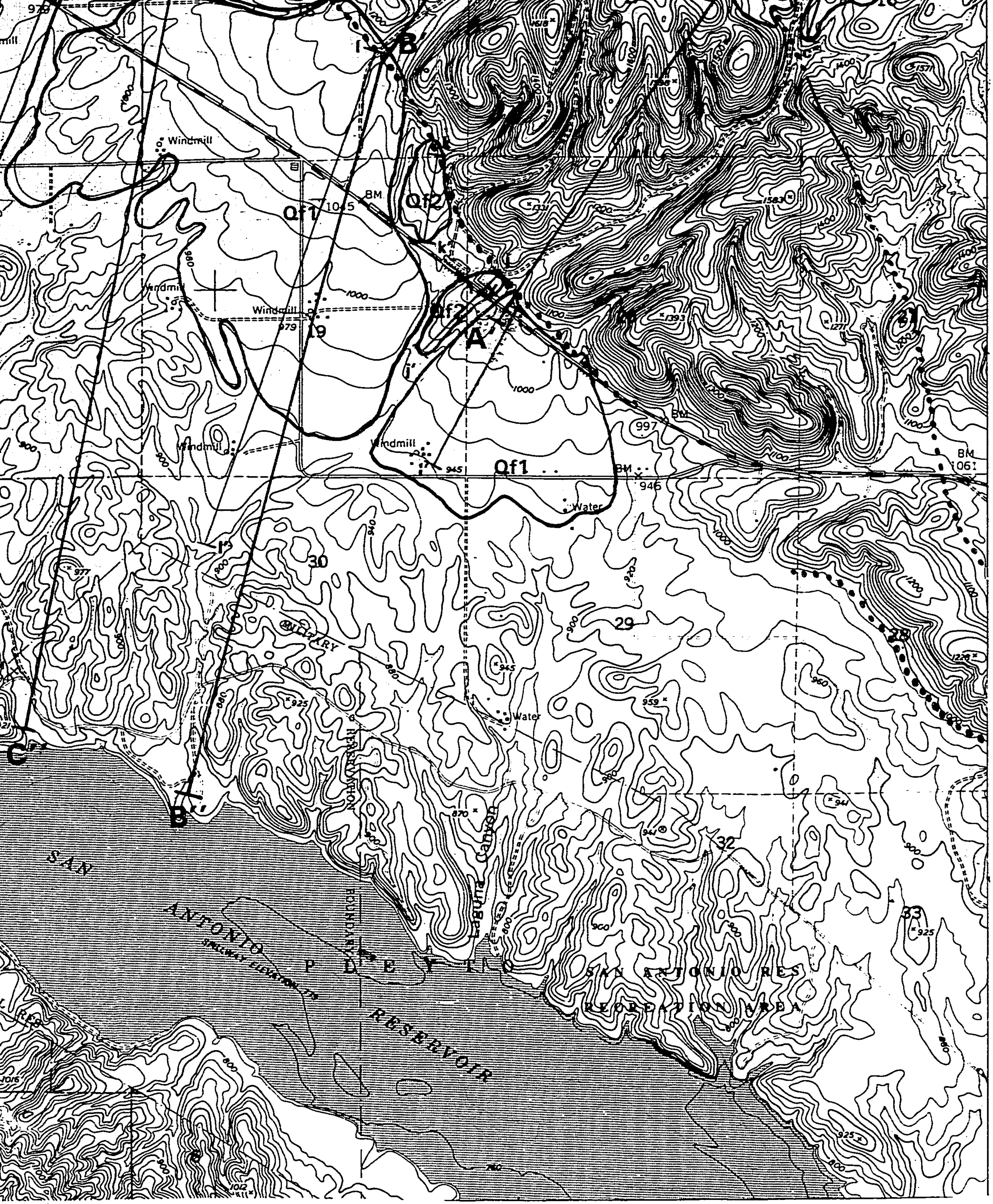
5-minute quadrangles, Cosio Knob,
), and Williams Canyon, California

sity

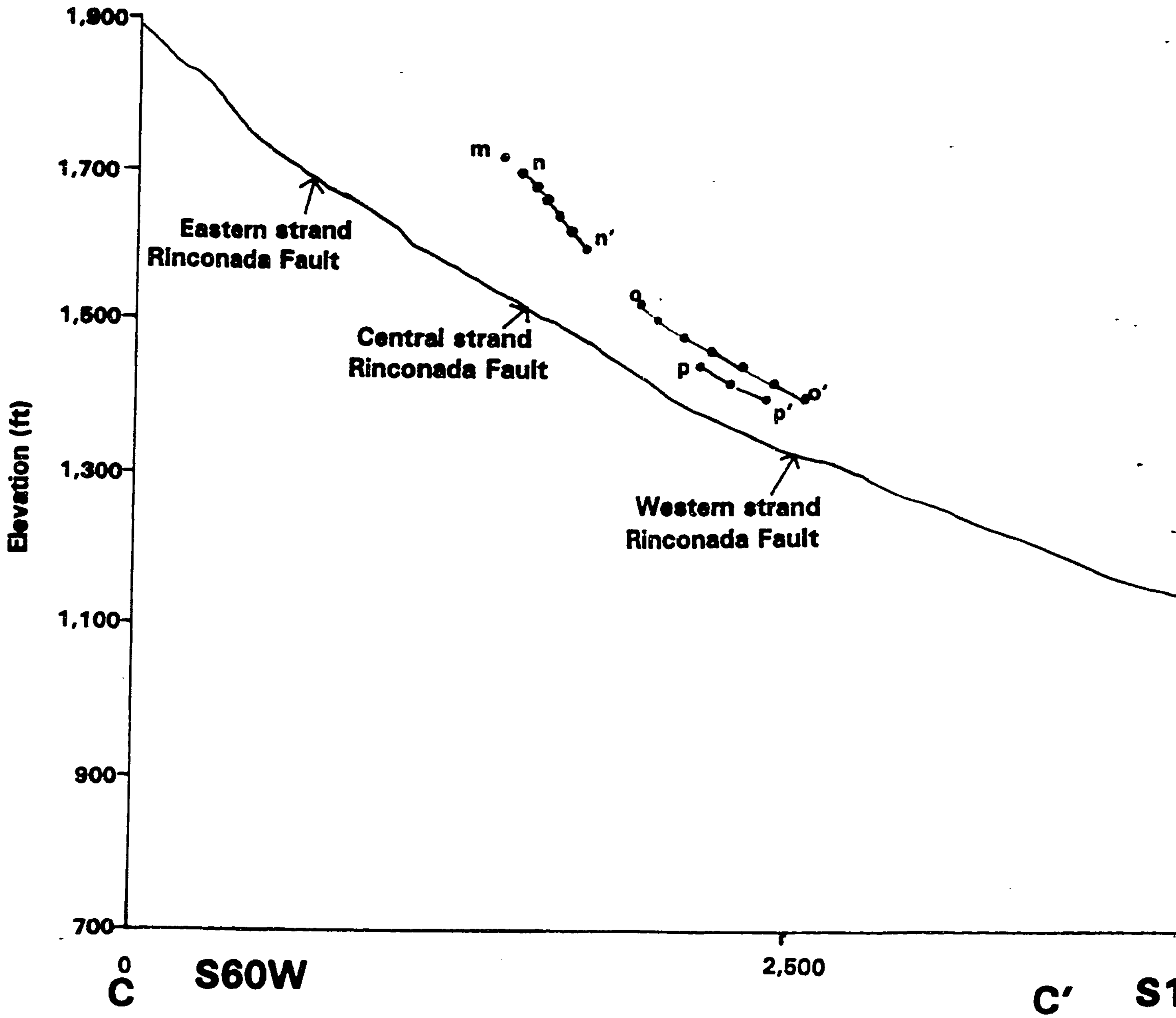




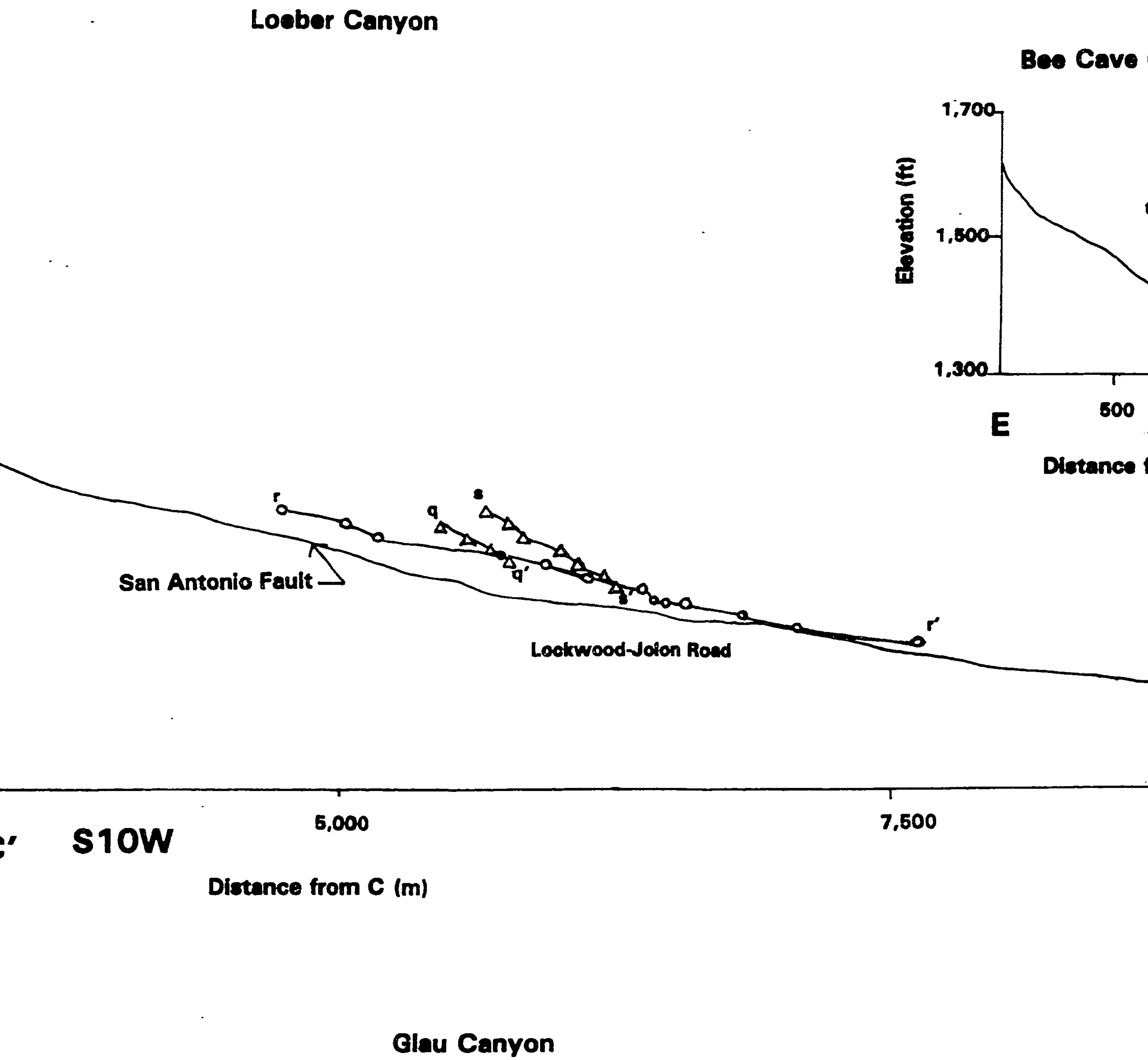
Windmill
22
23
24
25
26
27
35
36
Canyon
D
C
B
RIVER
SAN



B
A'
A
B'
C'
Qf1
Qf2
Windmill
Water
BM
19
21
28
29
30
32
33
MILITARY
RESERVATION
BOUNDARY
Laguna Canyon
SAN ANTONIO RESERVOIR
SPILLWAY ELEVATION 779
SAN ANTONIO RES
RECREATION AREA
P D E Y T O


1,900
1,700
1,500
1,300
1,100
900
700
Elevation (ft)
m
n
n'
o
o'
p
p'
Eastern strand
Rinconada Fault
Central strand
Rinconada Fault
Western strand
Rinconada Fault
0
C
S60W
2,500
C'
S1

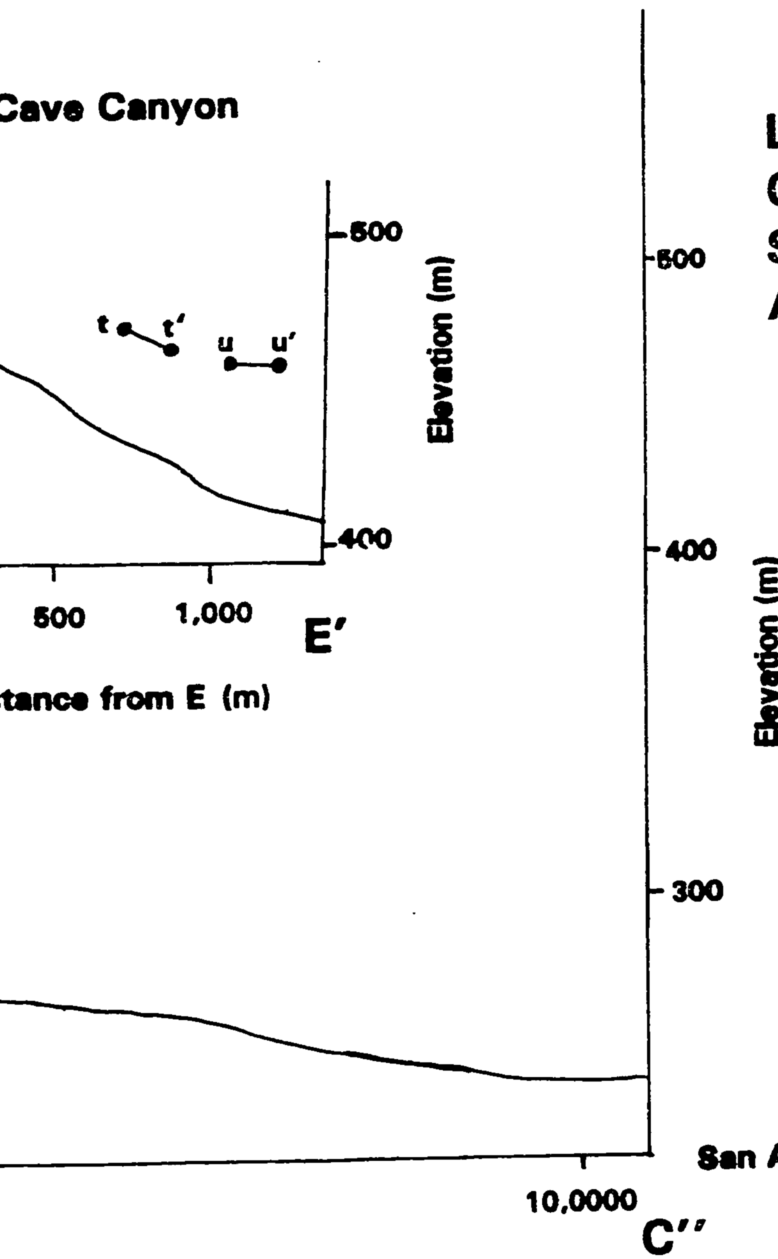

2,200
2,000



Loeber Canyon
Bee Cave
1,700
1,500
1,300
Elevation (ft)
500
E
Distance f
r
s
q
q'
s'
r'
San Antonio Fault
Lockwood-Jolon Road
5,000
7,500
S10W
Distance from C (m)
Glau Canyon

PLATE II

LONGITUDINAL PROFILES OF QUATERNARY ALLUVIAL SURFACES, LOEBER, GLAU, AND BEE CAVE CANYONS

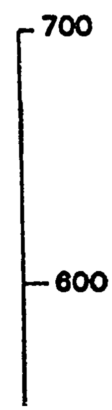


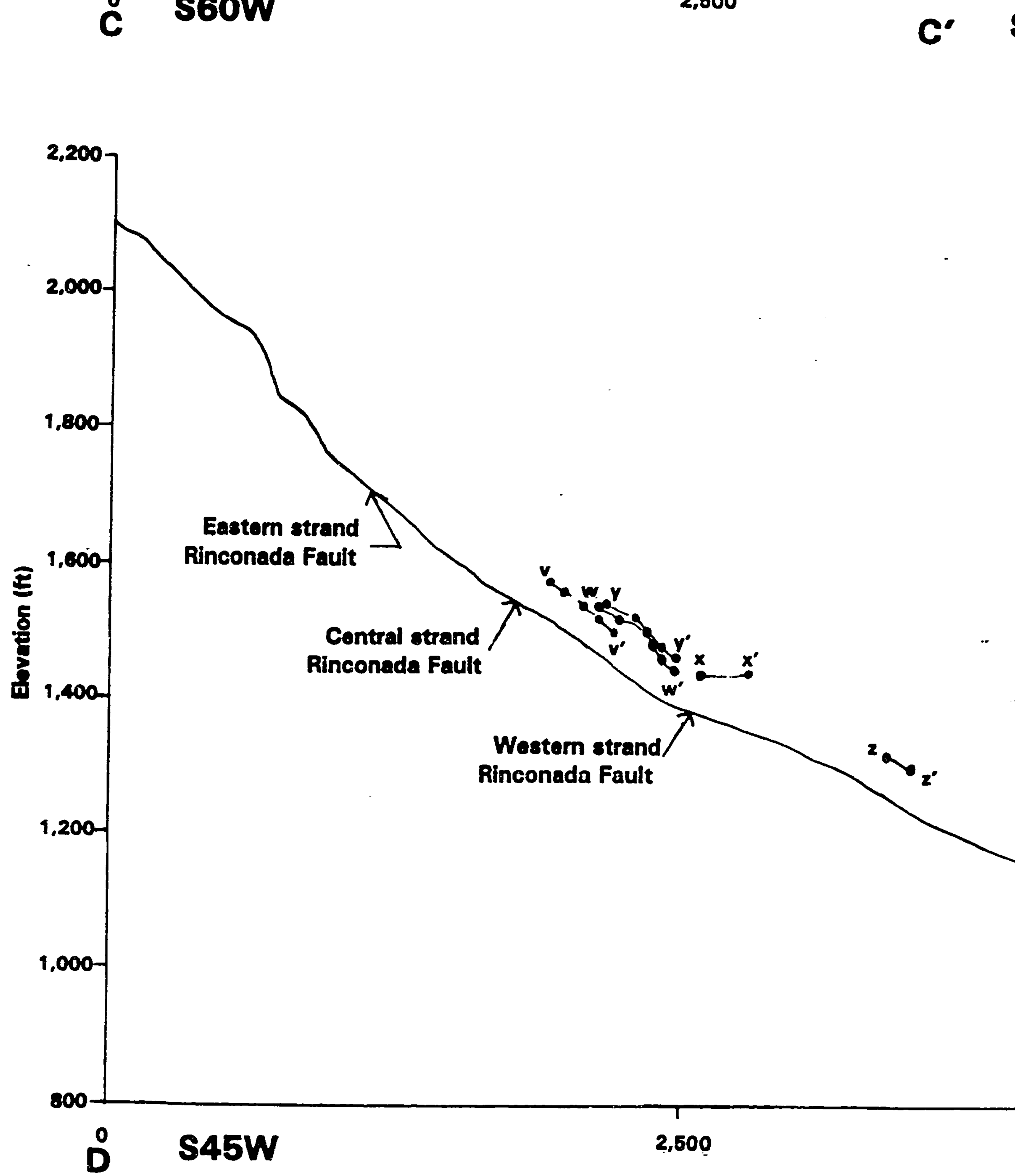
Explanation

Stream profile

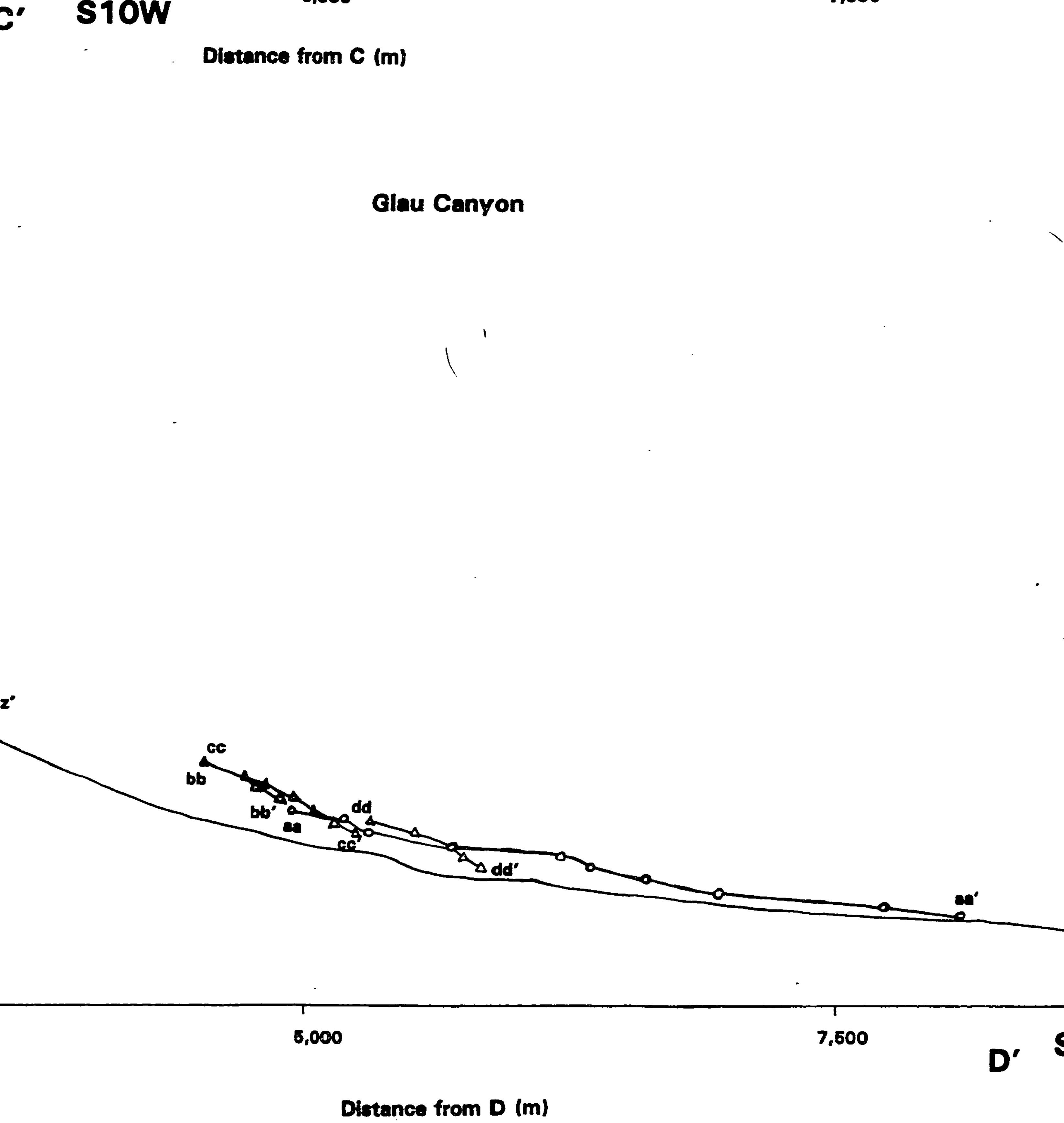
- Qf1
- Qf2
- Qf3
- Qf4

Horizontal scale 1:24,000
Vertical exaggeration 10:1

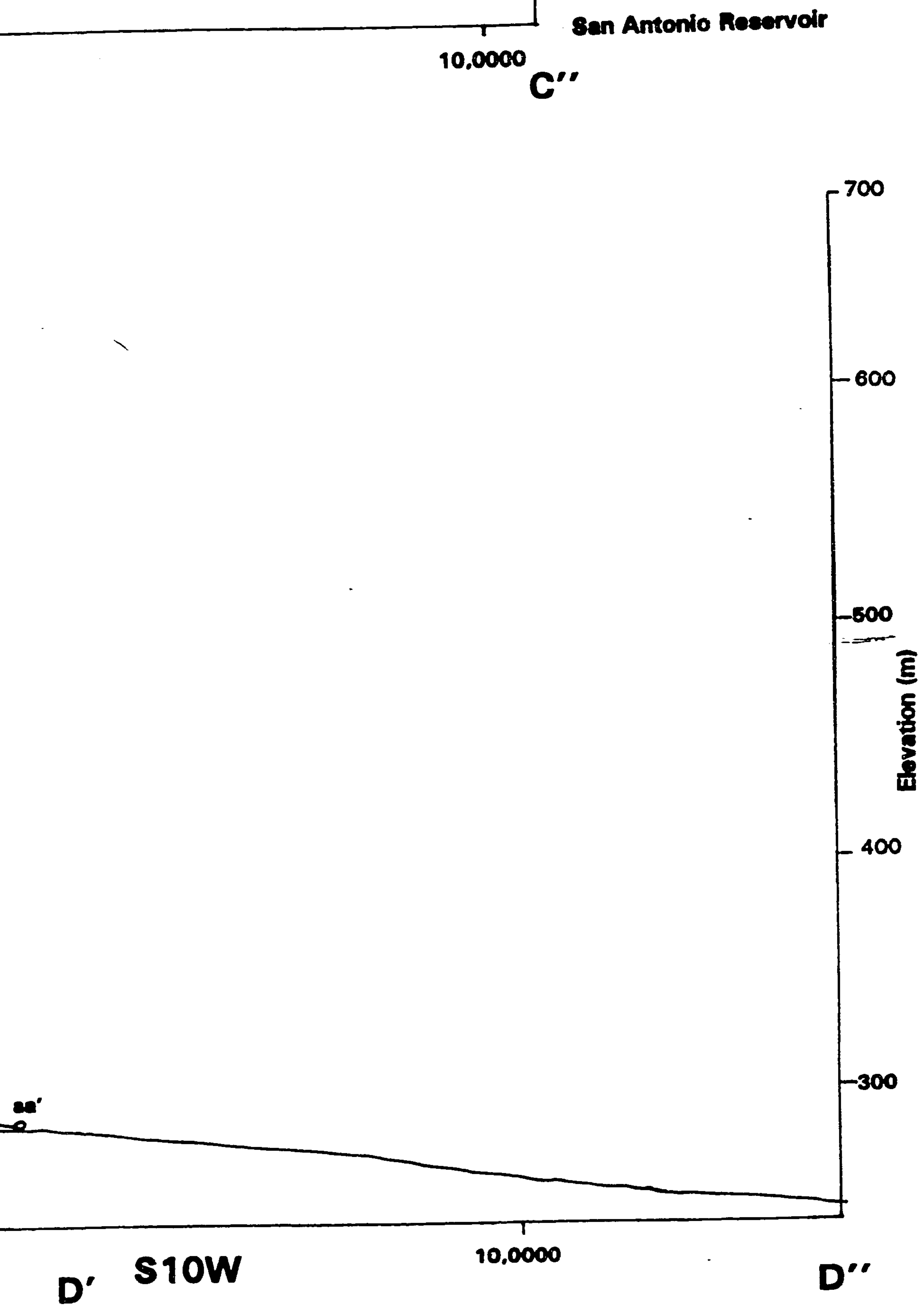




C
S60W
2,500
C′
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
Elevation (ft)
Eastern strand
Rinconada Fault
Central strand
Rinconada Fault
Western strand
Rinconada Fault
v
v′
w
w′
y
y′
x
x′
z
z′
0
D
S45W
2,500



C'
S10W
Distance from C (m)
Glau Canyon
z'
cc
bb
bb'
aa
dd
cc'
dd'
aa'
5,000
7,500
D'
Distance from D (m)



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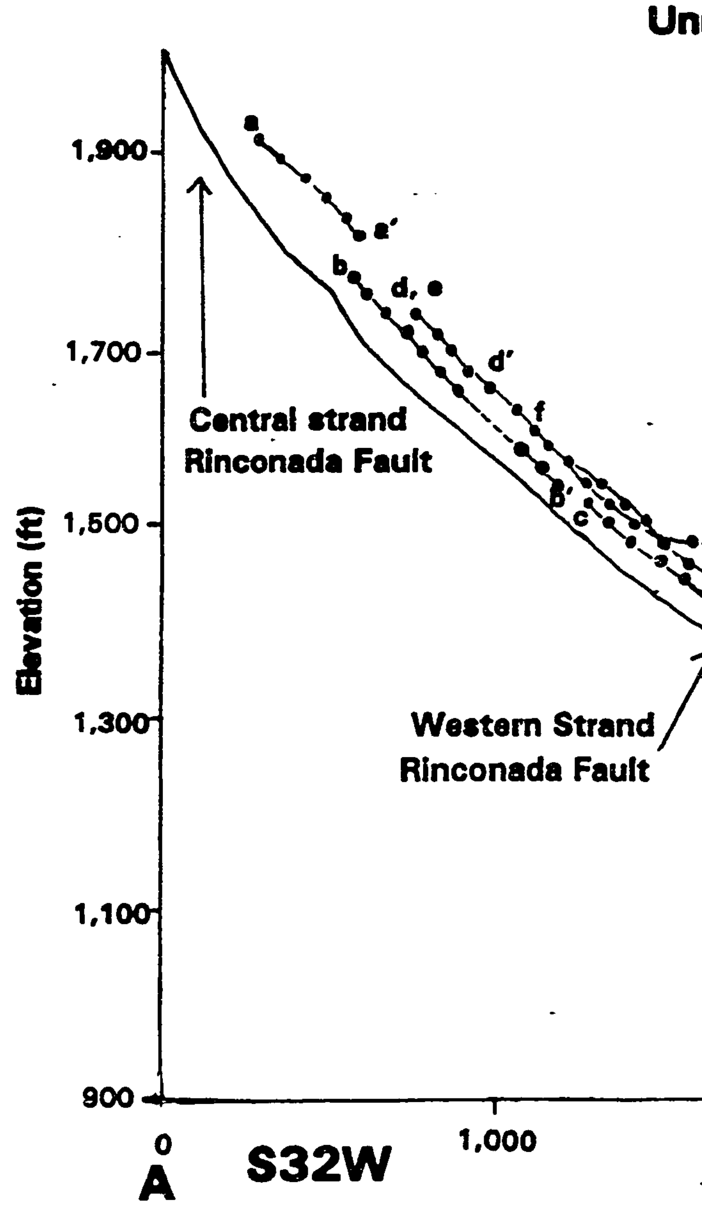
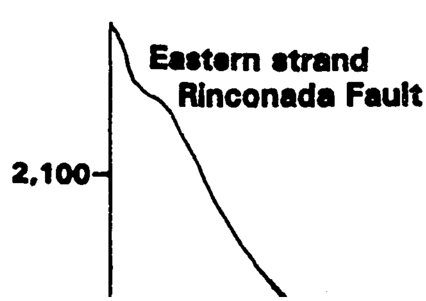
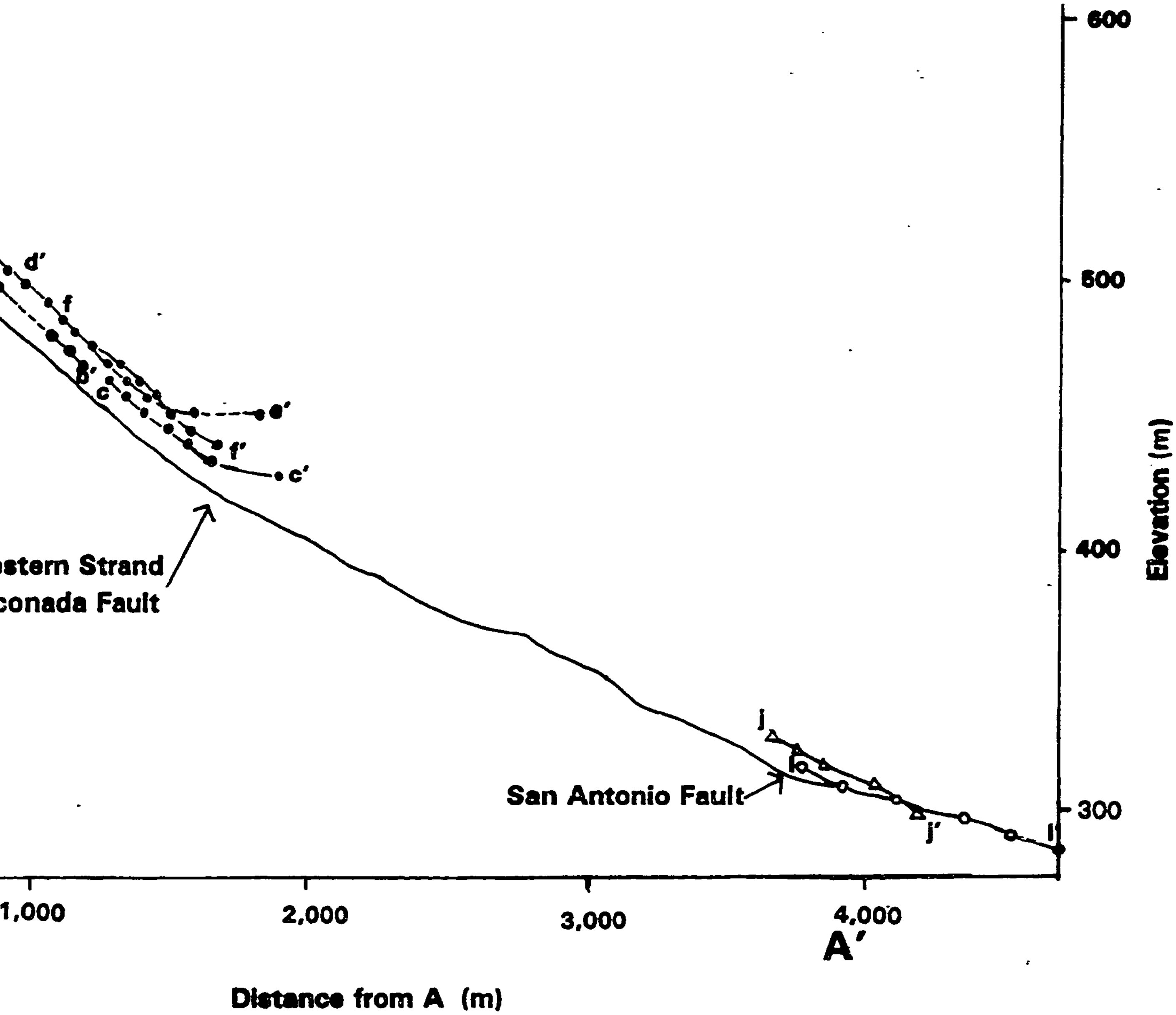


Elevation (ft)
1,900
1,700
1,500
1,300
1,100
900
0
1,000
A
S32W
Central strand
Rinconada Fault
Western Strand
Rinconada Fault
a
a'
b
b'
c
d, e
d'
f



Eastern strand
Rinconada Fault
2,100

Unnamed Eastern Canyon



Williams Canyon

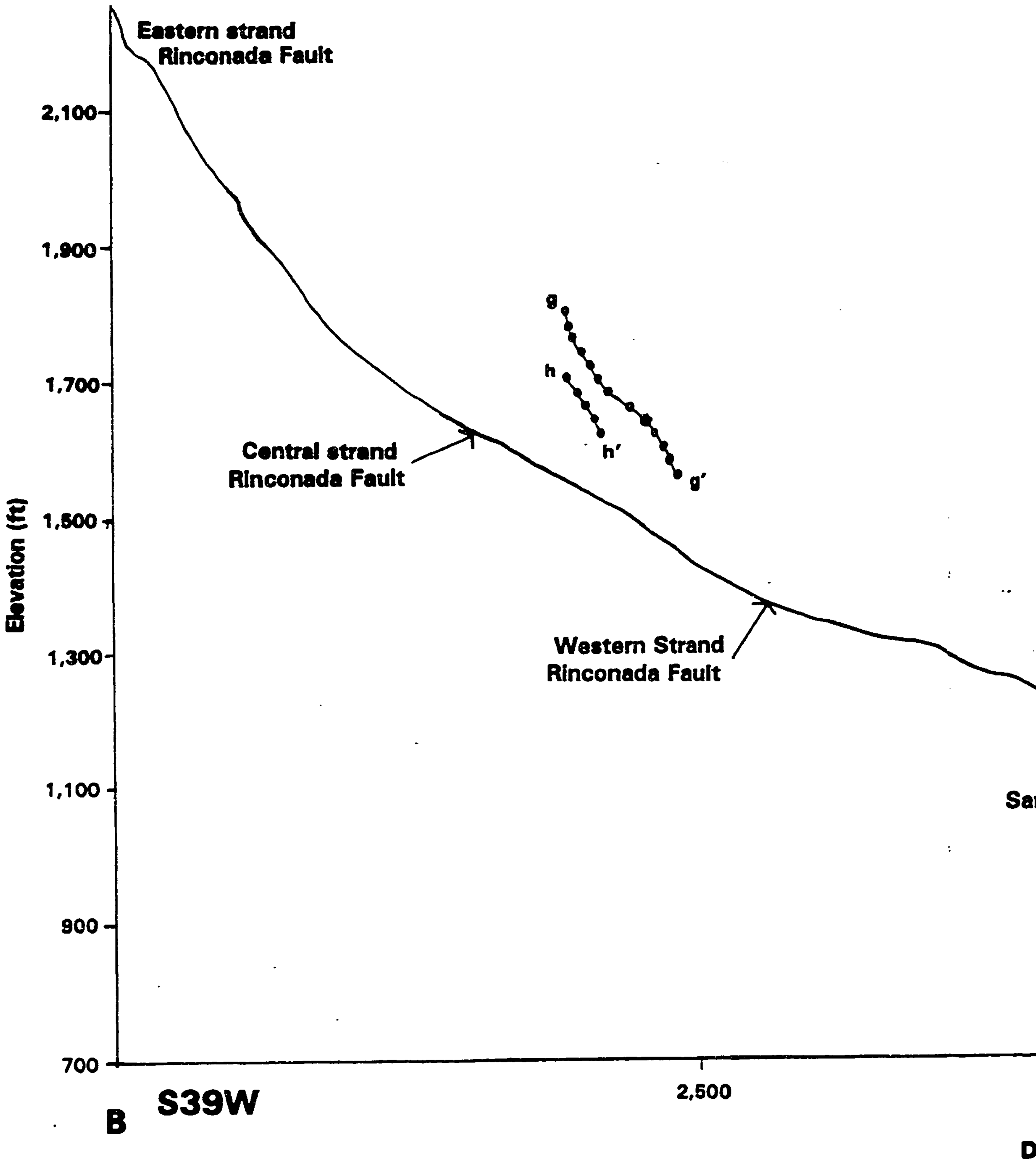
PLATE III
LONGITUDINAL PROFILES OF QUATERNARY ALLUVIAL SURFACES, WILLIAMS AND UNNAMED EASTERN CANYON

Explanation

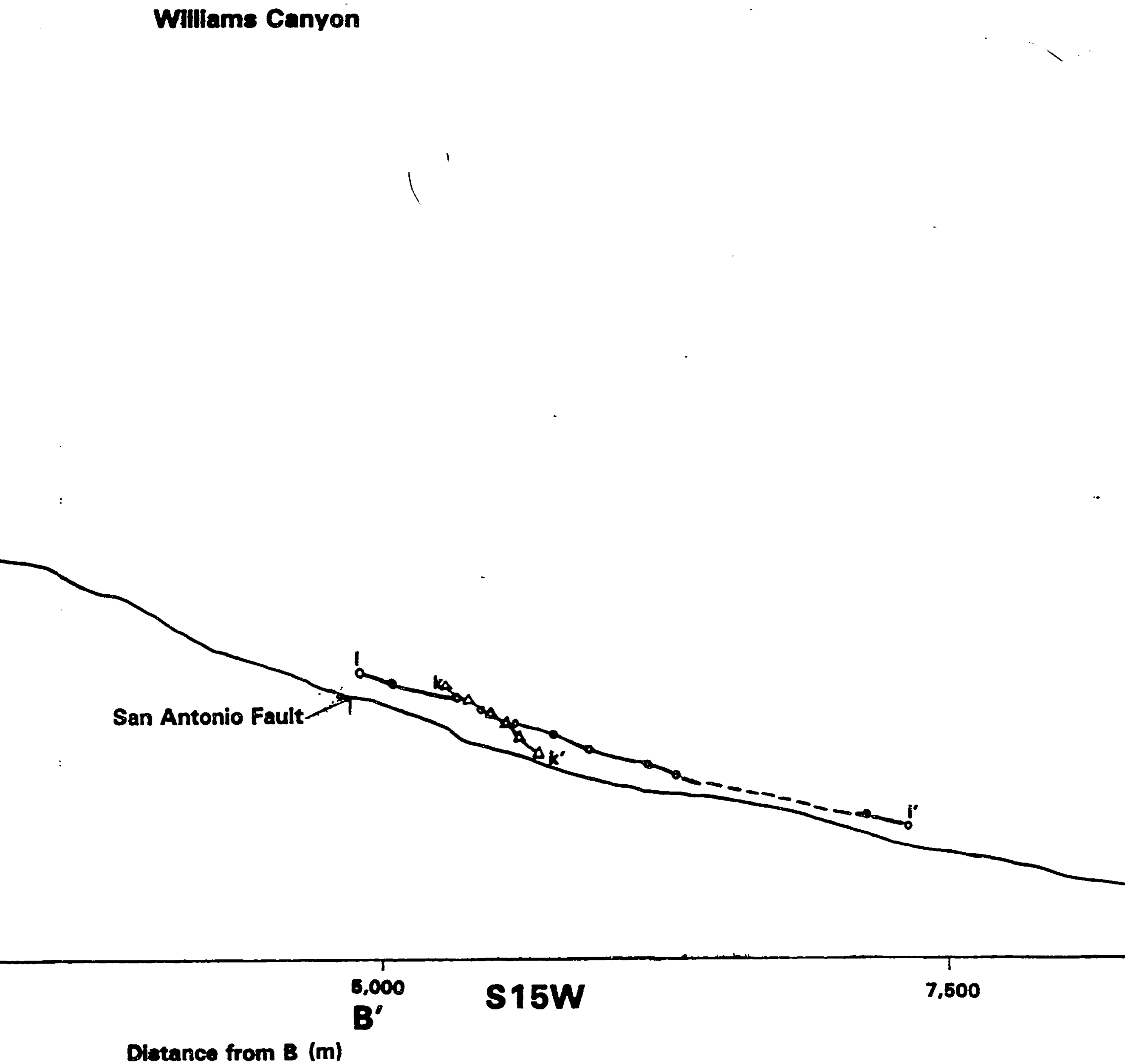
Stream profile

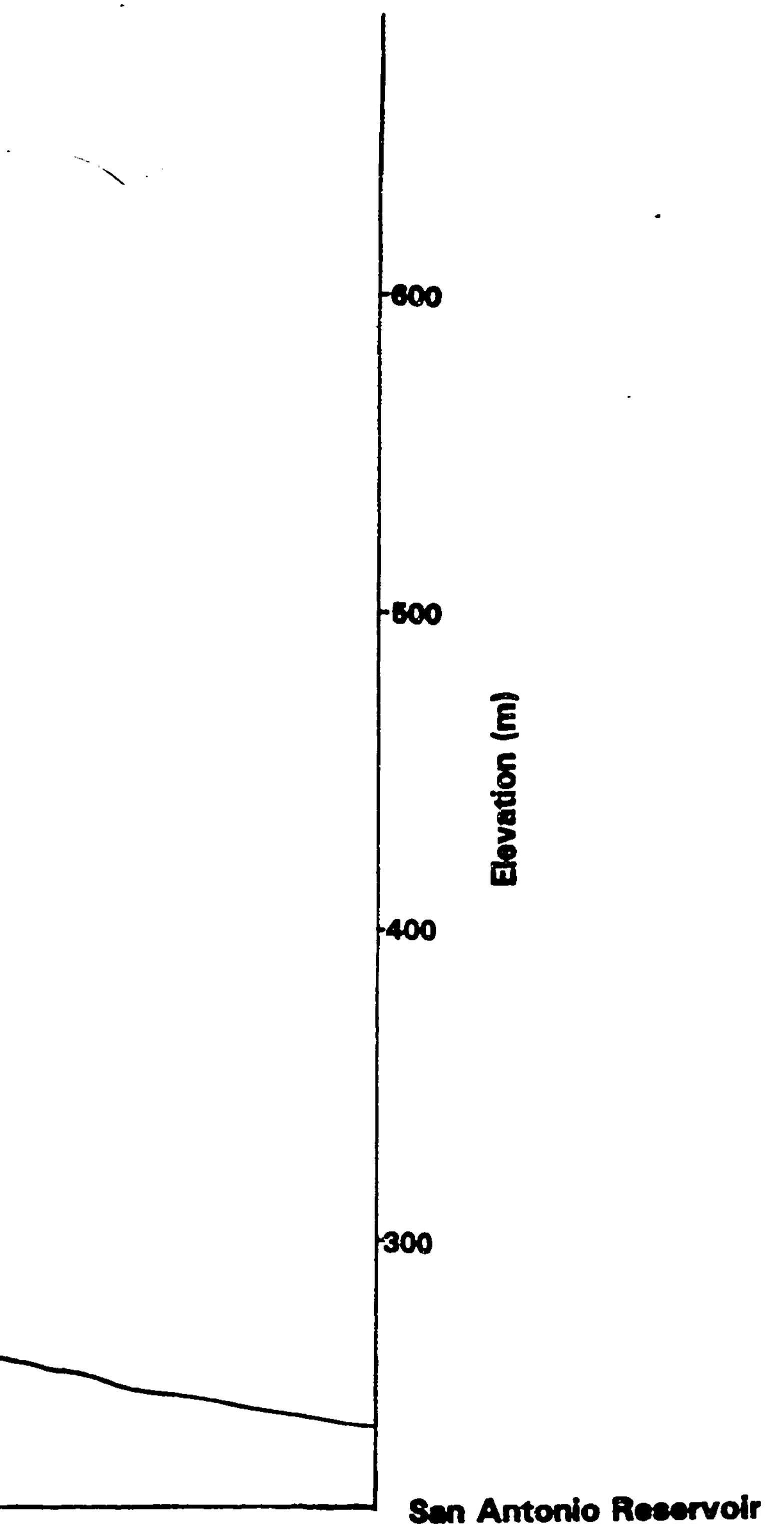
o—o—o—o	**Qf1**	(dashed across drainages)
Δ—Δ—Δ	**Qf2**	
□—□—□—□	**Qf3**	
●—●—●	**Qf4**	

Horizontal scale 1:24,000
Vertical exaggeration 10:1



Eastern strand
Rinconada Fault
2,100
1,900
1,700
1,500
1,300
1,100
900
700
Elevation (ft)
g
h
h'
g'
Central strand
Rinconada Fault
Western Strand
Rinconada Fault
2,500
S39W
B


Williams Canyon
San Antonio Fault
l
k
k'
l'
5,000
B'
S15W
7,500
Distance from B (m)



B''

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Oversize maps and charts are microfilmed in sections in the following manner:

LEFT TO RIGHT, TOP TO BOTTOM, WITH SMALL OVERLAPS

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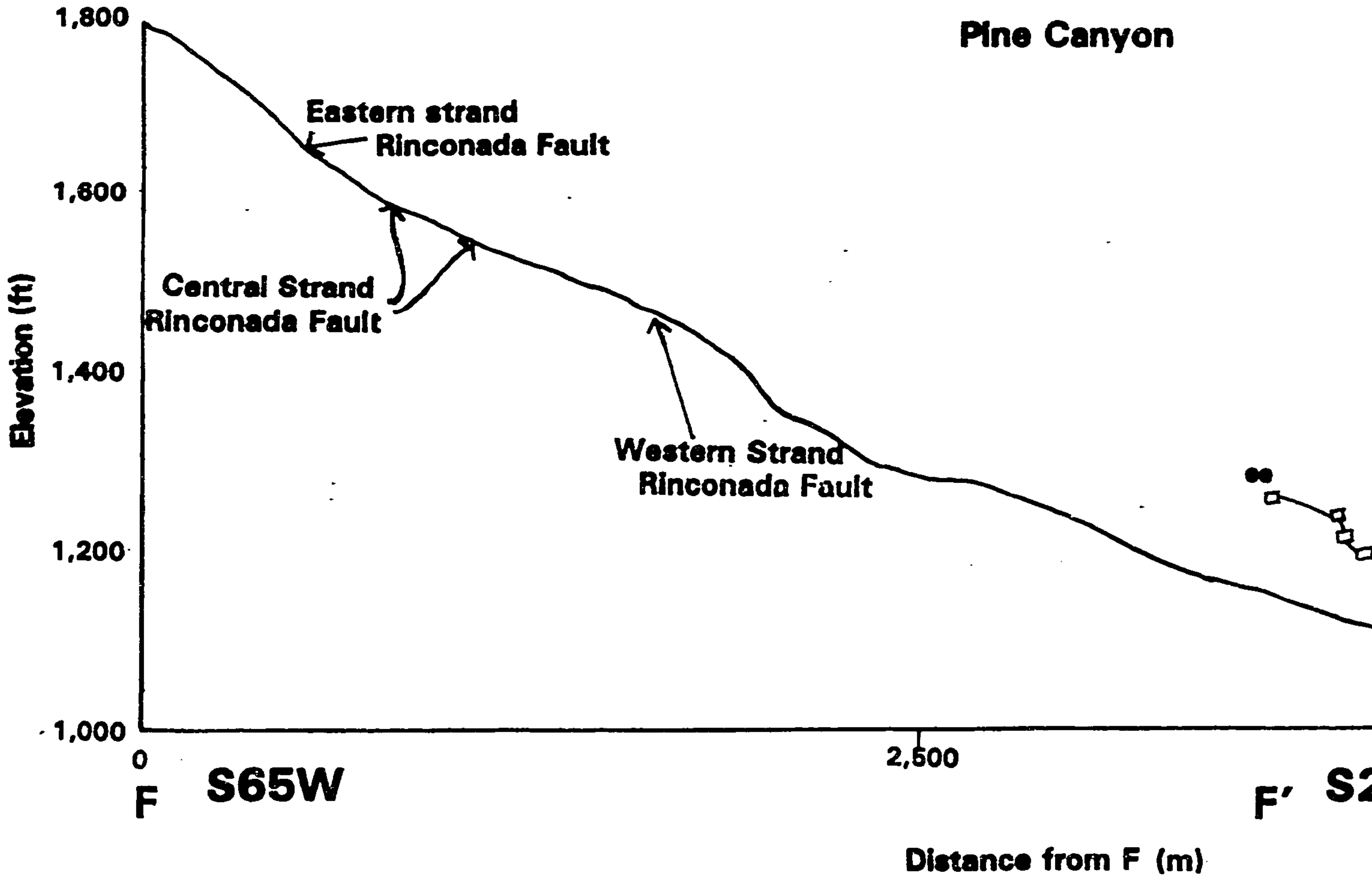
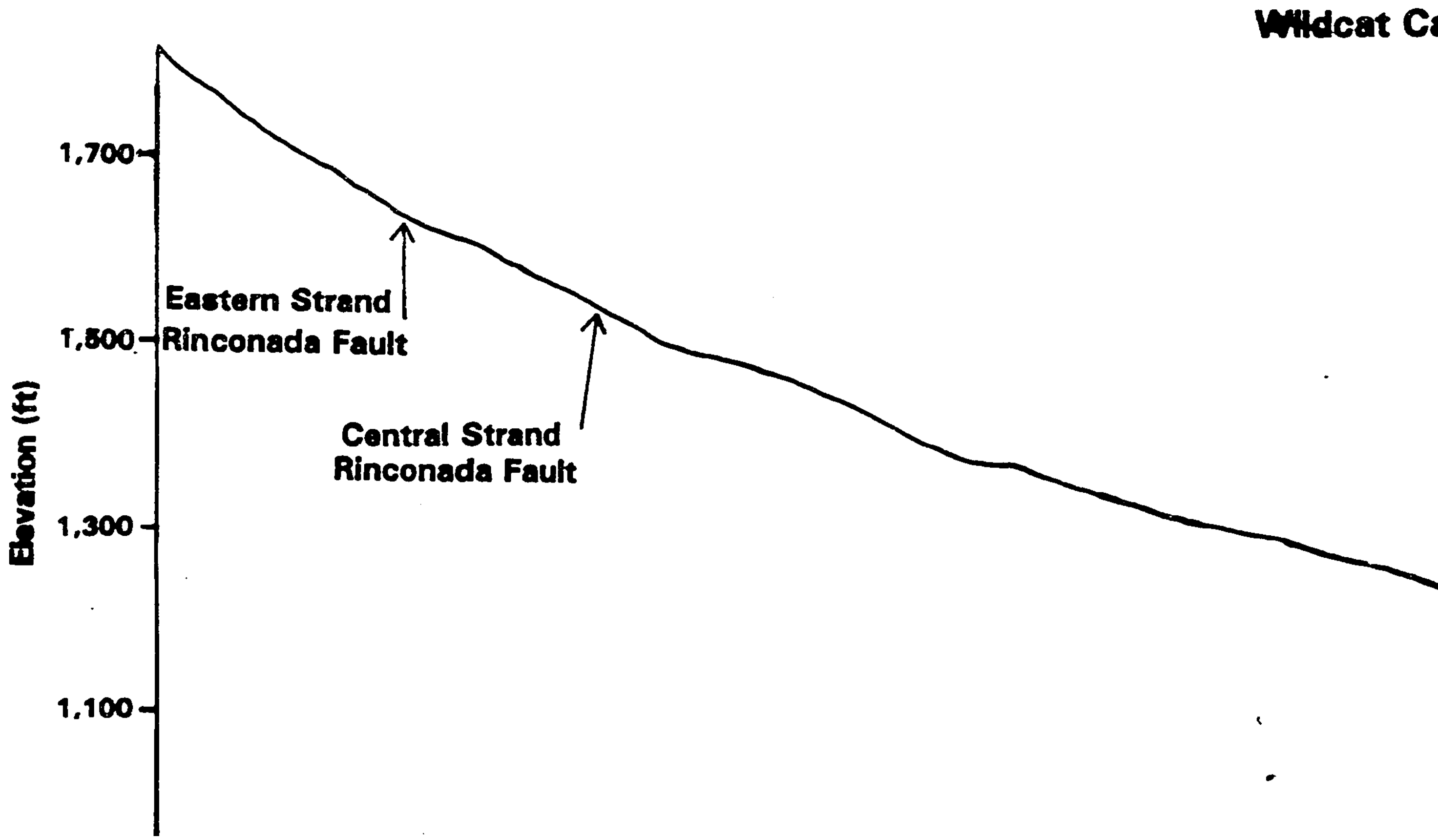
Black and white photographic prints (17"x 23") are available for an additional charge.



Pine Canyon
Eastern strand Rinconada Fault
Central Strand Rinconada Fault
Western Strand Rinconada Fault
Elevation (ft)
1,800
1,600
1,400
1,200
1,000
0
2,500
F
S65W
F'
Distance from F (m)



Eastern Strand Rinconada Fault
Central Strand Rinconada Fault
Elevation (ft)
1,700
1,500
1,300
1,100

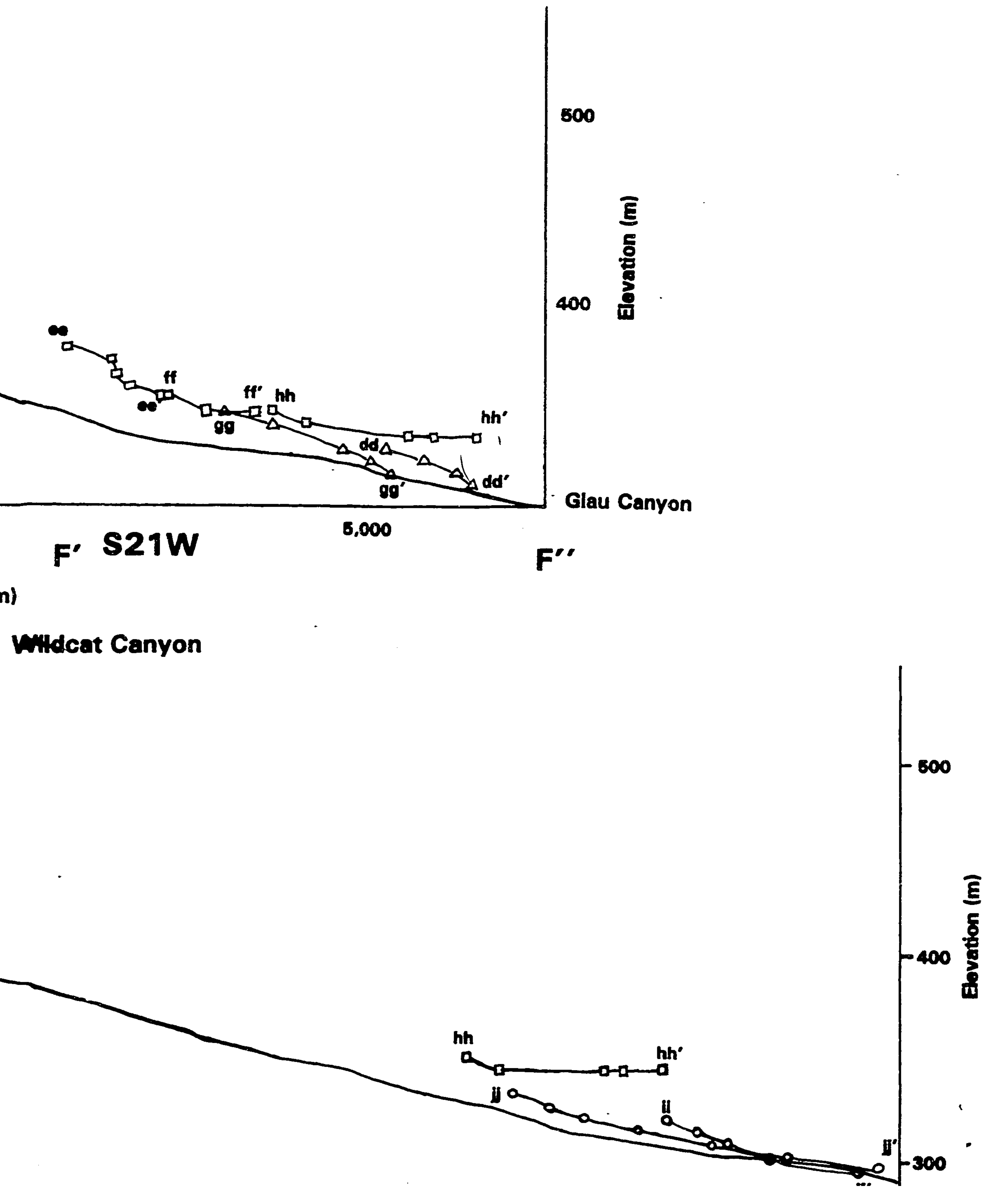

500
400
Elevation (m)
ee
ff
ee
ff'
hh
gg
hh'
dd
dd'
gg'
Glau Canyon
5,000
F'
S21W
F''
n)
Wildcat Canyon
500
400
Elevation (m)
hh
hh'
jj
ii
jj'
300

PLATE IV

LONGITUDINAL PROFILES OF QUATERNARY ALLUVIAL SURFACES, PINE, WILDCAT, AND WEFERLING CANYONS

Explanation

Stream profile

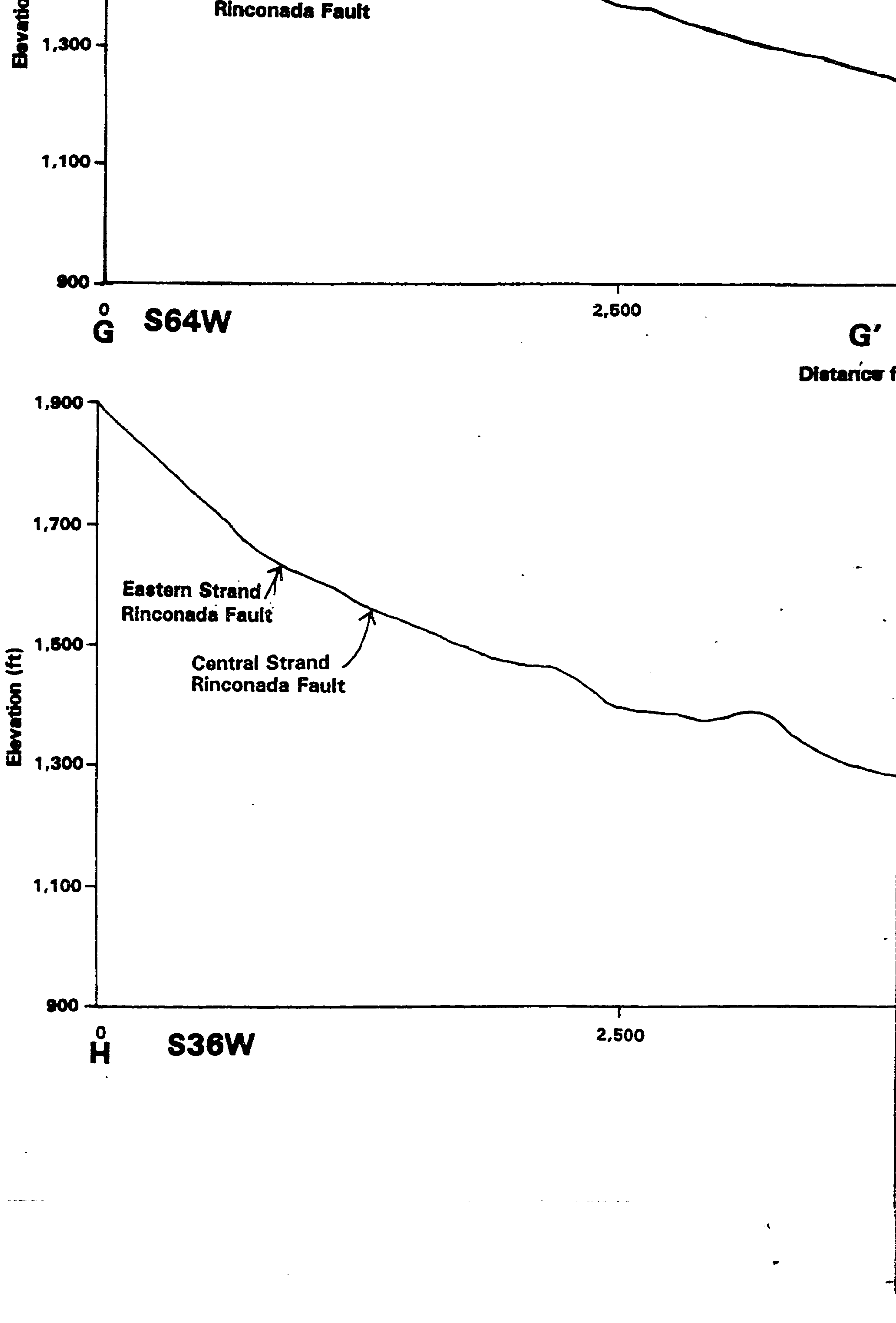
Qf1

Qf2

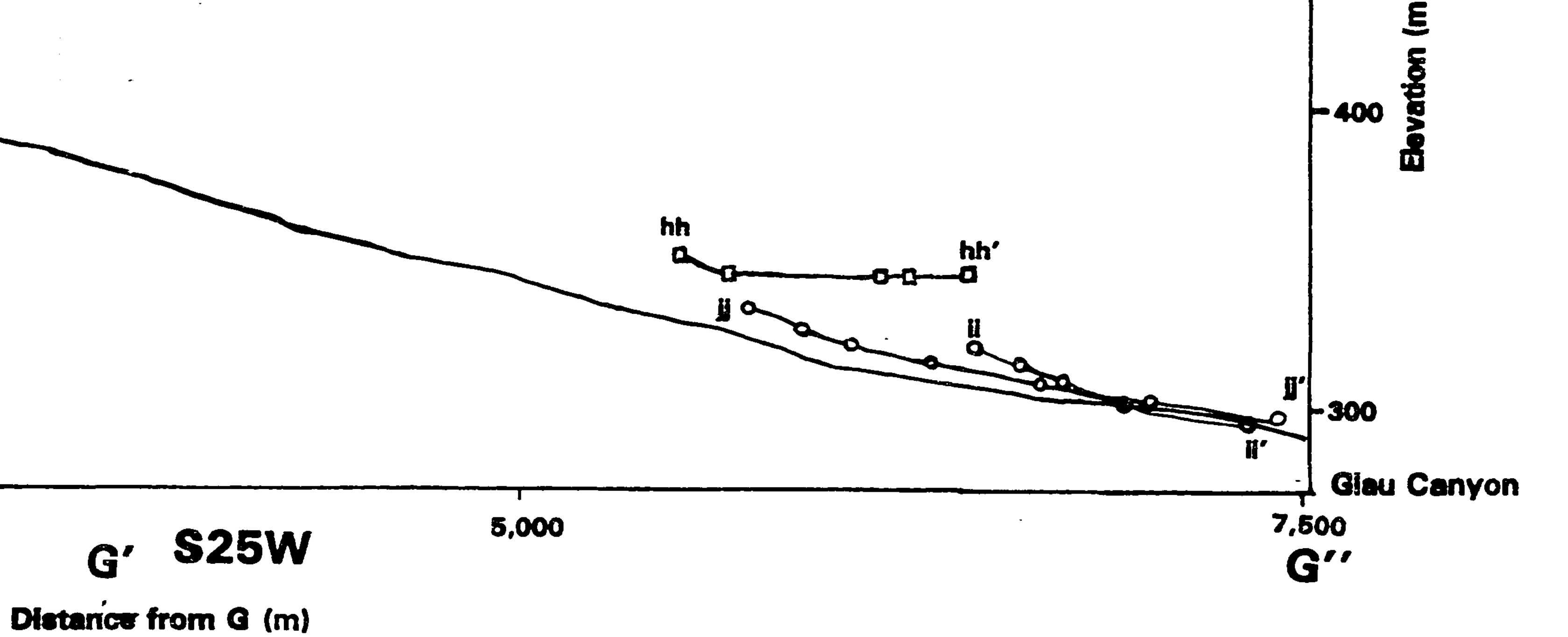
Qf3

Qf4

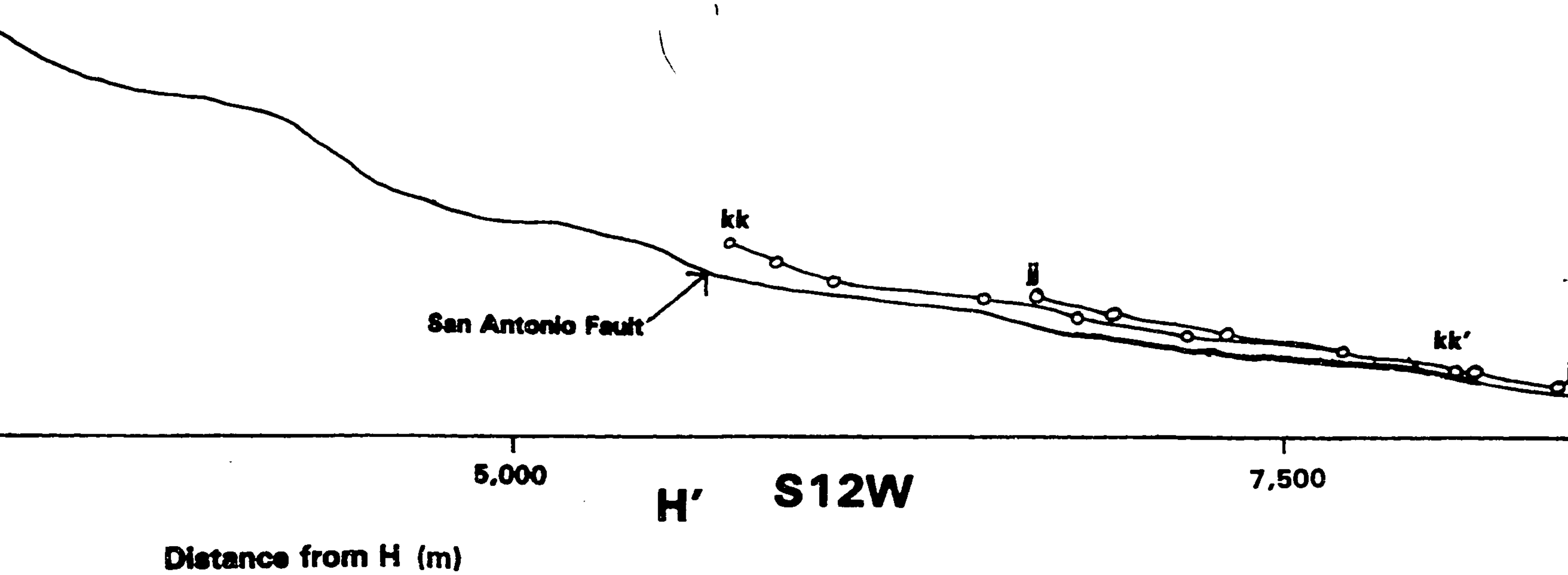
Horizontal scale 1:24,000
Vertical exaggeration 10:1

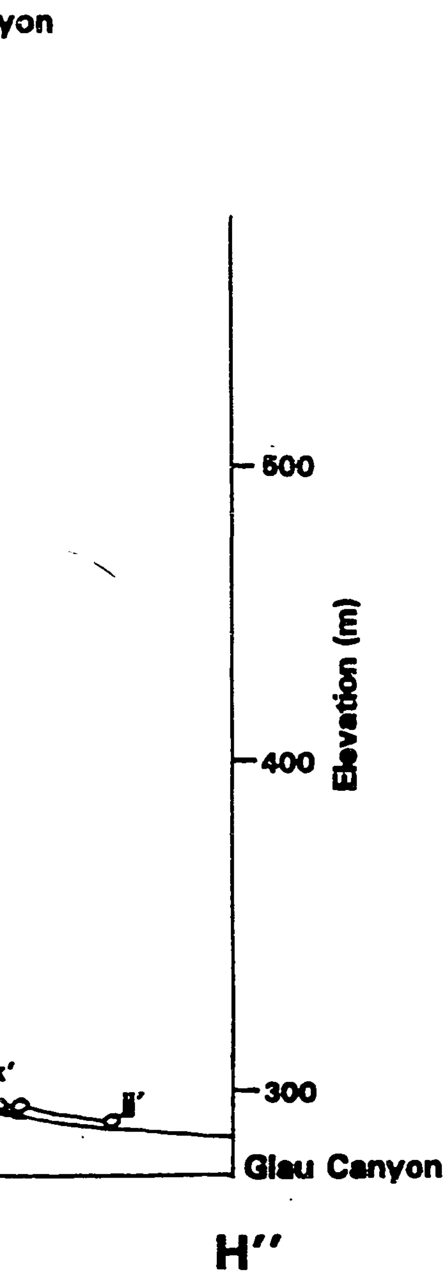


Rinconada Fault
Elevatio
1,300
1,100
900
0
G
S64W
2,500
G'
Distance f
1,900
1,700
Eastern Strand
Rinconada Fault
1,500
Central Strand
Rinconada Fault
Elevation (ft)
1,300
1,100
900
0
H
S36W
2,500



Weferling Canyon





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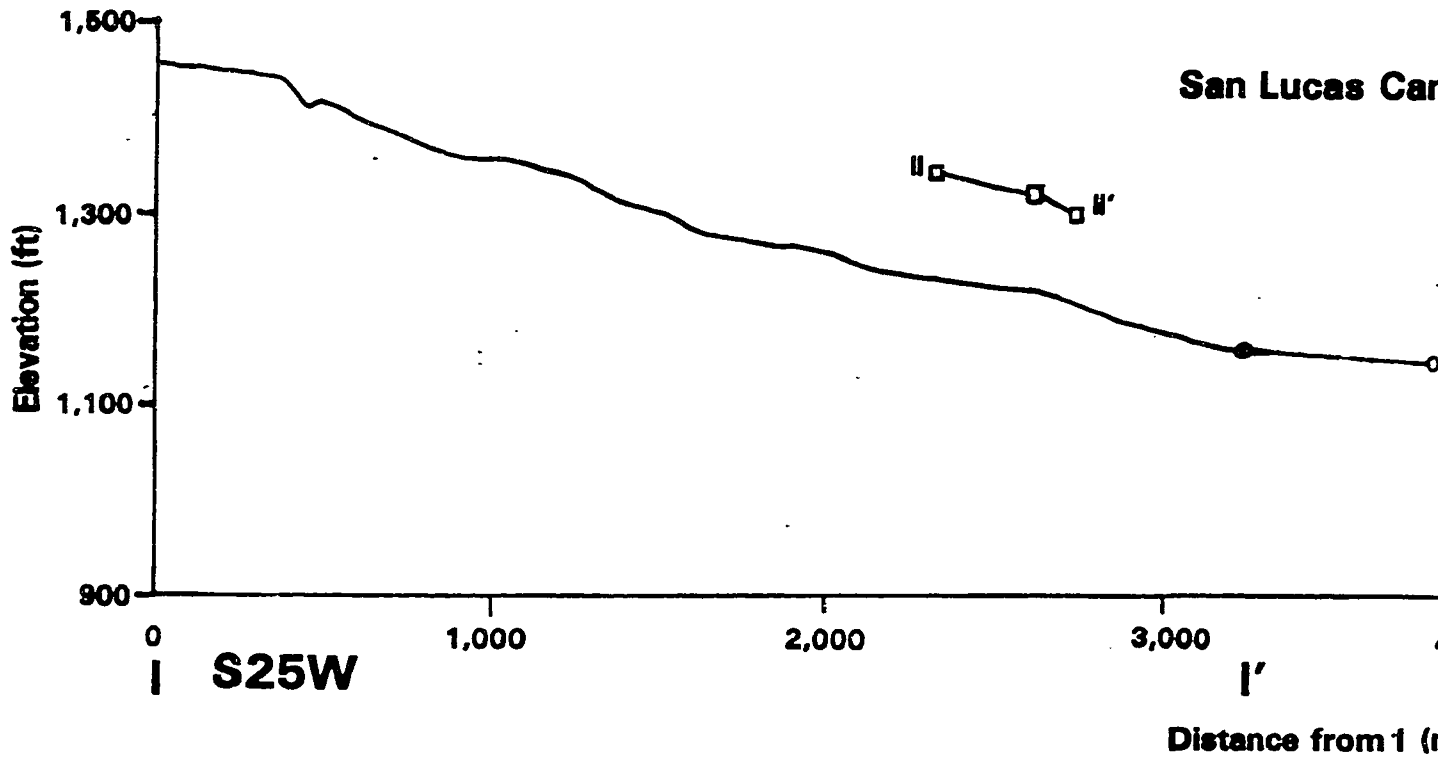
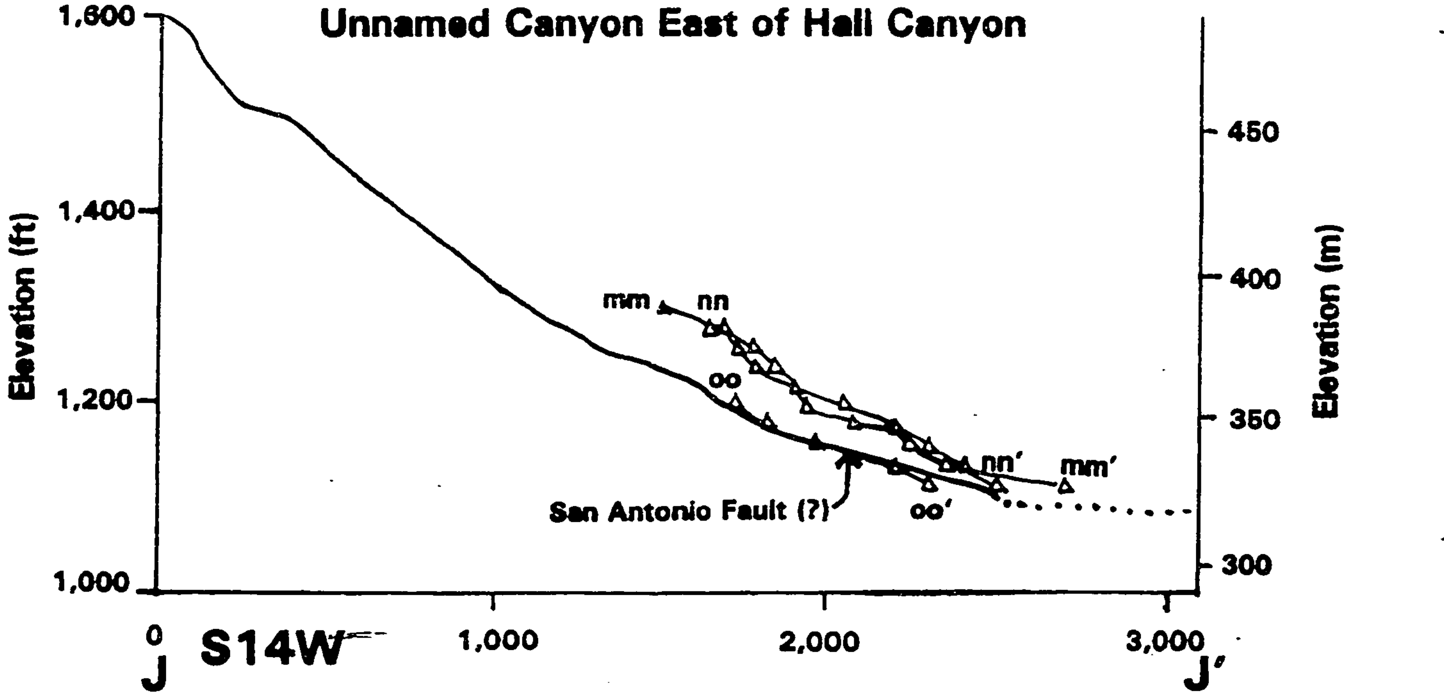
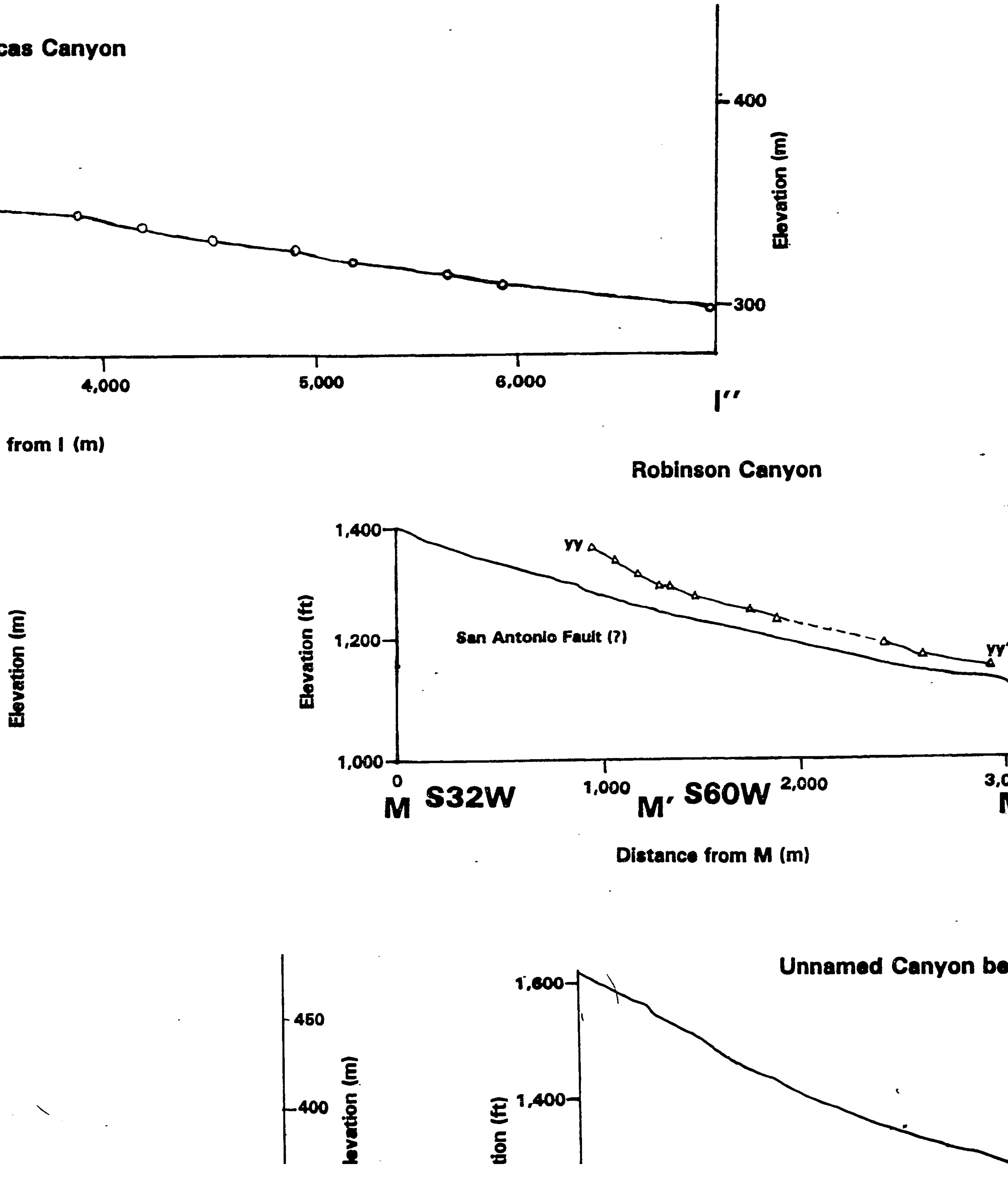

San Lucas Car
Elevation (ft)
1,500
1,300
1,100
900
ll
ll'
0
1,000
2,000
3,000
I
S25W
I'
Distance from I


Unnamed Canyon East of Hall Canyon
Elevation (ft)
1,600
1,400
1,200
1,000
Elevation (m)
450
400
350
300
mm
nn
oo
nn'
mm'
oo'
San Antonio Fault (?)
0
1,000
2,000
3,000
J
S14W
J'
Distance from J (m)


Hall Canyon
1,600
1,400
vvation (ft)
vv
rr
rr'
ss
qq



cas Canyon
400
300
Elevation (m)
4,000
5,000
6,000
I''
from I (m)
Robinson Canyon
1,400
1,200
1,000
Elevation (ft)
YY
YY'
San Antonio Fault (?)
0
1,000
2,000
3,0
M
S32W
M'
S60W
Distance from M (m)
Elevation (m)
450
400
levation (m)
Unnamed Canyon be
1,600
1,400
tion (ft)

PLATE V
LONGITUDINAL PROFILES OF QUATERNARY ALLUVIAL SURFACES, SAN LUCAS CANYON, HALL CANYON, AND JOLON VALLEY AREAS

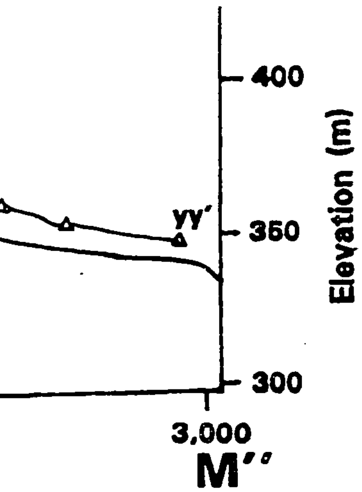
Explanation

Stream profile

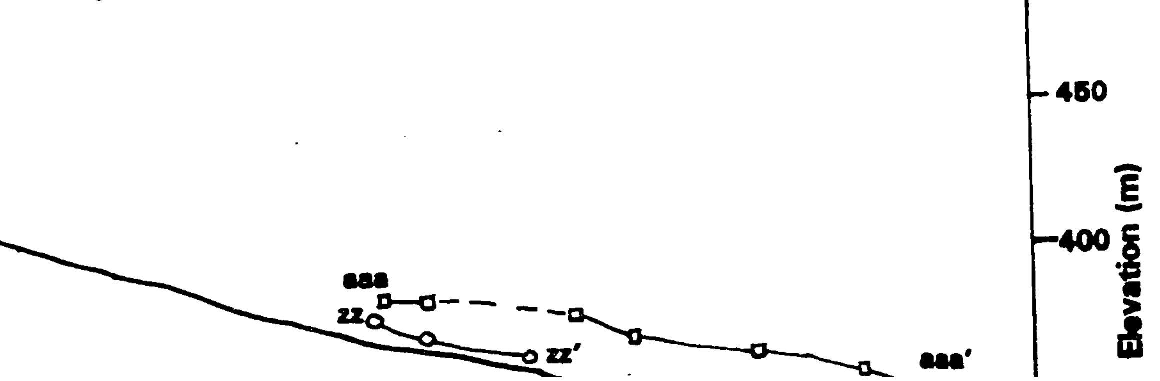
- Qf1
- Qf2
- Qf3
- Qf4

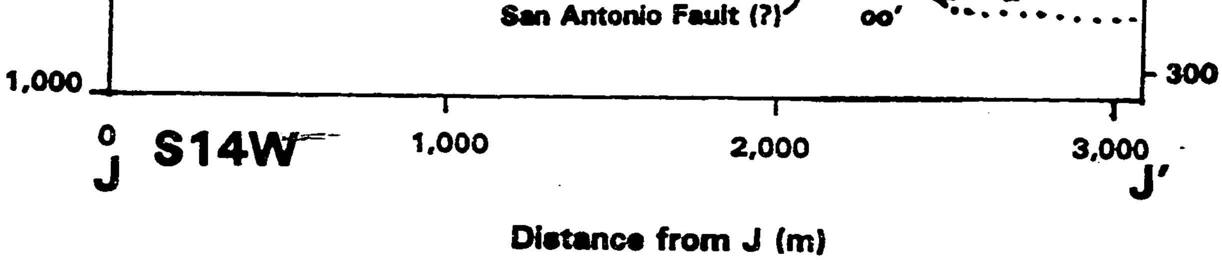
(dashed across drainages)

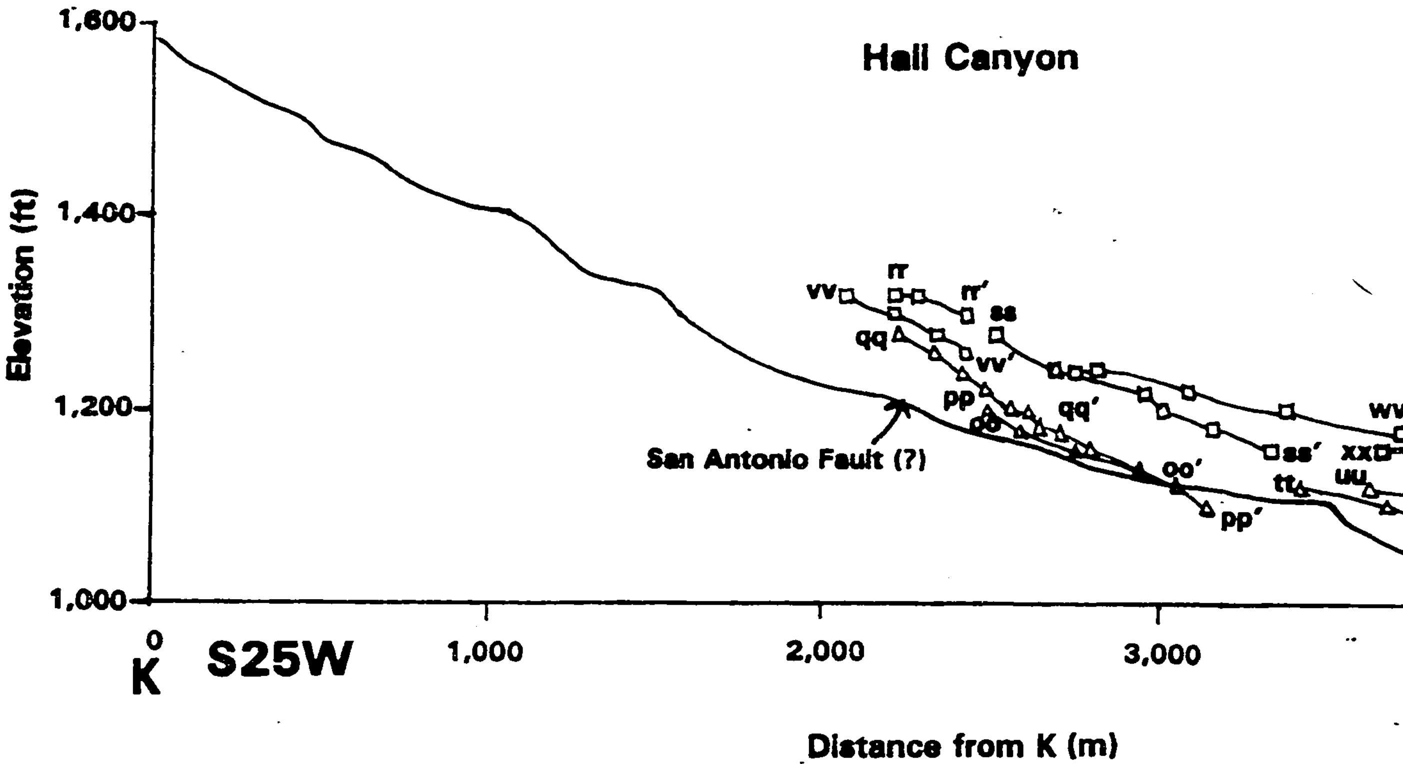
Horizontal scale 1:24,000
Vertical exaggeration 10:1

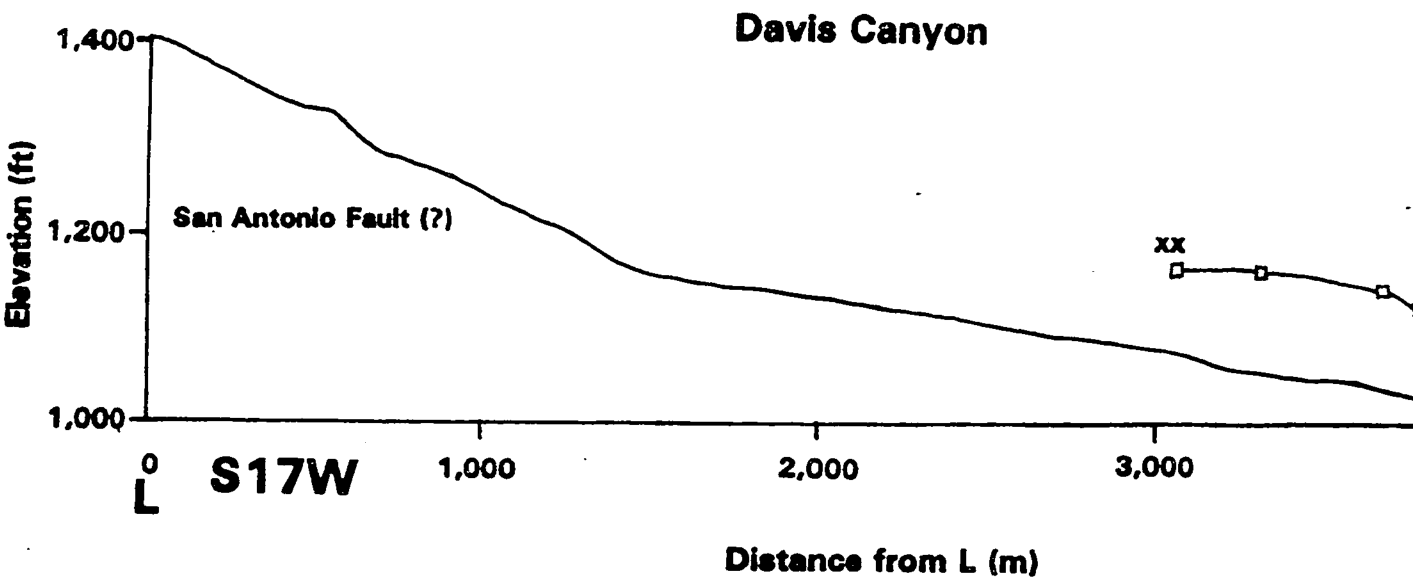


Canyon between Robinson and Pole Canyons

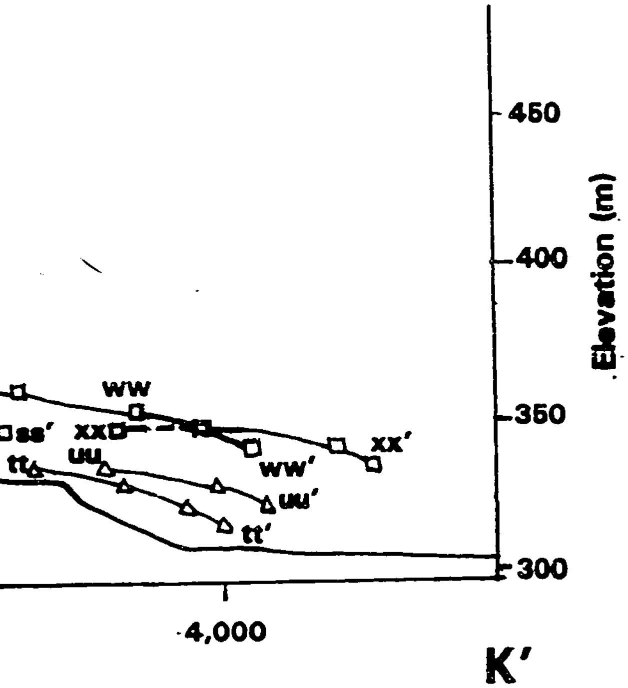


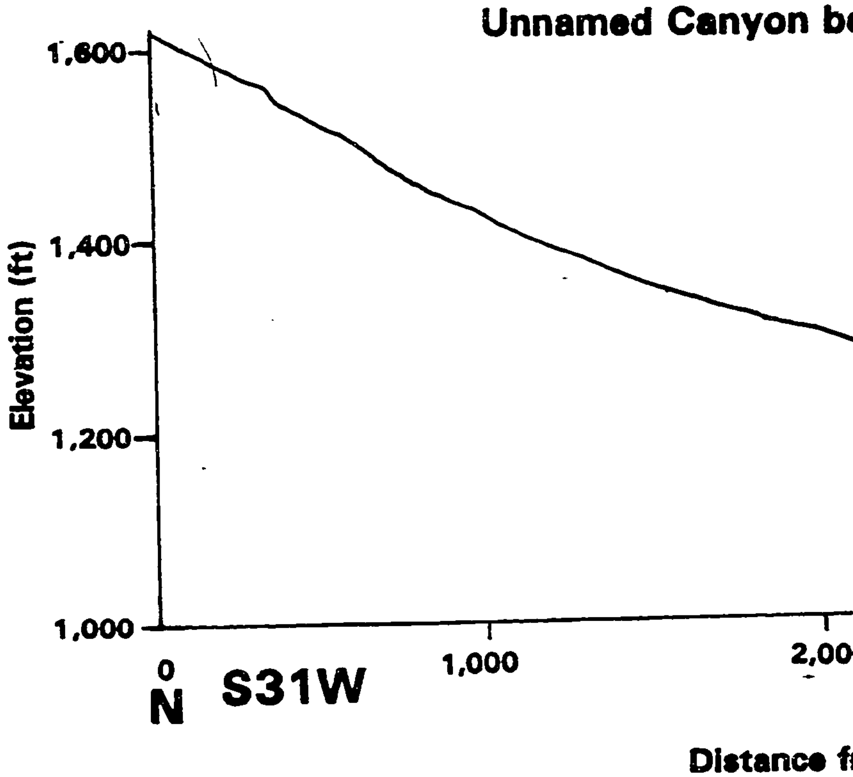

San Antonio Fault (?)
oo'
1,000
300
0
J
S14W
1,000
2,000
3,000
J'
Distance from J (m)

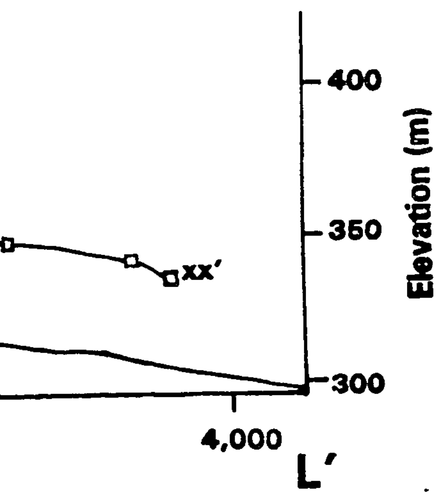

Hall Canyon
Elevation (ft)
1,600
1,400
1,200
1,000
vv
rr
rr'
ss
qq
vv'
pp
qq'
San Antonio Fault (?)
oo'
pp'
ss'
xx
tt
uu
0
K
S25W
1,000
2,000
3,000
Distance from K (m)

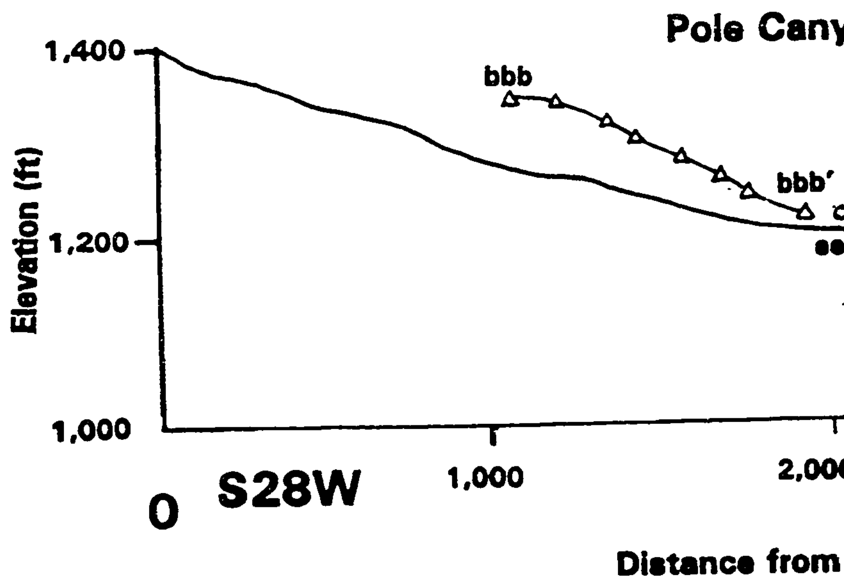

Davis Canyon
Elevation (ft)
1,400
1,200
1,000
San Antonio Fault (?)
xx
0
L
S17W
1,000
2,000
3,000
Distance from L (m)

Distance from M (m)

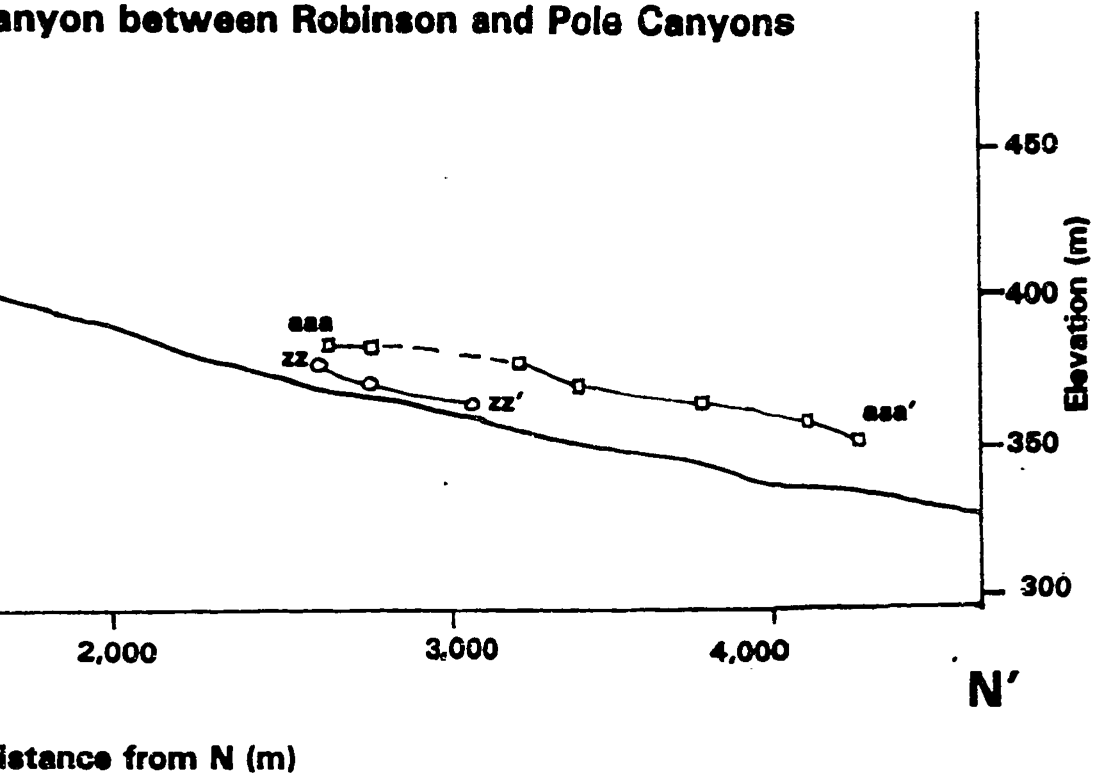








anyon between Robinson and Pole Canyons



le Canyon

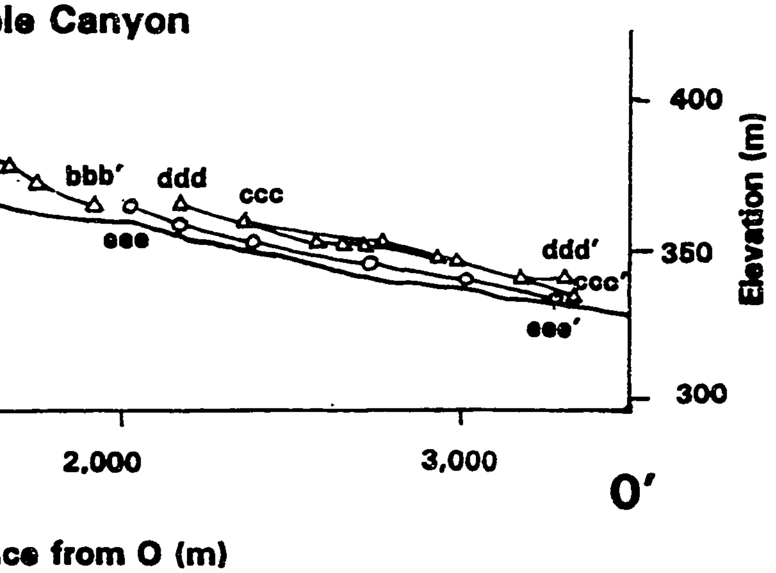


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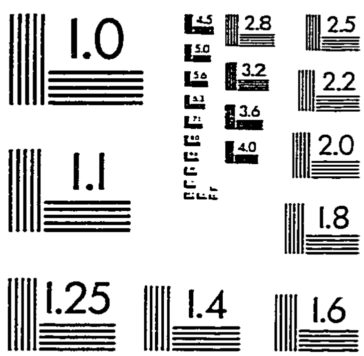
IMAGE EVALUATION TEST TARGET (QA-3)



150mm

6″

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