Late Cenozoic Stratigraphy and Structure of the Western Margin of the Central San Joaquin Valley, California

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ABSTRACT

Late Cenozoic Stratigraphy

Late Cenozoic deposits in the west-central San Joaquin Valley and adjacent foothills of the Diablo Range consist mainly of unconsolidated, poorly-sorted to well-sorted gravel, sand, silt and clay derived primarily from the Diablo Range and secondarily from the Sierra Nevada. Sedimentary structures, such as channeled contacts, laminated bedding, cross-stratification and clast-imbrication indicate that most of the deposits were transported and laid down by running water. These deposits are described and their facies relationships are illustrated in the "Late Cenozoic Stratigraphy" section of this report (see Figures 17, and 26, and Table 9).

Sediment shed from the Diablo Range accumulated primarily as a complex of coalescing alluvial fans on the piedmont slope of a San Joaquin Valley that at one time extended across the foothill belt to the present margin of the central Diablo Range; and as local fills within stream valleys of the Diablo Range foothills tributary to the San Joaquin Valley. These deposits are well exposed in Interstate-5 roadcuts, California Aqueduct and Delta-Mendota canal cuts, and stream banks along the many ephemeral and intermittent streams draining the Diablo Range.

Sediment derived from the Sierra Nevada is confined primarily to the floodbasin of the San Joaquin Valley. It includes arkosic riverine and floodbasin deposits from the San Joaquin River and associated sloughs, as well as local ephemeral and perennial pond, swamp, oxbow-lake and lake deposits. These deposits are well-exposed in stream banks of the San Joaquin River and a few of the larger sloughs such as Salt Slough, Mud Slough and Kings Slough. Well-sorted, fine- and medium-grained, quartzose, cross-bedded sand, presumably derived from the Sierra Nevada, locally interfinger with or underlie fine-grained Coast Range alluvial-fan deposits. The sand probably originated by eolian reworking of Sierran alluvium from the floodbasin of the lower San Joaquin River or from fans of the northeastern San Joaquin Valley. These deposits are locally well exposed in Interstate-5 roadcuts, primarily between Orestimba and Garzas Creeks.

The geomorphic character of the alluvium laid down by streams draining the Diablo Range reflects late Cenozoic uplift of the foothills and subsidence of the valley. Within the foothills and near the foothill-valley margin, the deposits form a sequence of inset stream terraces and nested alluvial fans. Valleyward, however, each deposit forms a veneer over older alluvial-fan deposits.

Based primarily on geomorphic and pedologic indicators of relative age (see Figure 19 and Table 10), and to a lesser extent on lithologic and absolute age criteria, the late Cenozoic deposits are divided into five stratigraphic units. In order of decreasing age, these include the formally recognized Tulare Formation (Watts, 1894; Anderson, 1905) of late Pliocene and Pleistocene age, and the informally named Los Banos alluvium of middle and late Pleistocene age, San Luis Ranch alluvium of late Pleistocene and early Holocene age, and Patterson alluvium and Dos Palos alluvium of Holocene age. The Los Banos and San Luis Ranch alluvium are further divided into three and two members, respectively. Each of these members ranges in thickness from

less than 1 m up to 15 m and thus represents, at least in part, a distinct period of aggradation.

The lithology age and distribution of these units is described in the "Stratigraphic Divisions" section of this report and is summarized in Figure 25 and Table 11. Plates 1 through 23 show the local distribution of these units on 7.5-minute Quadrangles. Mapping criteria are diagrammatically illustrated in Figure 19 and described in the "Mapping Criteria" section of this report.

Indirect evidence suggests that deposition of these units resulted primarily from climatic change rather than intermittent uplift of the Diablo Range. The units are recognized throughout 1500 Km^2 of the west-central San Joaquin Valley and are present along streams in foothill areas of both relative Quaternary upwarping and downwarping, suggesting a climatic rather than local tectonic control for their deposition. In addition, longitudinal terrace profiles converge downstream and drainages are commonly deeply incised into prior stream valley fills especially near the foothill-valley margin, whereas divergent terrace-profiles and stream incision into bedrock at the valley margin would be expected if the deposits reflect vertical uplift or faulting of the Diablo Range. Eastward tilting ofthe foothills would, however, produce onvergent profiles The Coast Range alluvial-fan deposits rest on, and locally interfinger with, reworked glacial outwash from the Sierra Nevada, a relation suggesting that they may be postglacial. Locally, fluvial facies of Coast Range fan deposits grade upward into mudflow facies possibly reflecting a progressive decrease in precipitation. These and other arguments are described in the "Depositional Model for Late Cenozoic Deposits" section of this report and are summarized in Table 15.

Depositional Model

Hypothetically, I believe that the post-Tulare alluvial units and their land forms record intervals of widespread deposition in the valley separated by intervals of relative landscape stability, when underloaded streams incised their channels and soils developed on stable slopes. Field observations suggest that the alternating periods of deposition and landscape stability are caused principally by regional climatic fluctuations rather than tectonism (see Table 15). Periods of deposition probably reflect transitions from humid to more arid conditions, while landscape stability probably occurs during humid and possibly during arid conditions. This hypothetical model is presented in the section entitled "Depositional Model for Late Cenozoic Deposits," (see Table 16 for summary) and is briefly summarized below.

Climatic fluctuations induce changes in surface runoff and in the type, distribution and density of vegetation which, in turn, strongly influence the production, erosion, transport and deposition of sediment, particularly in non-glaciated areas such as the Diablo Range. Major periods of aggradation probably result from the transition from more humid to more arid conditions. Decreasing precipitation reduces vegetation cover, and slope material weathered during the preceding humid period is exposed to erosion. Total surface runoff also progressively decreases in response to decreasing precipitation but remains sufficient for a long enough time to produce a major period of upland erosion. The increased erosion rates increase the load-to-discharge ratios in each stream causing aggradation on the alluvial fan.

Streams probably incise their channels and soils develop on stable slopes during both humid and arid conditions. During transitions from arid to humid periods and during humid periods, surface runoff is relatively high but erosion of the upland and consequent deposition in the valleys are hindered by relatively lush vegetation in the drainage basin. The underloaded streams commonly incise their channels and any sediment shed by the Diablo Range bypasses the valley-margin alluvial-fans and is delivered directly to the lower-fan and floodbasin areas of the Valley. Soils form on stable upper-fan, terrace, and hillslope surfaces. The degree of soil development typically decreases downfan possibly reflecting the more continual deposition on the lower fan and flood basin. During arid periods, vegetation cover is reduced exposing slopes to erosion, but erosion and fluvial deposition in the Valley is hindered because of low surface runoff. Short duration, high intensity storms, however, commonly produce mudflows at this time.

If this model approximates the actual paleohydrology of Diablo Range streams, the five members of Los Banos and San Luis Ranch alluvium recognized in the west-central San Joaquin Valley indicate a minimum of five wet-to-dry transitions during the late Quaternary. In the subsurface of the San Joaquin Valley, the Tulare Formation contains the 615,000-year old Corcoran Clay. Several buried soils are extensive below this lacustrine clay (see plate 25) and suggest that the climatic fluctuations may also have influenced earlier Quaternary alluvial events as well. The Corcoran Clay and underlying soils are described in the section entitled "Subsurface Stratigraphy."

Late Cenozoic Structure

The regional late Cenozoic stratigraphy provides a framework for evaluating the rates and patterns of late Cenozoic deformation in the west-central San Joaquin Valley. A complete discussion of this deformation is presented in the section entitled "Late Cenozoic Structure."

Three principal late Cenozoic stratigraphic datums exist: two piedmont surfaces of regional extent preserved across the foothills of the Diablo Range, and the Corcoran Clay in the subsurface of the San Joaquin Valley. Deformation of these units indicates that Pleistocene folding and faulting are common in the San Joaquin Valley and bordering foothills of the Diablo Range.

The principal late Cenozoic structure in the San Joaquin Valley is a large northwest-trending syncline whose axial part has subsided at a minimum rate of 0.2 to 0.3 m per 1000 years during the past 600,000 years. The structural axis, located 5 to 10 km east of the western valley margin, has remained stationary during the late Quaternary and governs the general location and orientation of the valley. The topographic axis of the valley, approximated by the interface of Sierran and Coast Range deposits in the valley subsurface (plate 25), has rarely coincided with the structural axis, suggesting that rates of sedimentation have equalled or exceeded rates of subsidence. The topographic axis has migrated repeatedly during the late Quaternary, apparently in response to changes in sedimentation rates on the east- and west-side alluvial fans. Development of a large lake, in which the Corcoran Clay was deposited, represents a period when the structural and topographic axes apparently coincided and the rate of subsidence exceeded sedimentation to produce a basin of interior drainage. Diatoms from the clay indicate that the lake was predominantly freshwater and was not an arm of the sea. The freshwater character, however, suggests that the lake was probably periodically flushed through an outlet to the sea. Origin of the Corcoran Clay and computation of the deformation and sedimentation rates in the San Joaquin Valley are presented in the "Late Cenozoic Stratigraphy"and "Late Cenozoic Structure" sections of this report.

Within the foothills, the principal Quaternary folds include the Panoche Hills, Wisenor Hills, Los Banos Hills and Laguna Seca Hills anticlines and the Little Panoche Valley, San Luis Valley, Carrisalito Flat and Salt Creek synclines. These structures, much smaller than the San Joaquin Valley syncline, typically have northeastor east-trending axes. The Panoche Hills, however, appears to be a simple quaquaversal dome. Evidence for these folds is presented in the section entitled "Late Cenozoic Structure."

The Panoche Hills anticline, the largest foothill structure, has risen at a minimum rate of 0.3 to 0.4 m per millenium during the late Quaternary. Minimum rates of uplift for the smaller Laguna Seca Hills and Wisenor Hills anticlines approximate 0.2 m per millenium.

Three northwest-trending fault systems displace Quaternary deposits in the Los Banos area: the Ortigalita Fault system, forming the principal contact between the Franciscan Assemblage of the central Diablo Range and the Great Valley Sequence of the foothills; the San Joaquin Fault system, separating the foothills from the San Joaquin Valley; and the O'Neill Fault System, which consists of numerous small bedding-plane faults between the San Joaquin and Ortigalita Fault systems. Evidence for displacement along these faults is presented in the section entitled "Late Cenozoic Structure".

The Ortigalita Fault displaces late Pleistocene alluvium and probably displaces Holocene alluvium. Its linear, en echelon trace and fault-plane solutions of recent tremors suggest a predominance of lateral displacement. Escarpments along the fault, however, typically have a west-southwest aspect suggesting that oblique displacement may have uplifted the foothill belt relative to the central Diablo Range. This Quaternary activity along the Ortigalita Fault is a reactivation of an earlier Tertiary structure along which Taliaferro (1943), Briggs (1953), Leith (1949) and Page (1981) suggests that the central Diablo Range was elevated. The presence of roughly coeval basalt flows of the Quien Sabe Volcanics at similar elevations on both sides of the fault, however, places important age constraints on this Tertiary activity. The volcanics are dated 7.5 to 10 m.y. (Snyder and Dickenson, 1981; Garniss Curtis, personal communication, 1981) indicating that the principal uplift of the central Diablo Range along the Ortigalita Fault ceased prior to the late Miocene. This activity is discussed in the "pre-Late Cenozoic Structure" section of this report.

The San Joaquin Fault system of Herd (1979b) displaces Quaternary alluvium but is overlain by undisplaced late Pleistocene and Holocene alluvium. The fault is typically a single strand with a linear, faceted, east-facing escarpment. Vertical displacement of pre late Pleistocene Quaternary alluvium across the fault ranges from 0 to more than 140 meters. The magnitude of lateral displacement and orientation of the fault plane are not known.

The O'Neill Fault system of Herd (1979a) displaces Quaternary alluvium but is commonly overlain by unfaulted late Pleistocene and Holocene alluvium. The fault planes dip northeast and apparently coincide with bedding planes in the homoclinally tilted Great Valley Sequence. Vertical displacement across the faults ranges from 0 to approximately 100 meters with the eastern block relatively upthrown. Quaternary folds indicated by contour reconstruction of late Quaternary alluvial surfaces, are vertically but not laterally displaced by the O'Neill Fault system. Attitude of the fault plane and sense of displacement therefore suggest that these are high-angle reverse faults. The numerous small faults in the system thus differ from the larger, bordering faults although the Ortigalita Fault also commonly has west-facing escarpments. They appear to be secondary bedding-plane flextural slip adjustments to continued uplift and flexture of the foothill belt during the Quaternary. Displacement across these faults is typically greatest on the crest of the previously mentioned anticlines and decreases on their limbs suggesting that the folds may in part be "arches" or "warps" produced by activity on these faults

Pre-late Cenozoic Tropical Soil

A buried soil of probable Oligocene or early Miocene age crops out in widely separated localities in the east-central foothills of the Diablo Range. Especially well-preserved and exposed in the Laguna Seca Hills, it is characterized by vivid purplish-red and red, iron-oxide stained sediments in its upper horizons and greenish-gray kaolinite with red iron-oxide nodules in its lower horizons. The stratigraphic units on which the soil developed include the upper Eocene Kreyenhagen Formation and possibly by the upper Eocene and lower Oligocene(?) sandstone of Poverty Flat. The soil is overlain by the Miocene and lower Pliocene(?) Oro Loma Formation and possibly the early Miocene Valley Springs Formation. The morphological and mineralogical features of the soil are similar to those of tropical oxisols (Soil survey Staff, 1975) suggesting that a tropical climate may have existed in the western San Joaquin Valley sometime during the Oligocene or earliest Miocene. This soil is described and the age of and implication of a tropical climate are discussed in the "Tertiary Oxisol" section of the report.

CONTENTS

ILLUSTRATIONS

TABLES

PLATES

Conversion Factors and Method of Indicating Geographic Locality

Quantities in this study are reported in the International system (SI) or Metric Units rather than the traditional North American inch-pound units. For readers who prefer the inch-pound units, equivalent units are as follows:

Inch pound units		S I (metric) units
One acre-foot	equals	1233 cubic meters
one foot	equals	0.3048 meters
one inch	equals	2.54 centimeters
one mile	equals	1.609 kilometers
one square mile	equals	2.590 square kilometers

Geographic localities are indicated in terms of the Section, Township and Range rectangular coordinate system used by the U.S. Geological Survey, U.S. Bureau of Reclamation, and California Department of Water Resourcees for the subdivision of public land. For example, in Figure 1a. station "X" is located in NE 1/4, SW 1/4, Sec 9, T 11 S, R 8 E. Core and Auger holes are named and located by a variation of the rectangular coordinate system. Within each Section, 40 acre tracts are lettered serially as shown in Figure 1b and locations are given by Township number, Range number, Section number and 40 acre tract. For example Core "X" would be referred to as 11/8-9 G.

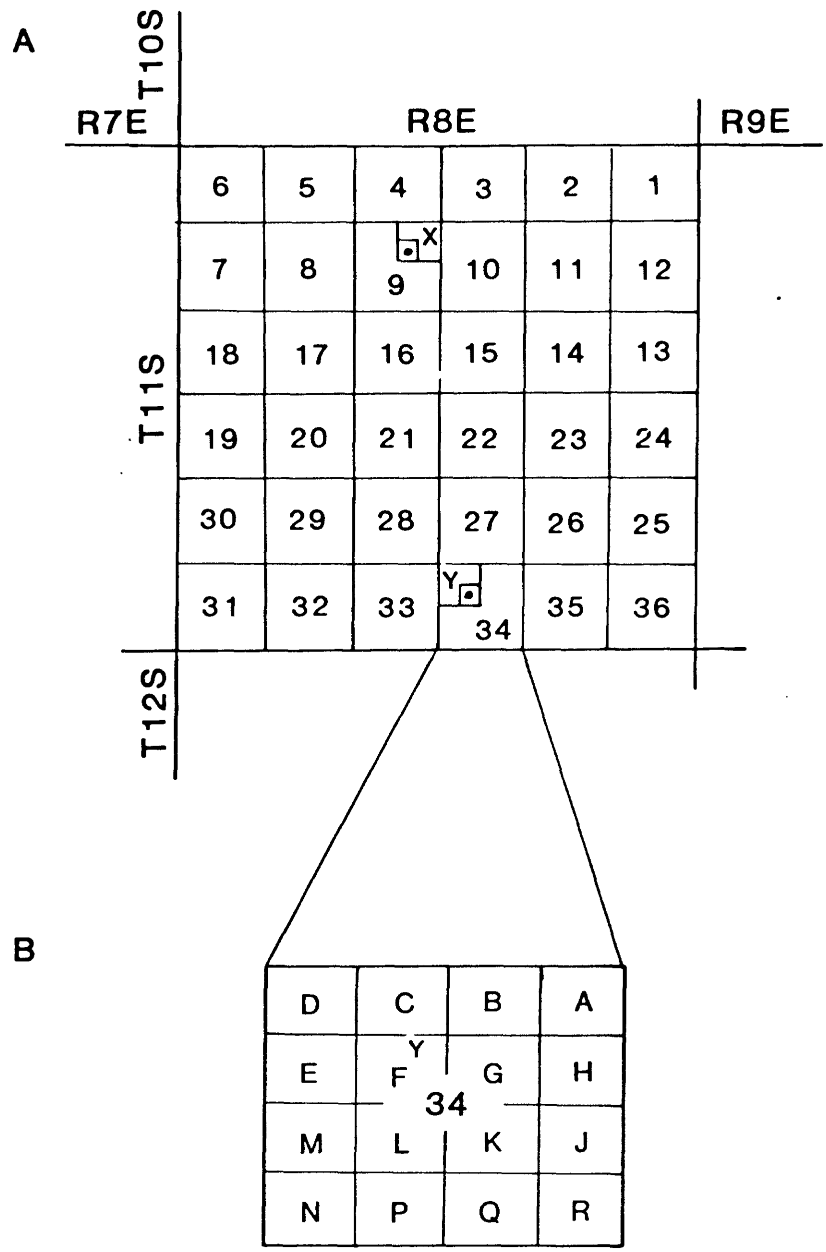

Figure 1: A) Field stations are located using the Section, Township and Range rectangular coordinate system for the subdivision of public land (Mount Diablo Baseline and Meridian). For example - the locality of station "X" is the NE 1/4, SW 1/4, Section 9, T11S, R8E.
B) Core, well and auger stations are located by alphabetically dividing the 640 acre-sections into 40 acre tracts. For example - the locality of station "Y" is T11S, R8E, Section 34-F, or further abreviated to 11/8-34F.

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The study also benefited greatly from work performed by a number of geologists. The recognition and distribution of Tertiary deposits in the vicinity of Orestimba Creek was greatly improved by the preliminary release of data by Alan Bartow. I am deeply indebted to Ira Klein, formerly of the U. S. Bureau of Reclamation, who conducted pioneering investigations on the subsurface geology of the San Joaquin Valley in the 1950's upon whose astute field and laboratory observations of test cores I relied heavily. Eugene Begg and Roger Hansen of the University of California, Davis provided several uranium-disequillibrium-series dates; Beta Analytical Inc. of the University of Miami and Stephen Robinson of the U. S. Geological Survey (USGS) provided numerous radiocarbon dates; Charles Repenning of the USGS and Donald Savage of the University of California, Berkeley identified several vertebrate bones recovered prior to and during this study; John Barron and J. Platt Bradbury of the USGS identified diatoms from several marine and nonmarine clay beds; and J. W. Hillhouse of the USGS analyzed numerous samples from the Tulare and Oro Loma Formation for remnant magnetization.

Brian Atwater, Carol Price and Emily Taylor of the USGS assisted on several shallow drilling investigations in the San Joaquin Valley and contributed valuable observations and information on the recognition of subsurface geologic and pedologic horizons. Sam Shaler adeptly operated the truck-mounted auger.

U.S. Bureau of Reclamation geologists, Larry Anderson and Mark Anders, graciously provided access to several back-hoe trenches excavated across potential fault scarps. Landowners throughout the San Joaquin Valley and foothills of the Diablo Range kindly provided access to private property without which the drilling studies and field work required for completion of this investigation would not have been possible.

INTRODUCTION

General

The late Cenozoic tectonic and climatic history of the San Joaquin Valley and adjacent Sierra Nevada and the Diablo Ranges is thick sequence of alluvial-fan and terrace deposits in the San Joaquin Valley. These deposits have been studied extensively in the eastern and northeastern portions of the valley where their detailed stratigraphy has proven to be a valuable aid in deciphering the late Cenozoic tectonic and climatic history of the region (Arkley, 1954, 1962; Davis and Hall, 1958; Janda. 1966; Marchand, 1977; Marchand and Allwardt, 1981). Alternations of glacial and interglacial conditions in the Sierra Nevada have created a sharply defined chronologic sequence of glacial-outwash alluvial deposits in the eastern Valley. The deposits form a sequence of inset stream terraces and nested alluvial fans near the foothills of the Sierra Nevada and a series of overlapping alluvial fans toward the valley axis in response to continued westward tilting of the Sierran block (Marchand, 1977).

The effects of Quaternary climatic changes in the nonglaciated Coast Ranges, however, were more subtle than those in the Sierra Nevada, making a distinct chronology of alluvial deposits difficult to recognize in the western San Joaquin Valley. This absence of a readily recognizable chrono-sequence has generally discouraged detailed stratigraphic study of the late Cenozoic deposits, and hence, the late Cenozoic strutural history of the Western San Joaquin Valley and foothills of the Diablo Range is only known in general terms (Briggs, 1953; Taliaferro, 1943; Herd, 1979a, b; and Page, 1981; among others). Subsurface investigations have been concerned primarily with the hydrologic and engineering properties of the late Cenozoic deposits or have addressed the deeper oil-bearing strata, whereas surface investigations have generally concentrated on the older rocks and geologic history of the Coast Ranges (see Bertoldi, 1979; and Page, 1981, for detailed reviews respectively). Local geologic studies which have been completed on late Cenozoic deposits in the western and southern San Joaquin Valley include those by Bull (1964a,b) Green and Cochran (1958), Meade (1968) and McGill (1951).

In these widely separate topical studies, abiguity in the stratigraphic nomenclature and regional extent of late Cenozoic deposits has persisted. For example, many Diablo Range geologists refer to the deformed deposits along the eastern margin of the range as the Miocene and Pliocene Oro Loma Formation, while geologists studying the San Joaquin Valley refer to these deposits as the Pliocene and Pleistocene Tulare Formation.

This paper describes the late Cenozoic deposits in the west-central San Joaquin Valley, and uses their lithologic, stratigraphic, geomorphic, and pedologic relations to interpret the tectonic and climatic history of the west-central San Joaquin Valley and adjacent Diablo Range. The purposes are essentially three-fold: (1) to establish a regional stratigraphy and uniform stratigraphic nomenclature for late Cenozoic deposits in the western San Joaquin Valley; (2) to evaluate the age, rates, patterns and styles of deformation in the west-central San Joaquin Valley and adjacent foothills of the Diablo Range; and (3) to evaluate the climatic and/or tectonic causes for alluviation in the western San Joaquin Valley.

The principle conclusions of this work are: 1) a regionally consistent stratigraphy of late Cenozoic deposits is present in the west-central San Joaquin Valley; 2) the stratigraphy provides evidence for considerable late-Pleistocene deformation and faulting within the San Joaquin Valley and bordering foothills of the Diablo Range; and 3) the alluvial deposits probably accumulated mainly during transitions from more humid to more arid conditions in the Diablo Range. A hypothetical climatic model for the deposition is proposed.

Results of this study have important social and economic value beyond their purely scientific importance. There is increasing interest in Quaternary faulting and in slope stability, reflecting increased safety and environmental concerns in urban planning and in the placement of sensitive facilities such as reserviors, power plants, hospitals and schools. Assessment of site suitability requires knowledge of the late Cenozoic geologic history. Alluvial deposits, however, have many limitations for deducing detailed geologic history such as: (1) abrupt lateral variation in lithology; (2) an incomplete stratigraphic record due to frequent intervals of erosion or interruptions in deposition; and (3) lack of sufficient datable material. The stratigraphy developed during this study for the west-central San Joaquin Valley provides a chronologic framework for using local deposits and landforms to evaluate seismic hazards and slope stability in the eastern foothills of the Diablo Range.

Alluvial deposits are also important for agriculture. The warm climate and rich well-drained alluvial soils make the San Joaquin Valley the richest agricultural area in the state and one of the richest in the country. Age and distribution of alluvial deposits in the valley are an important control on the distribution of soil types, which are major factors in the suitability of the land for many crops.

Futhermore, agriculture in the valley is dependent on irrigation from gound-water and surface water sources. Ground-water is drawn principally from aquifers in late Cenozoic unconsolidated deposits underlying the San Joaquin Valley. It is hoped that the preliminary subsurface stratigraphy presented in this report contributes to the understanding of the valley's aquifer system and will provide a framework for future subsurface and groundwater investigations.

<u>Location of and reasons for choosing study area</u>

The west-central San Joaquin Valley and adjacent foothils of the Diablo Range encompasses an area of 1800 km^2 west of the lower San Joaquin River between latitudes $36^o45'$ and $37^o22'30"$ North, in western Fresno, Merced, and Stanislaus Counties, and easternmost San Benito County. The western margin is at the base of the central core of the Diablo Range (Refer to Physiography Section). Figure 2 shows the geographic location of the study area and the U.S. Geological Survey 7.5-minute Quadrangles included. This area, which contains several of the larger streams draining the Diablo Range (Figure 3), was chosen for investigation because a preliminary air-photo reconnaissance study of the western San Joaquin Valley indicated that these streams are bordered by well-preserved terrace sequences. The highest terrace forms an extensive summit surface over the low foothills and thus provides a broad datum from which to evaluate Quaternary deformation of the foothills. The

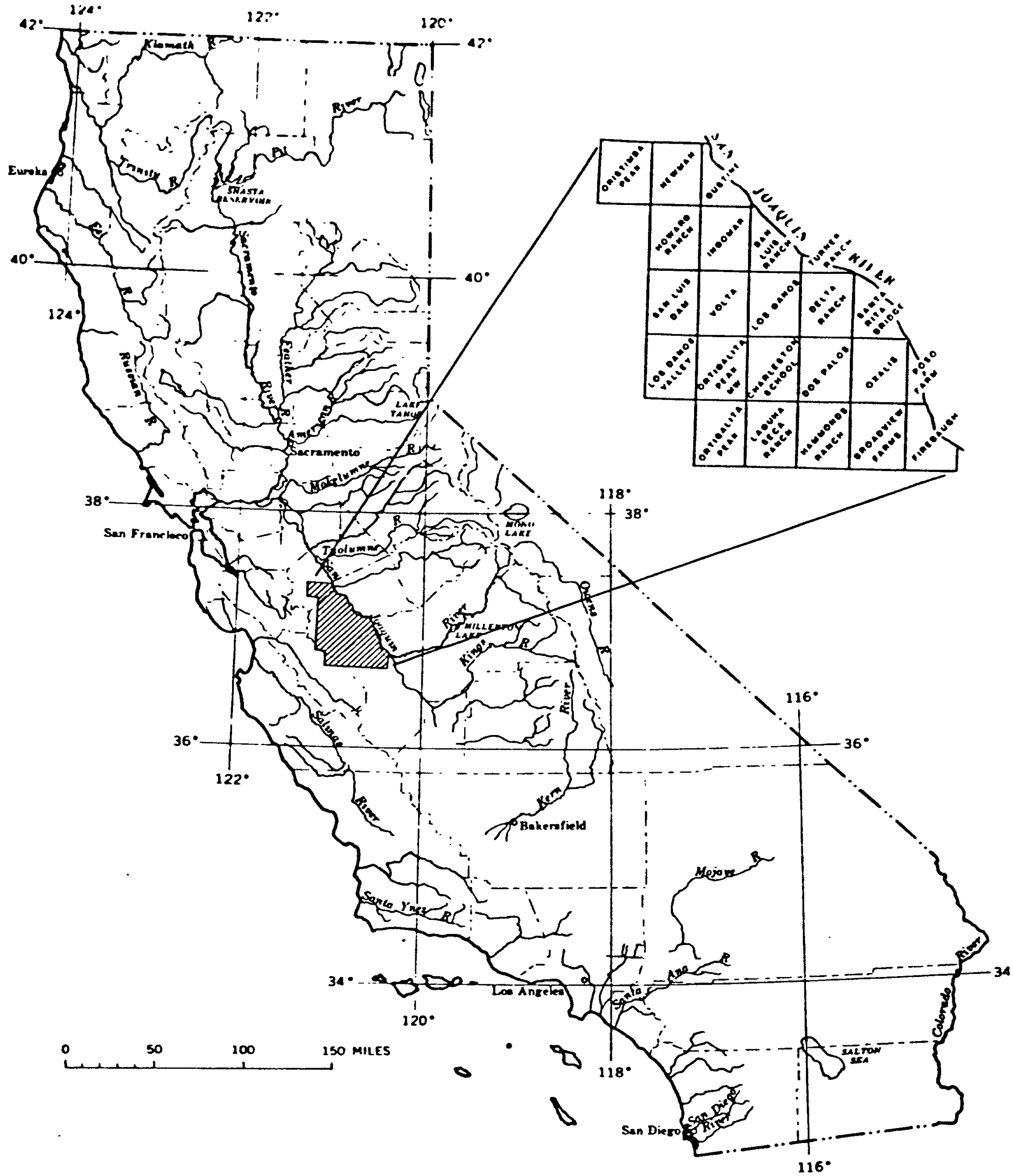

Figure 2: Index map of California showing location of west-central San Joaquin Valley study area and U.S. Geological Survey 7.5-minute Topographic Quadrangles included in the area.

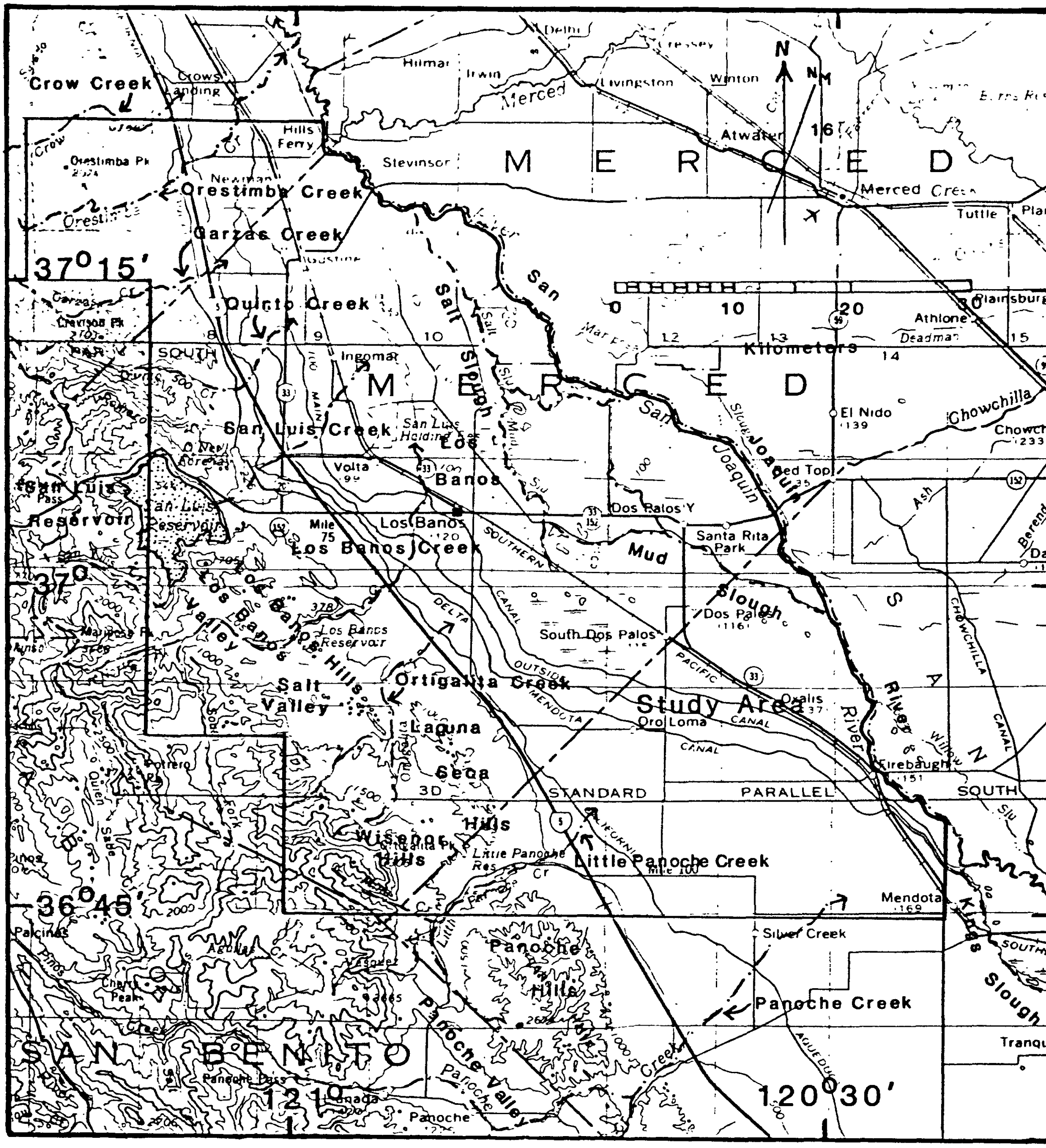

Figure 3: Major Diablo Range drainages in the west-central San Joaquin Valley and bordering foothills of the Diablo Range. The streams generally flow from southeast to northwest or east to west in broad, terraced valleys carved in the foothills between the central Diablo Range and San Joaquin Valley. Stream discharge infiltrates the piedmont alluvial-plain of the western San Joaquin Valley and rarely reaches the San Joaquin River.

streams rarely reach the San Joaquin River even during floods, and thus their alluvial fans serve as local base level. The sea probably did not invade the valley to this latitude during Quaternary sea level fluctuations and therefore did not influence deposition of the alluvial deposits. This portion of the valley and adjoining foothills have undergone relatively simple uplift and homoclinal deformation since the late Tertiary in contrast to more complex deformation to the north and south.

Physiographic Divisions

The study area straddles the boundary between the Great Valley and the Coast Range physiographic provinces of California, as described by N. M. Fenneman, (1931) and O. P. Jenkins (1943) and illustrated in Figure 4. These provinces can be divided into four natural topographic divisions in the west-central San Joaquin Valley. The Coast Range province is divided into central Diablo Range and the foothills of the Diablo Range. The Great Valley province is divided into the piedmont alluvial plain of the western San Joaquin Valley and the floodbasin of the San Joaquin River. Table 1 summarizes the characteristic geomorphic and lithologic features of these divisions and Figure 5 illustrates their distribution. In general, the divisions form four northwest-trending belts through the study area each characterized by a distinct bedrock lithology. The central Diablo Range is largely west of the study area but includes the southwestern portions of San Luis Dam, Ortigalita Peak and Los Banos Valley 7.5-minute Quadrangles. The other three divisions each include approximately 1/3 of the study area.

Numerous streams and gullies erode the foothill belt and build alluvial fans onto the piedmont plain of the San Joaquin Valley. The larger streams, (Figure 3) which head in the central Diablo Range, typically flow northeast across the foothills orthogonal to the regional trend of the foothill belt. These streams, collectively referred to in this report as "major Diablo Range drainages", include, from north to south, Crow Creek, Orestimba Creek, Garzas Creek, Quinto Creek, San Luis Creek, Los Banos Creek, Salt Creek, Ortigalita Creek and Little Panoche Creek. They rarely receive suffiecent water to sustain a continuous flow from source to mouth throughout the year and are generally dry thoughout most of their lengths by midsummer. Although winter and spring rains are commonly sufficient for them to flow across the foothill belt from December to May, continual seepage into their alluvial fans generally prevents surface discharge into the lower San Joaquin River. Numerous small streams and gullies are tributary to these streams. Others, however, drain onto the floor of the San Joaquin Valley along the range-front between the major drainages and have built independent alluvial fans.

Accessibility

Interstate-5 is the principle highway through the region following the margin of the Valley and roughly bisecting the area from northwest to southeast. Numerous city and county roads, easily reached from Interstate-5, provide ready access to most of the region. These roads are generally located on the U.S. Geological Survey 7.5-minute topographic maps (plates 1 to 23).

Limits to access affect only small areas of the Diablo Range where locked gates commonly block private roads and require owners' permission. These

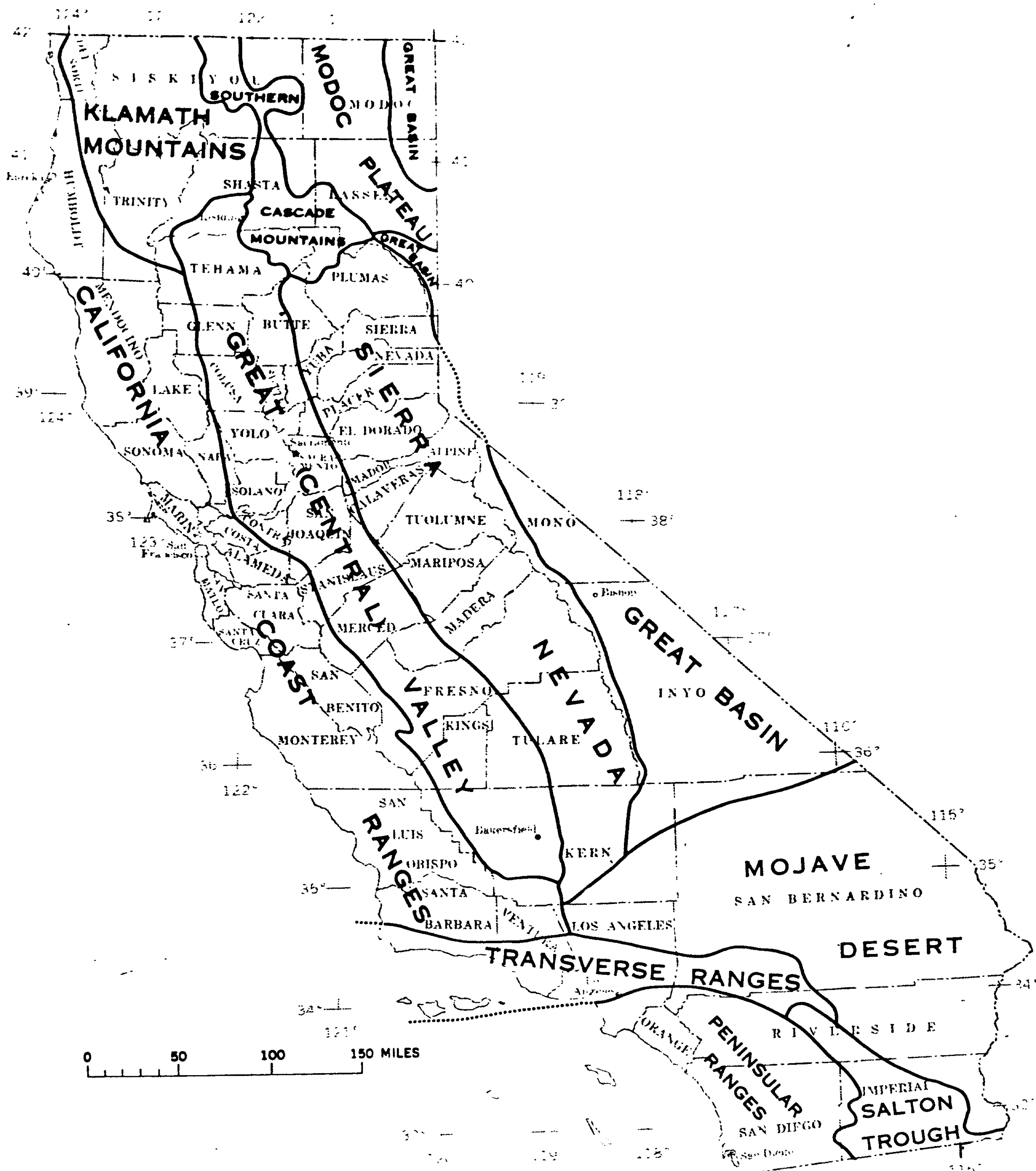

Figure 4: Physiographic provinces of California (from O. P. Jenkins, 1943). The study area straddles the margin of the Central Valley and California Coast Ranges provinces.

Table 1: Physiographic divisions of the west-central San Joaquin Valley and bordering Diablo Range and their characteristic features.

PROVINCE (Jenkins, 1943)	DIVISION	CHARACTERISTIC FEATURES
Coast Ranges	Central Diablo Range	General: Northwest-trending continuous mountain range. Rises sharply above eastern foothills to altitudes of 915 to 1100 m (3000 to 3500 ft) at crest, with maximum elevation of about 1550 m (5000 ft). Underlain principally by rocks of the Franciscan assemblage, secondarily by rocks of the Quien Sabe Volcanics, and locally by the basal ophiolite and lower rocks of the Great Valley Sequence. The range lies mainly west of the study area but underlies the southwestern portion of the Los Banos Valley, San Luis Dam and Ortigalita Peak 7.5-minute Quadrangles. Special Features: Erosion of the range has produced a steep and rugged terrain with local relief exceeding 300 m (950 ft.). Most major streams crossing the foothill belt have their headwaters in this part of the range. The range trends to the northwest and southeast into large synclinal valleys: Livermore Valley to the northwest and Panoche Valley to the Southeast.
	Foothills of Diablo Range	General: Northwest-trending belt of hills, typically 12 to 30 km wide, and underlying western and southwestern 1/3 of study area. Hills rise smoothly to abruptly above valley floor to altitudes of 65 of 825 m (200 to 2500 ft); maximum altitude generally increases from east to west and north to south. The hills are typically weakly to moderately dissected and commonly have a smooth, rolling topography with local relief from 2 to 30 m. The higher hills, however, are generally rugged and intricately dissected with steep slopes and local relief exceeding 300 m. Rocks of the Great Valley Sequence underlie majority of the hills. Locally, in Orestimba Creek area and in Laguna Seca Hills, rocks of Tertiary age underlie eastern 1 to 8 km of the belt. Special Features: Hills commonly have gravel-veneered, concordant summits, remnants of formerly extensive pediments. The pediments, coeval with some stream-terrace deposits, have been uplifted, deformed and weakly to strongly dissected. Southern portion of belt consists primarily of isolated groups of hills separated by broad, terraced valleys. These hills and valleys are commonly the sites of localized uplift and subsidence. Local geographic names for these areas are shown on the 7.5-minute Quadranges and include Wisenor, Los Banos, Conglomerate, Panoche and Laguna Seca Hills, and San Luis, Panoche, Little Panoche, Wisenor, Los Banos, Carrisalito Flat, and Salt Valleys. The valleys typically are underlain by thick sequences of Late Cenozoic alluvium and are topographically separated from the San Joaquin Valley by low ridges or hills. Narrow, terraced canyons connect the foothill valleys with the San Joaquin Valley.
CENTRAL VALLEY	Piedmont Plain	General: Northwest-trending belt of coalescing alluvial-fans, 15 to 25 km wide, underlying central 1/3 of study area. The piedmont is bordered on the east by the Valley floodbasin and on the west by the foothills of the Diablo Range. The alluvial-plain slopes gently northeast from a maximum altitude of 200 m at the edge of the foothills south of Little Panoche Creek, to 18 m on the outer-fan of Orestimba Creek. The alluvial-fans were built principally by the major Diablo Range drainages. Fan surfaces are typically unmodified to weakly dissected with local relief of 3 m. Stream channels and fan-head trenches (Bull, 1964) however, are commonly incised 5 to 15 m. The surfaces slope moderately to gently 18m to 2/km eastward toward the Valley axis, commonly with decreasing gradient valleyward. Special Features: Piedmont-Foothill border is commonly an abrupt east-facing, faceted escarpment with local relief up to 120 m. Less commonly, the piedmont surfaces merge with the gently sloping, gravel-veneered surface across the summit of the foothills. A narrow, laterally discontinuous, belt of mudflow-fans, 0 to 8 km wide, fringes the piedmont-foothill border and slopes eastward up to 10 m/km. Mudflows generally debouch from the numerous small ephemeral streams and gullies which head in the foothill belt.
	Floodbasin	General: Northwest-trending, nearly flat surface in topographic axis of Joaquin Valley. Basin ranges in width from 5 to 30 km and underlies the eastern and northeastern 1/3 of study area. It slopes very gently, 0.5 to 1 m/km northwestward and is principally the site of floodplain and riverine deposition from the San Joaquin River and associated sloughs, swamps and ephemeral ponds. Abandoned channels, levees, ponds and sloughs create a local, hummocky relief of 0.5 to 5 m. Under natural conditions, early summer snow-melt from Sierra Nevada caused the San Joaquin River to overtop its banks and flood the basin. Impoundments in foothills of Sierra Nevada and artificial levees along river and sloughs now contain these floods. Special Features: In general, the basin attains its maximum width near the town of Los Banos and is narrowest near the town of Newman. Present course of the San Joaquin River approximately follows eastern margin of the floodbasin. The River gradient increases from 0.4 m/km near Los Banos to 1.0 m/km near Newman in conjunction with constriction of the floodbasin. Constriction coincides with impingement of Merced River alluvial fan, the first glacial outwash fan north of the San Joaquin River alluvial fan.

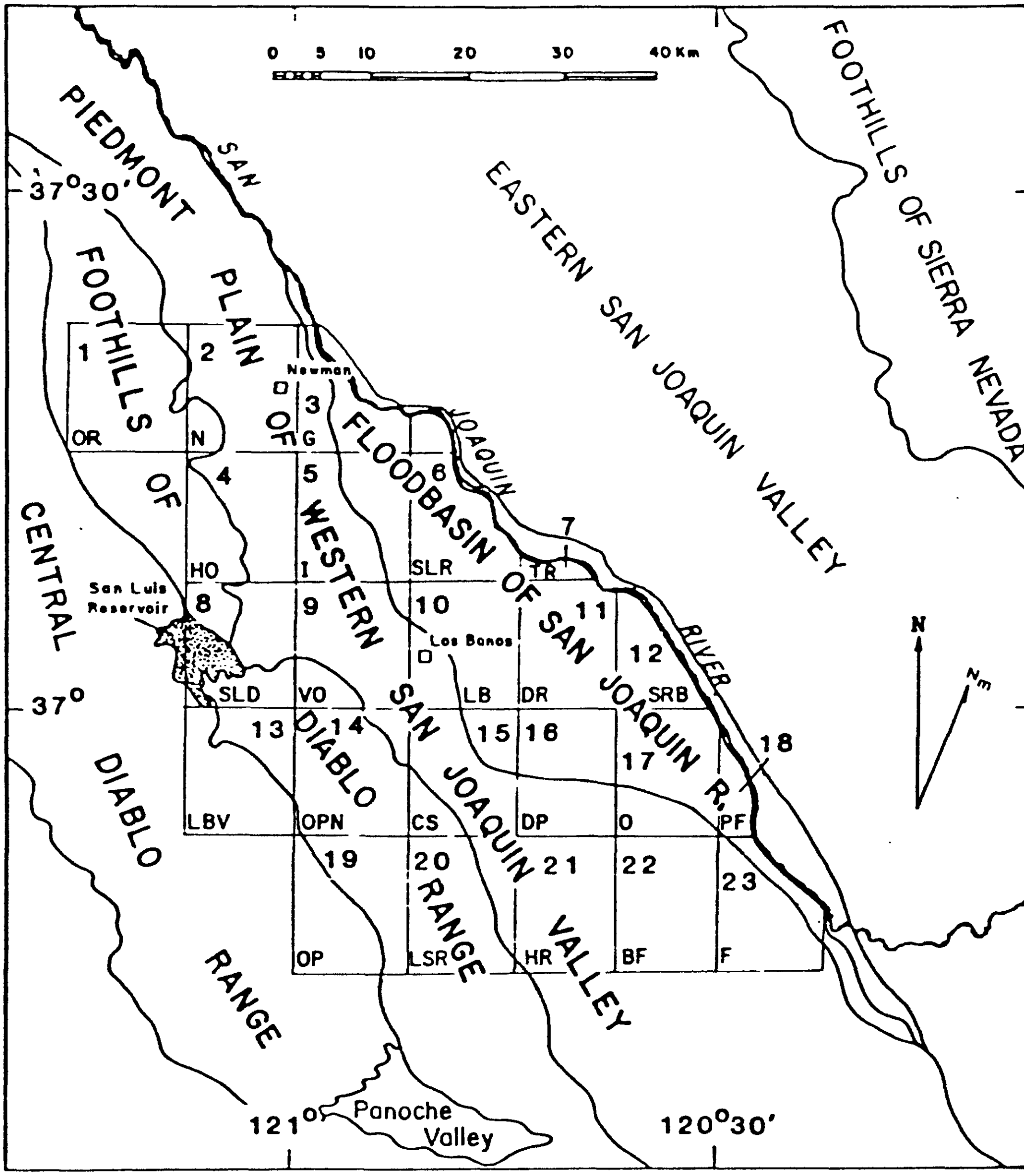

Figure 5: Physiographic divisions of the San Joaquin Valley and Diablo Range recognized in this study and their distribution relative to the 7.5-minute quadrangles in the study area. OR - Orestimba Peak, N - Newman, G - Gustine, HO - Howard Ranch, I - Ingomar, SLR - San Luis Ranch, TR - Turner Ranch, SLD - San Luis Dam, VO - Volta, LB - Los Banos, DR - Delta Ranch, SRB - Santa Rita Bridge, LBV - Los Banos Valley, OPN - Ortigalita Peak Northwest, CS - Charleston School, DP - Dos Palos, O - Oxalis, OP - Ortigalita Peak, LSR - Laguna Seca Ranch, HR - Hammonds Ranch, BF - Broadview Farms, F - Firebaugh. Plate numbers are indicated.

right-of-entry restrictions did not limit the areal extent of mapping, however, as all landowners graciously granted access.

Climate

The west-central San Joaquin Valley, situated in the rain-shadow of the Diablo Range, is characterized by a climate of long, hot, dry summers and mild winters. Figure 6 shows the monthly temperature and precipitation range for five weather stations in the Valley and Diablo Range. Stations at Newman, Los Banos, and Hanford show the temperature and precipitation distribution from north to south along the axis of the Valley; Stations at San Luis Dam and Idria show the change in climate with increasing elevation in the Diablo Range. Figure 7 shows the location of these five stations and the general distribution of precipitation throughout the central San Joaquin Valley and adjacent Coast Ranges. The distribution of precipitation was interpreted from data for 37 weather stations in the west-central California (Table 2). In general, the climate ranges from temperate to semi-arid in the northern San Joaquin Valley to semi-arid to arid in the southern San Joaquin Valley.

Most of the precipitation in the area falls as rain in the winter months (Figure 6). In general, the annual precipitation increases with increasing elevation, from 6 to 8 inches in the valley to 8 to 15 inches in the foothills and 15 to 20 inches in the central Diablo Range; and decreases from north to south within the valley and foothills (Figure 7). Total annual precipitation, however, varies considerably from year to year and in one year out of ten may be as little as 3 inches on the Valley floor or as much as 30 inches in the central Diablo Range (Isgrig, 1969).

This distribution of precipitation is controlled principally by the Diablo Range. The rain falls primarily from cyclonic storms that move east across California from the northeast Pacific. Adiabatic cooling of the moisture laden air as it moves over the Diablo Range results in condensation and precipitation in the mountains. Subsequent adiabatic warming of the air as it descends the east flank of the range permits the retention of more water vapor than is available, consequently forming a rain shadow across the foothill belt and western San Joaquin Valley. The annual rainfall decreases from north to south, however, principally because of the lesser frequency of Pacific cyclonic storms in the lower latitude.

Rare summer rains occur mainly as scattered thundershowers but also as infrequent cyclonic storms. Except for the thunderstorms, intensity of the precipitation is generally low and essentially all the precipitation infiltrates the soil mantle. In the eastern foothills of the central Diablo Range, the average intensity of rainfall in one year out of two amounts to 0.40 to 0.50 inches in one hour, 0.75 to 1.50 inches in six hours and 1.00 to 3.00 inches in 24 hours (Isgrig, 1969).

Summers are warm to hot, with typical mean daily maximum temperatures for July ranging from 92^{0}F to 100.6^{0}F. In contrast, winters are cool, with the typical mean daily temperature for January ranging from 33^{0}F to 37^{0}F. In general, mean daily maximum and minimum temperatures and mean annual temperatures increase from north to south and follow an inverse relationship to rainfall, being warmer in the valley and cooler in the central Diablo Range (Figure 6). The daily temperature range is often 30 to 40^{0}F, particularly in

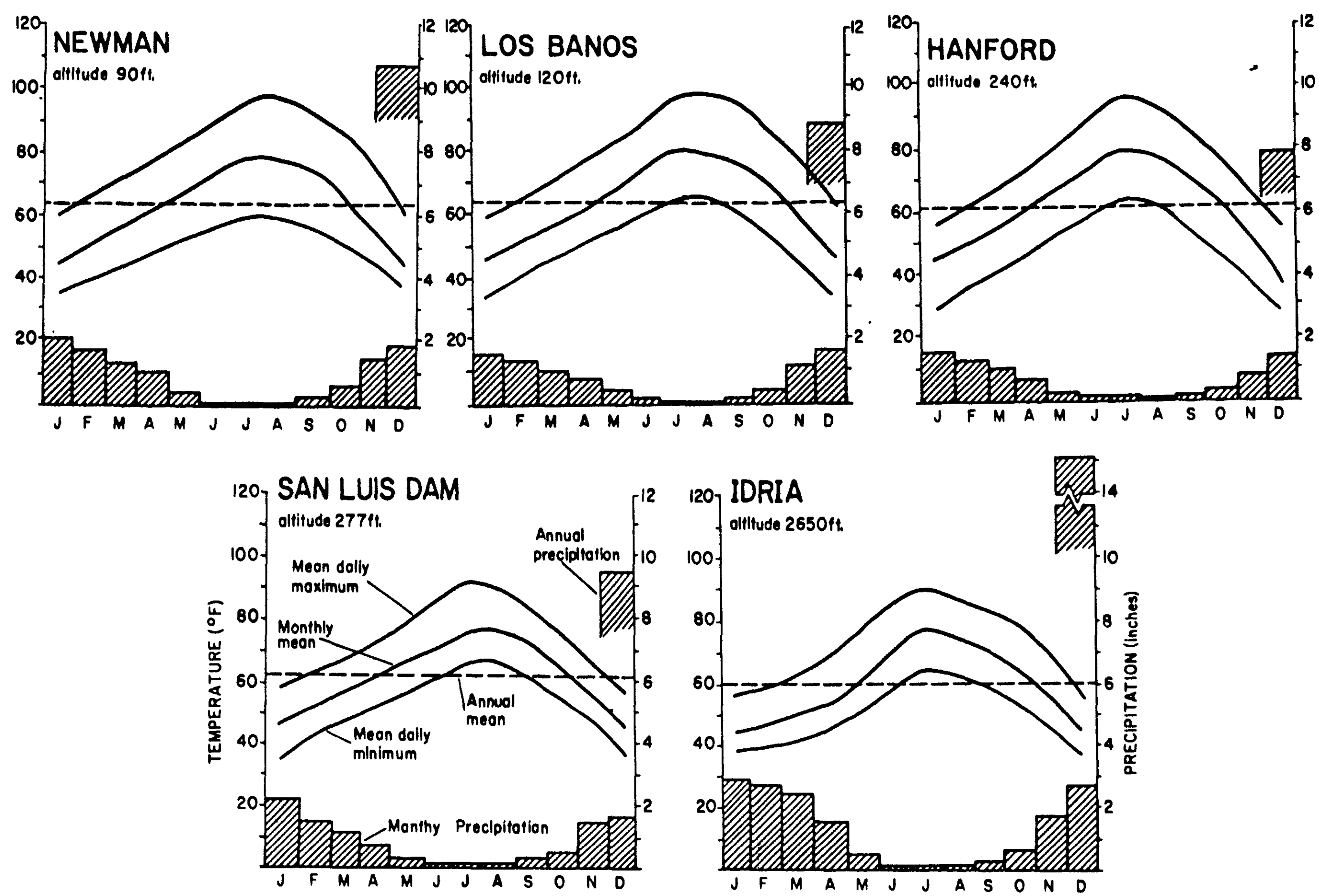

Figure 6: Temperature and precipitation data for five weather stations in the San Joaquin Valley and Diablo Range. Stations are located on Figure 7. Compiled for the years 1967 to 1976, inclusive (source: National Oceanic and Atmospheric Administration, Climatological Data Bulletin, Volumes 71 to 80).

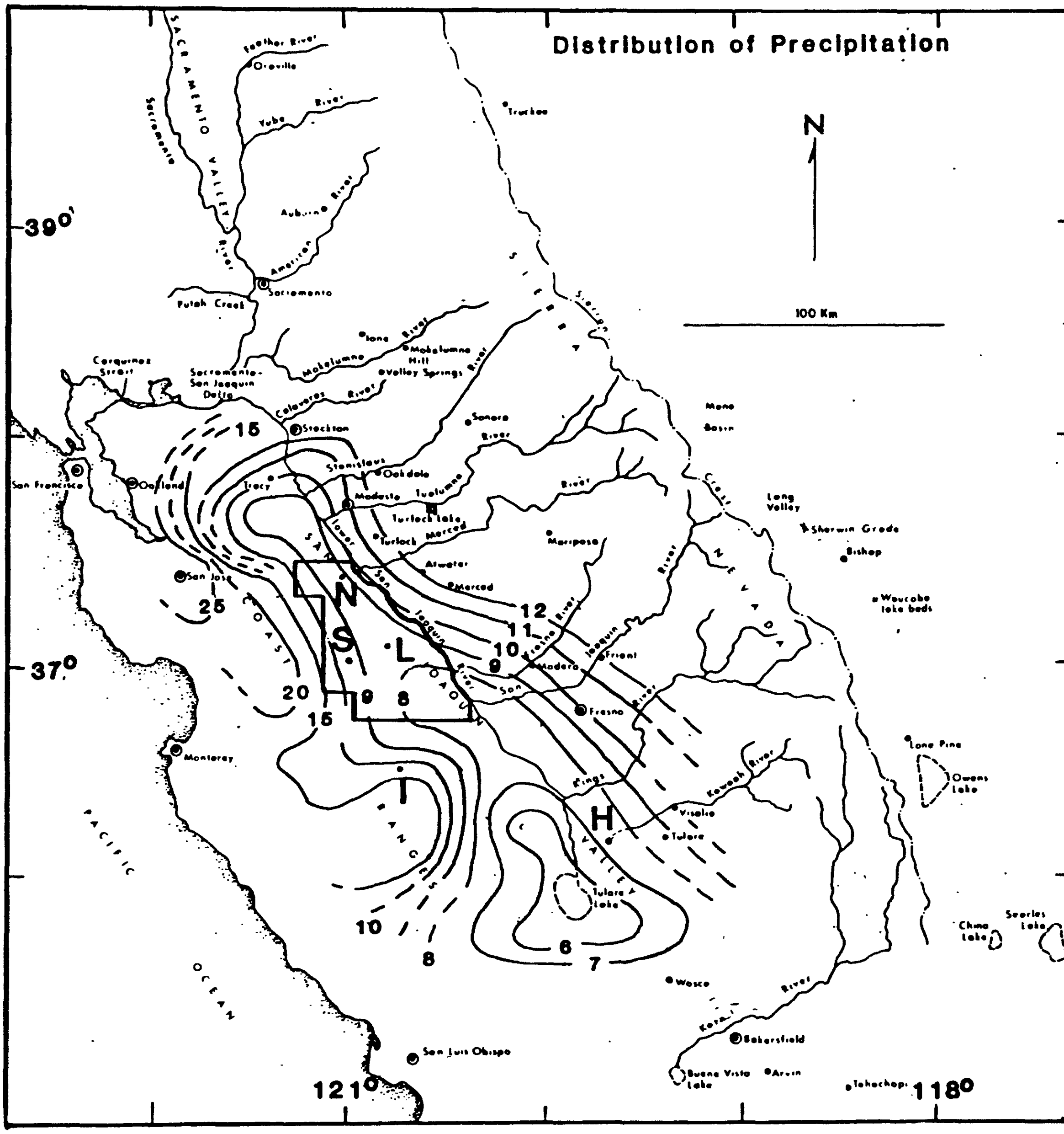

Figure 7: Distribution of mean annual precipitation in the central San Joaquin Valley. Compiled for the years 1967, to 1976, inclusive (source: National Oceanic and Atmospheric Administration, Climatological Data Bulletin, Volumes 71 to 80). Weather station data is listed in Table 2 and shown for five stations in Figure 6. I - Idria, S - San Luis Dam, N - Newman, L - Los Banos, H - Hanford. Study area is indicated.

Table 2: Precipitation data for 37 weather stations in the San Joaquin Valley and bordering foothills of the Diablo Range. Compiled for the years 1967 to 1976, inclusive (source: National Oceanic and Atmospheric Administration, Climatological Data Bulletin, Volumes 71 to 80).

Station	Latitude	Longitude	Mean Annual Precipitation	Total Precipitation June through Sept., incl.
Buena Vista	36°50'	121°10'	13.40	0.20
Castle Rock Radiation Lab	37°38'	121°30'	8.58	0.1
Coalinga	36°09'	120°21'	7.28	1.46
Corcoran	36°06'	119°34'	5.97	0.17
Del Puerto Road Camp	37°25'	121°23'	9.36	0.1
Five Points	36°22'	120°09'	6.05	0.17
Fresno	36°46'	119°43'	10.5	0.15
Hanford	36°46'	119°39'	7.84	0.20
Idria	36°25'	120°40'	15.86	0.20
Kerlinger	37°41'	121°26'	8.12	0.21
Kettleman Station	36°04'	120°05'	6.12	0.14
Kettleman City	36°00'	119°58'	7.27	
Little Panoche Detention Reservoir	36°52'	120°25'	8.11	
Lone Tree Canyon	37°37'	121°23'	8.39	
Los Banos	37°03'	120°52'	8.90	0.34
Los Banos Arbura Ranch	36°53'	120°56'	9.21	0.23
Los Banos Detention Reservoir	37°01'	120°56'	6.72	0.24
Madera	36°57'	120°02'	10.75	0.20
Manteca	37°48'	121°12'	11.39	0.1
Mendota Dam	36°47'	120°22'	7.54	0.1
Merced	37°19'	120°29'	12.12	0.44

Table 2: Continued

Mercey Hot Springs	36°42'	120°52'	8.92	0.22
Modesto	37°39'	121°00'	12.20	0.18
Mt. Hamilton	37°20'	121°39'	27.20	
Newman	37°18'	121°02'	10.67	0.10
Pacheco Pass	37°04'	121°11'	17.12	0.31
Panoche	36°36'	120°52'	8.63	0.1
Panoche Junction	36°33'	120°29'	6.02	0.13
Pinnacles National Monument	36°29'	121°11'	16.02	0.17
San Luis Dam	37°03'	121°04'	11.73	0.42
Santa Rita Peak	36°19'	120°35'	23.46	0.55
Stayton Mine	36°45'	121°10'	22.74	0.46
Tracy Carbona	37°42'	121°25'	10.31	0.46
Tracy Pump Plant	37°48'	121°35'	31.42	0.25
Turlock	37°29'	120°51'	11.89	0.1
Upper Tres Pinos	36°38'	121°02'	13.63	0.16
Westhaven	36°13'	119°59'	6.87	0.14

the summer when temperatures in the valley commonly exceed 100^{0}F. Maximum mean daily temperatures of 115^0 and 110^0 have occured at the towns of Newman and Los Banos, respectively. The length of the frost-free growing season averages 277 days in the valley, with the average earliest frost occuring by Novermber 24th and average latest frost occuring before February 17th.

Vegetation

The distribution, density, and type of vegetation in the San Joaquin Valley and foothills of the Diablo Range is strongly controlled by climate and altitude. Table 3 is a compilation of the dominant native and introduced trees, shrubs, herbs and grasses in the west-central San Jaoquin Valley compiled from U.S. Forest Service Range Surveys and U.S. Department of Agriculture soil-surveys in the area (Cole and others, 1943, 1948 1952; Isgrig, 1969; Harradine, 1950; Harradine and others, 1956; McLaughlin and Huntington, 1968).

Diablo Range Vegetation

On the cooler, wetter slopes of the central Diablo Range, the native vegetation is dominated by various species of shrubs, including chamise, California sagebrush, big sagebrush, and by species of live and white oak on north-facing slopes. Juniper, buckeye, and digger pine grow at the higher altitudes and in sheltered local draws.

On the warmer, drier slopes of the foothills, the native vegetation consists primarily of various species of shrubs, herbs and grasses. Dominant shrubs include chamise and California sagebrush on slopes with northern exposure and big sagebrush on slopes having a southern exposure. Buckbrush, birchleaf mountain-mahogany, slender oat, soft chess, peppergrass and lupine are also abundant plants. California blue oak, and digger pine are dominant trees along streams and gullies with northern exposure and sycamore, cottonwood and willow are common along streams, springs and other areas with perennial near-surface groundwater. These trees give way to juniper, California live oak, interior live oak and buckeye along protected areas of the higher foothills and lower slopes of the central Diablo Range.

In general, for the same altitude, the density of vegetation in the foothills decreases from north to south in conjunction with decreasing precipitation and increasing temperature. A moderate growth of shrubs and grasses typically covers the area north of Orestimba Creek decreasing to scant coverage south of Little Panoche Creek.

The distribution density and type of vegetation in the foothills, however, has been significantly altered by domestic practices. For example: the oak-woodland areas in the foothills, particularly the Panoche Hills, was largely removed for firewood in the late 1800's and early 1900's; and domestic overgrazing, particularly in the hills south of San Luis Creek, has severely retarded the growth of native bunchgrasses, causing their replacement by introduced species of annual grasses. Because annual grasses are less capable of maintaining a slope-stabilizing root-mass, the stability of natural slopes, surface infiltration of rainfall, and consequently runoff and erosion rates in these areas may have been significantly altered.

Table 3: Scientific and common names of the characteristic herbaceous and woody plants in the west-central San Joaquin Valley and bordering foothills of the Diablo Range (summarized from U.S. Forest Service Range Surveys and U.S. Department of Agriculture soil surveys in the area, Cole and others, 1943, 1948, 1952; Harradine, 1950; Harradine and others, 1956; Isgrig, 1969; and McLaughlin and Huntington, 1968).

Scientific name	Common name
TREES	
Aesculus californica	California buckeye.
Juniperus californica	California juniper.
Platanus racemosa	California sycamore.
Populus fremontii	Fremont cottonwood.
Quercus agrifolia	California live oak.
Q. douglasii	Blue oak.
Q. lobata	California white oak
Q. wislizeni	Interior live oak
Salix sp	Willow
Pinus sabiniana	Digger Pine
SHRUBS	
Adenostoma fasciculatum	Chamise.
Allenrolfea occidentalis	Inkweed (iodine-weed).
Aplopappus linearifolius	Narrowleaf goldenbush.
Artemisia californica	California sagebrush.
A. tridentata	Big Sagebrush.
Atriplex sp	Saltbush.
Ceanothus cuneatus	Wedgeleaf ceanothus (buckbrush).
Cercocarpus betuloides	Birchleaf mountain-mahogany.
Ephedra californica	California jointfir.
Eriogonum fasciculatum	Flat-top buckwheatbrush.
Prunus ilicifolia	Hollyleaf cherry.

Table 3: Continued

GRASSES	
Avena barbata	Slender Oat.
Bromus mollis	Soft chess.
B. rubens	Foxtail chess.
Cynodon dactylon	Bermuda grass.
Distichlis spicata	Seashore saltgrass.
Festuca megalura	Fostail fescue.
Hordeum murinum	Mouse barley.
Koeleria phleoides	
Melica bulbosa	Oniongrass.
Poa scabrella	Pine bluegrass.
P. secunda	Sandberg bluegrass.
Sporobolus airoides	Bunch grass.
Stipa pulchra	Purple needlegrass.
HERBS	
Achyrachaena mollis Schauer	Blowwives.
Amsinckia douglasiana DC	Buckhorn.
Athsanus pusillus (Hook.) Greene	
Baeria spp	Goldfields
Brodiaea laxa (Benth.) S. Wats	Grass nut.
Calandrinia caulescens H. B. K.	Rockpurslane.
Capsella bursa-pastoris (L.) Medic	Shepherds-purse.
Erodium botrys Bertol	
Erodium circutarium (L.) L'Her	Alfileria.
Erodium moschatum (L.) L'Her	Heronbill.
Eschscholtzia californica Cham	California-poppy
Galium aparine L	Goosegrass.
Gilia tricolor Benth	Birdseye.
Godetia spp	Godetia.
Gridelia robusta Nutt	Gumweed.
Gutierrezia spp	Snakeweed.
Hemizonia kelloggii Greene	Tarweed.
Hemizonia virgata A. Gray	
Layia platyglossa	Tidytips.
Lepidium nitidum Nutt	Peppergrass.
Lotus scoparius (Nutt.) Ottley	Deervetch.
Lotus subpinnatus Lag	Birdsfoot trefoil.
Lupinus bicolor Lindl	Lupine.
Marrubium vulgare L	Horehound.
Microseris douglasii (DC.) Sch. Bip	
Mentia perfoliata	Miner's lettuce.
Orthocarpus purpurascens Benth	Owlclover.
Plagiobothrys tenellus A. Gray	Popcorn flower.
Plantago erecta Morris	Plantain.
Salicornia ambigua	Pickleweed.
Stellaria nitens Nutt	Chickweed.
Trifolium gracilentum Torr. and Gray	Pin-point clover.
Trifolium variegatum Nutt	White-tip clover.

The distribution and length of growing season for grasses, herbs and shrubs in the foothills is also influenced by local, microclimate fluctuations. Slopes with sheltered north exposure typically maintain a more luxuriant grass and plant cover until mid to late summer than do the more exposed south-facing slopes, whose grasses commonly die by early summer (Figure 8). North-facing slopes are commonly steeper, probably reflecting the stabilizing influence of the longer-living vegetative cover, a phenomenon first observed in the foothills of the Diablo Range by Bull (1964) in the Tumey and Panoche Hills south of the study area. This local microclimatic influence on vegetation density and distribution is perhaps indicative of the effects which fluctuating regional climatic change would have on slope stability, erosion and sediment transport in the foothills.

San Joaquin Valley Vegetation

On the alluvial fans and valley basin areas where rainfall is less and temperature significantly warmer, soils become a significant factor in the distribution of the native vegetation. Two particular soil groupings can be considered: (1) fine-grained, poorly-drained basin soils with a high content of alkaline salts; and (2) coarser-grained, well-drained alluvial-fan and bedrock soils.

Under natural conditions, the basin soils typically support a thick, native vegetation of alkalai-tolerant salt grass (Distichlis spicata), bunch grass (Sporobolus airoides), tule (Scirpus sp.), salt bush (Atriplex sp.), pickleweed (Salicornia ambigua) and other salt-tolerant plants. Large areas of impeded drainage on the Valley floodbasin are typically covered with a dense growth of these plants. Reclamation of these areas by artificial drainage and leach irrigation for livestock grazing and cultivation of alfalfa, feed-corn and cotton is currently underway, however, and has elminated this native alkali-tolerant vegetation from many areas of the basin.

Well-drained soils developed on the alluvial fans and low foothill areas have a moderate to scant cover of introduced annual grasses and associated herbaceous plants. Most of the native vegetation in these areas, probably including several varieties of perennial bunch grasses, has been removed or greatly altered by extensive agricultural cultivation and livestock grazing. The most abundant native plants remaining include foxtail chess, slender oats, peppergrass, plantain, and burclover.

Figure 8: Vegetation contrast in early summer. Vegetation remains green on slopes with sheltered northern exposure but dries and turns brown on slopes with southern exposure by early summer. South-facing slopes are thus exposed to relatively greater sheet erosion and are commonly reduced to relatively gentler gradients (view east, SW 1/4, Sec. 24, T13S, R10E; Laguna Seca Ranch 7.5-minute Quadrangle).

PRE-LATE CENOZOIC GEOLOGY

Introduction

Late Cenozoic deposits in the west-central San Joaquin are largely derived from pre-late Cenozoic bedrock units in the Diablo Range. These rocks include the Franciscan assemblage, here of late Jurassic and Cretaceous age, the Great Valley Sequence of late Jurassic, Cretaceous and early Tertiary age and a younger, less extensive sequence of Tertiary marine and continental rocks. Table 4 summarizes their lithology and age and Figure 9 illustrates their distribution in the study area. In general, their distribution reflects the structural development of the Diablo Range. A summary of this structure therefore, is presented following discussion of the pre-late Cenozoic stratigraphy.

The riverine and floodbasin deposits of the San Joaquin River and associated sloughs, and the minor volume of eolian sand, are derived principally from the plutonic, metamorphic, volcanic and sedimentary bedrock of the Sierra Nevada. Bateman and Wahrhaftig (1966) described the general lithology and distribution of these rocks in the Sierra Nevada; Clark (1964) described the lithology and stratigraphy of the western Sierra Nevada metamorphic belt; Schweickert and others (1977) described the paleotectonic and paleogeographic implications of the Calaveras Formation in the western Sierra Nevada; Duffield and Sharp (1975) described the lithology and stratigraphy of melange and ophiolitic rocks in the western Sierra nevada; Slemmons (1966) and Dalrymple (1964) described the lithology, stratigraphy and age of Cenozoic volcanic rocks in the west-central Sierra Nevada and Marchand and Allwardt (1981) briefly summarized the Tertiary sedimentary rocks in the west-central foothills of the Sierra Nevada. A discussion of these rocks is not presented and the reader is referred to these references for information.

Pre-late Cenozoic Stratigraphy

Franciscan assemblage

The Franciscan assemblage (Bailey, Irwin and Jones, 1964) forms the core of the central Diablo Range and underlies the southwestern and westernmost portion of the study area on the Los Banos Valley, Ortigalita Peak and Ortigalita Peak NW 7.5-minute Quadrangles (Figure 9). The assemblage consists mainly of coherent units of bedded graywacke and shale separated by zones of melange. In the Diablo Range, these rocks range in age from late Jurassic to late Cretaceous (Page, 1981). The graywacke commonly exhibits graded bedding, small-scale, ripple cross-stratification, and flute-cast sole markings, and is thus interpreted as being deposited by turbidity currents on a shallow to deep marine fan (Page 1981). The melange consists of large blocks, up to several kilometers long, of greenstone, graywacke, red and green radiolarian chert, gabbro and serpentinite set in a matrix of pervasively sheared graywacke, shale and serpentinite. Much of the assemblage has been subjected to blueschist or greenschist-facies metamorphism. Consequently, metagraywacke, metachert, actinolite schist, and glaucophane schist are common lithologies. The entire assemblage is structurally dismembered and local folds and faults typically have little regional significance.

Table 4: Summary of the lithology, distribution and age of pre-late Cenozoic rocks in the west-central San Joaquin Valley and bordering foothills of the Diablo Range. Refer to "Description of map units" for key to map symbols.

UNIT	AGE	LITHOLOGY	DISTRIBUTION	REFERENCES
Quien Sabe Volcanics	Upper Miocene	Basalt, andesite and dacite flows, andasite and rhyolite intrusive plugs.	Main volanic field is located west of study area; Basalt Hill outlier south of San Luis Dam.	Lieth (1949) Dibblee (1975) Snyder and Dickinson (1979)
Oro Loma Formation	Miocene	Poorly to moderately consolidated nonmarine gravel, sand, silt and minor clay. Clasts composed principally of Franciscan graywacke, greenstone, quartzite, quartz, green, red, and black chert, porphyritic volcanic rocks	Continuous exposure along front of Laguna Seca Hills. Forms top of homoclinally tilted bedrock sequence. Up to 300 m thick, erosional but concordant lower contact.	Briggs (1953) Dibblee (1975)
Carbona Formation of Pelletier (1951)	Miocene	Moderately to well-bedded, poorly to moderately consolidated nonmarine gravel, sand, silt, and minor clay. Clasts principally graywacke and less red and green quartzite-veined chert, meta volcanics and serpentinite.	Discontinuous exposure in vicinity of Orestimba Creek. Caps low hills bordering San Joaquin Valley and forms top of homo-clinaly tilted bedrock sequence. Up to 80 m thick. Erosional but concordant lower contact.	Pelletier(1951) Raymond (1969) Sonneman (1958)
Valley Springs Formation	Upper Oligocene(?) and lower Miocene	Tuffaceous sandstone, siltstone and claystone. Commonly heavily altered and cemented with clay. Locally conglomeratic. Clasts of Kreyenhagen diatomite common in lower portion	Discontinuous exposure overlying sandstone of Poverty Flat in Orestimba Creek area. Erosional lower contact. Locally exceeds 20 m thick.	J. A. Bartow (1981; personal communication)
sandstone of Poverty Flat	Upper Eocene and lower Oligocene(?)	Friable to indurated, sparsely fossil-iferous quartzose sandstone with interbedded kaolinite clay. Conglomerate locally present. Clasts include quartzite and Franciscan radiolarian chert. Nonmarine to shallow marine(?)	Discontinuous exposure in Orestimba Creek area. Locally exceeds 15m thick. Gradational lower contact with Kreyenhagen.	U.S. Bureau of of Reclamation (1961-4) J.A. Bartow (1981, personal communication)
Kreyenhagen Shale	Middle and upper Eocene	Diatomaceous marine shale with common glauconitic sandstone and limestone in lower portion. Thin regular laminae suggest deep, quiet water.	Continuous exposure between Ortigalita and Wildcat Creeks in Laguna Seca Hills. Discontinuous exposure in Orestimba Creek area. 100 to 250m thick. Gradational lower contact with Domengine, erosional over older formations.	Anderson (1905) Briggs (1953)
Domengine Sandstone	Middle Eocene	Slightly friable to indurated, quartzose to arkosic marine sandstone commonly glauconitic, locally contains glaucophane suggestive of Franciscan source.	Intermittently exposed in laterally continuous thin, 2 to 10m, belt in Orestimba Creek area. Erosional lower contact.	Anderson (1905) Payne (1951) Sonneman (1958)
Tesla Formation	Paleocene(?) Lower and Middle Eocene	Friable to moderately indurated carbon-aceous siltstone and shale interbedded with less abundant anauxitic quartzose sandstone. Shallow marine to swampy.	Intermittently exposed in laterally continuous belt between Rattlesnake and Wildcat Creeks in Laguna Seca Hills and in the Orestimba Creek area 10 to 50 m thick, gradational lower contact.	Huey (1948) Briggs (1953)
Laguna Seca Formation	Paleocene and lower Eocene	Concretionary, fossiliferous, micaceous sandstone interbedded with shale and siltstone. Shallow marine. Sandstone locally glauconitic and carbonaceous.	Intermittently exposed in northwest trending belt between Ortigalita and Wildcat Creeks in Laguna Seca Hills 350 to 400m thick, gradational(?) lower contact.	Payne (1951) Briggs (1953)
Great Valley Sequence: Moreno shale	Upper Cretaceous and Paleocene	Friable to moderately indurated shale with less abundant indurated arkosic sandstone. Locally shale is diatamaceous marine	Underlies majority of foothill region. Forms a northwest trending belt 10 to 15km wide through southwestern and western portion of study area, 2500 to 9000m exposed thickness. Fault contaot with Franciscan.	Bailey and others (1964) Payne (1951)
Great Valley Sequence: Panoche sandstone	Cretaceous	Predominantly shale in lower part becoming predominantly indurated arkosic sandstone with minor conglomerate in upper part. Clasts primarily andesite to ryholite porphyries, ignimbrites, granite, minor quartzite and blackchert marine.		
Franciscan assemblage	Upper Jurassic, Cretaceous and Paleocene (?)	Chaotic assemblage of coherent units of graywacke and metagraywacke separted by zones of melange. Melange consists of coherent blocks of graywacke, greenstone, radiolarion red and green chert and serpentinite imbedded in a matrix of pervasively sheared argillaceous shale and fractured graywacke. Assemblage commonly subjected to greenschist to blueschist grade metamorphism.	Underlies central Diablo Range in southwestern portion of study area. Thickness unknown.	Bailey and others (1964) Lieth (1949) Briggs (1953) Page (1981)

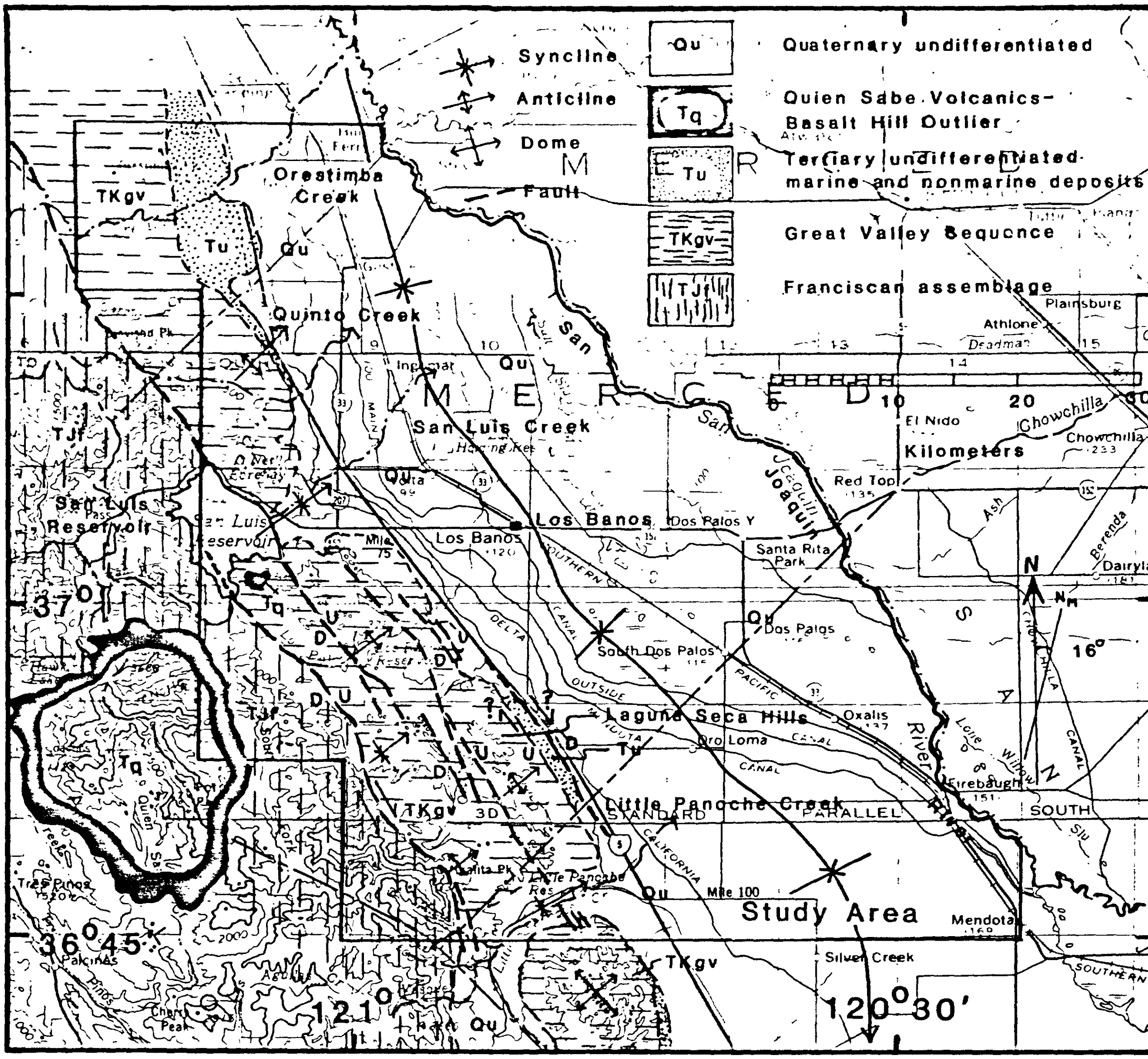

Figure 9: General distribution of pre- late Cenozoic rocks in the west-central San Joaquin Valley and bordering Diablo Range.

The Franciscan is thus a chaotic assemblage of metamorphosed terriginous sediment and oceanic material (Page 1981). Because of the extreme structural disorder, blocks of exotic lithologies, and presence of high-temperature metamorphic materials, it is interpreted to have accumulated in an accretionary prism formed during subduction of an oceanic plate beneath the margin of the North American plate (Hamilton, 1978, Blake and Jones, 1981). Competent bodies of graywacke and blocks of oceanic crust were dismembered and mixed in the pervasively sheared matrix, possibly by olistostromes on the inner trench slope or by recurrent partial subduction (Page, 1981). The principal component of subduction is believed to be eastward, normal to the present continental margin (Hamilton, 1969) although recent work suggests a significant component of oblique subduction and northwestward motion along inter-arc strike slip faults (Blake and Jones, 1981)

Great Valley Sequence

Structurally overlying the Franciscan assemblage is the Great Valley Sequence (Bailey, Irwin and Jones, 1964), composed of relatively undeformed, unmetamorphosed, well-bedded shale, siltstone, sandstone and conglomerate (Blake and Jones, 1981). Sedimentary structures including graded bedding, ripple-cross-stratification and sole markings, indicate that most of these rocks accumulated as turbidites on deep marine fans (Nilsen and Dibblee, 1979). The lower strata locally rest on the Coast Range Ophiolite composed largely of basalt, Keratophy, diabase, gabbro, and ultramafic rocks. The principal structural contact separating the Great Valley sequence and its basal ophiolite from the Franciscan assemblage is the Coast Range Thrust (Bailey and others, 1964).

Within the study area, the Great Valley Sequence underlies the major part of the foothills region east of the main Diablo Range (Figure 9) and exceeds 9,000 meters in stratigraphic thickness (Briggs 1953). It ranges in age from upper Jurrassic or lower Cretaceous to upper Cretaceous or Paleocene (Briggs 1953, Page 1981). Anderson and Pack (1915) originally subdivided these deposits into the Panoche Formation, consisting of sandstone, sandy shale, and coarse conglomerate, overlain by the Moreno Shale onsisting of shale, sandy shale and less sandstone. Rapid lateral facies changes and numerous unconformities are common throughout the Sequence (Bennison 1962, Payne 1951, Dibblee and Nilsen, 1979) precluding further formational subdivision in the east central foothills of the Diablo Range.

Tertiary Marine and Nonmarine Deposits

Comparatively thin bedded Tertiary formations overlie the thick-bedded Great Valley Sequence and are exposed in a discontinuous narrow fringe along the eastern edge of the foothills (Anderson and Pack, 1915). These sediments and their distribution are summarized in Table 4. Principal exposures in the study area include a 5 to 15 km wide belt north of San Luis Creek, between Quinto and Orestimba Creeks, and a 2 km wide fringe along the front of the Laguna Seca Hills south of San Luis Creek.

North of San Luis Creek

North of San Luis Creek, the Tertiary rocks conformably overlie the Cretaceous Moreno Shale and are best exposed in the vicinity of Orestimba Creek. These rocks include the Paleocene(?) and lower Eocene Tesla Formation (Huey, 1948); the middle Eocene Domengine Sandstone (Anderson and Pack, 1915); the middle and upper Eocene Kreyenhagen Shale (Anderson and Pack, 1915); the upper Eocene and lower Oligocene(?) sandstone of Poverty Flat (U. S. Bureau of Reclamation, California Aqueduct study, 1964, unpublished data); the upper Oligocene(?) and lower Miocene Valley Springs Formation; and the Miocene and early Pliocene(?) Carbona Formation of Pelletier (1951). The general lithology, age and distribution of these Formations are summarized in Table 4. Additional information on the lithology, age and distribution of the sandstone of Poverty Flat, Valley Springs Formation and Carbona Formation has been obtained during this study and is presented here. The Tertiary rocks of the Laguna Seca Hills south of San Luis Reservoir are summarized following discussion of the Carbona Formation.

Sandstone of Poverty Flat

The sandstone of Poverty Flat consists principally of quartzose sandstone interbedded with kaolinitic clay and minor breccia and conglomerate. The unit grades downward over a zone of 2 to 5 m into interbedded diatomite, diatomaceous shale and sandstone of the Kreyenhagen Shale and is overlain by tuffaceous sandstone of the Valley Springs Formation. These stratigraphic relations and the lithology of the unit are well exposed in California Aqueduct exposures in secs. 20, 29, and 32 T7S, R8E, Newman 7.5-minute Quadrangle (Plate 2; Figure 10, between localities 36 and 39).

Clasts in the breccia and conglomerate are largely red radiolarian chert and deeply weathered sandstone and schist probably derived from the Franciscan assemblage. Angular fragments of unweathered Kreyenhagen diatomite are also locally abundant in the breccia and as isolated clasts in the sandstone suggesting that some erosion of the Kreyenhagen preceeded or accompanied deposition of the unit.

Pelecypod and plant impressions are abundant near the basal gradational contact (Figure 10, locality 36) 3 to 6 m stratigraphically above the highest laminated diatomite of the Kreyenhagen Formation. The pelecypods include Delectopecten lillisi (Hertlein), Tellina(?) sp., Pachecoa(?) sp. and Acila (Truncacila) which indicate a late Eocene to early Oligocene(?), shallow marine depositional environment (Ellen Moore, written communication, 1981). The associated plant impressions also suggest near-shore shallow marine or possibly estuarine, lagoon or swamp conditions. The laminated diatomite of the Kreyenhagen Shale, however, indicates deposition in quiet, marine water, probably within the oxygen-minimum zone where burrowing organisms cannot survive. The late Eocene oxygen-minimum zone probably ranged in depth, conservatively, from 200 to 1000 m (James Ingle, personal communication, 1981). The gradation from laminated diatomite to shallow marine sandstone, therefore, implies shallowing of the Kreyenhagen sea. The sandstone of Poverty Flat is thus interpreted to be a near-shore, shallow marine, possibly estuarine and fluvial deposit accumulating along the margin of the retreating Kreyenhagen Sea.

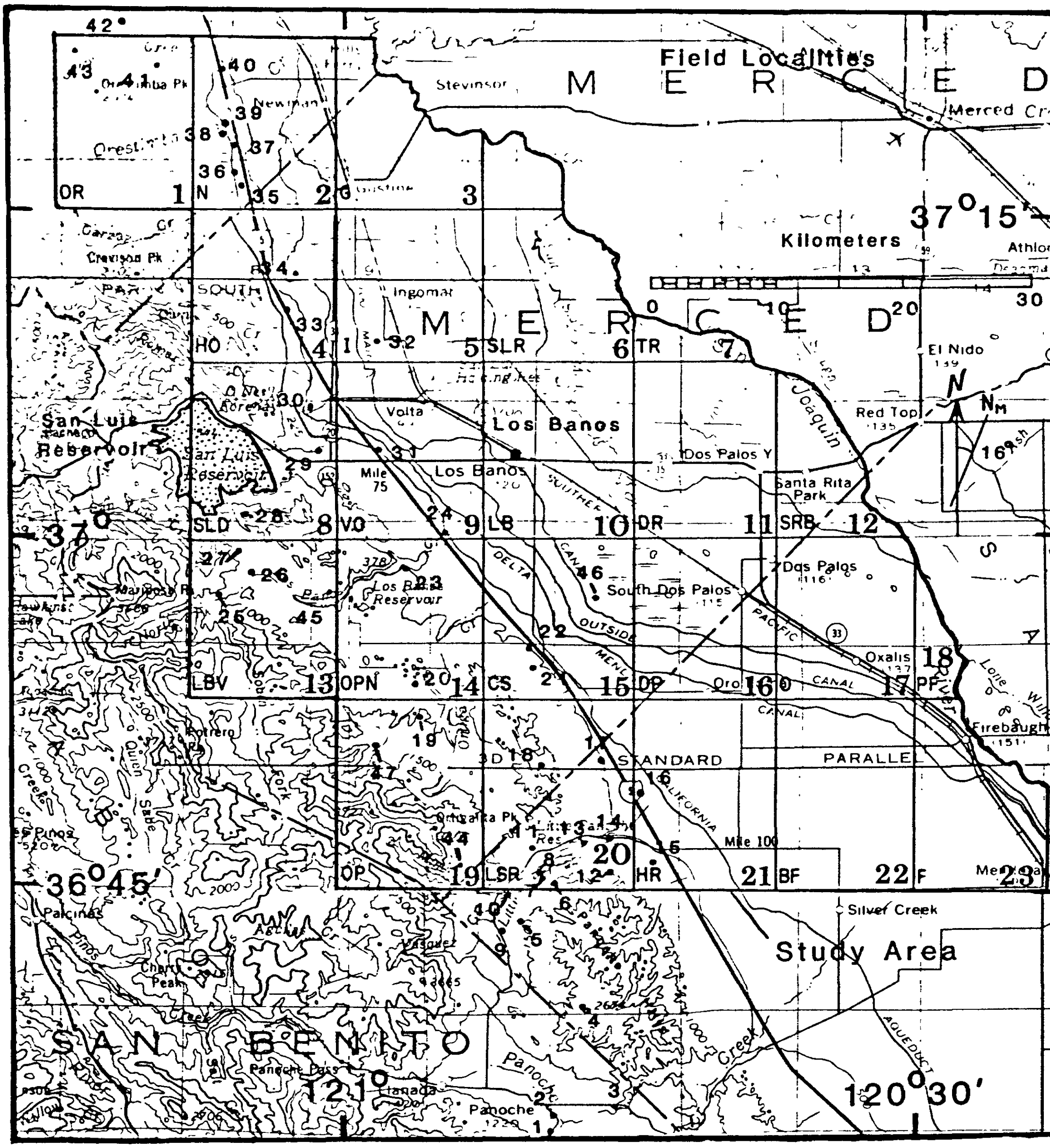

Figure 10: Field localities in the west-central San Joaquin Valley and bordering foothills of the Diablo Range referred to in text. Specific localities are listed in Table 5 using coordinate system described in Figure 1. Abbreviations of 7.5-minute quadrangles are shown. Refer to Figure 5 for list of quadrangle names.

Table 5. Location of localities shown on Figure 10.

1. NE 1/4, SW 1/4, Sec. 31, T15S, R11E, Panoche Valley 7.5-minute Quadrangle.
2. SW 1/4, SW 1/4, Sec. 30, T15S, R11E, Panoche Valley 7.5-minute Quadrangle.
3. SW 1/4, Sec. 27, T15S, R11E, Panoche Valley 7.5-minute Quadrangle.
4. Secs. 18, 20, 21, T14S, R11E, Mercey Hot Springs 7.5-minute Quadrangle.
5. NW 1/4, Sec. 11, T14S, R10E, Mercey Hot Springs 7.5-minute Quadrangle.
6. Sw 1/4, Sec. 31, T13S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 1.
7. NE 1/4, SE 1/4, Sec. 36, T13S, R10E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 1.
8. NW 1/4, SE 1/4, Sec. 36. T13S, R10E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 1.
9. SW 1/4, SW 1/4, Sec. 11, T14S, R10E, Mercey Hot Springs 7.5-minute Quadrangle.
10. SW 1/4, Sec. 35, T13S, R10E, Mercey Hot Springs 7.5-minute Quadrangle.
11. Secs. 24, 25, T13S, R10E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.
12. Secs. 27, 28, 33, 34, T13S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.
13. NE 1/4, SW 1/4, Sec. 20, T13S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.
14. Secs. 20, 21, T13S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.
15. Secs. 25, 26, 35, 36, T13S, R11E, Hammonds Ranch 7.5-minute Quadrangle, Plate 21.
16. SE 1/4, SW 1/4, Sec. 11, T13S, R11E, Hammonds Ranch 7.5-minute Quadrangle, Plate 21.
17. SE 1/4, SE 1/4, Sec. 29, T12S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.

Table 5: Continued.

18. Sec. 36, T12S, R10E, Secs. 31, 32, T12S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20.

19. Secs. 35, 36, T12S, R9E, Ortigalita Peak 7.5-minute Quadrangle, Plate 19.

20. Sec. 13, T12S, R9E, Ortigalita Peak NW 7.5-minute Quadrangle, Plate 14.

21. NW 1/4, SE 1/4, Sec. 1, T12S, R10E, Charleston School 7.5-minute Quadrangle, Plate 15.

22. SE 1/4, SE 1/4, Sec. 35, T11S, R10E, Charleston School 7.5-minute Quadrangle, Plate 15.

23. Secs. 13, 14, 24, T11S, R9E, Ortigalita Peak NW 7.5-minute Quadrangle, Plate 14.

24. SE 1/4, Sec. 6, T11S, R10E, Volta 7.5-minute Quadrangle, Plate 9.

25. T11S, R8E, Los Banos Valley 7.5-minute Quadrangle, Plate 13.

26. Secs. 14, 15, T11S, R8E, Los Banos Valley 7.5-minute Quadrangle, Plate 13.

27. Sec. 10, T11S, R8E, Los Banos Valley 7.5-minute Quadrangle, Plate 13.

28. Secs. 33, 34, T10S, R8E, San Luis Dam 7.5-minute Quadrangle, Plate 8.

29. N 1/2, Sec. 18, T10S, R9E, San Luis Dam 7.5-minute Quadrangle, Plate 8.

30. NE 1/4, Sec. 1, T10S, R8E, San Luis Dam 7.5-minute Quadrangle, Plate 8.

31. Secs. 23, 25, 36, T10S, R9E, Volta 7.5-minute Quadrangle, Plate 9.

32. Sec. 15, T9S, R9E, Ingomar 7.5-minute Quadrangle, Plate 5.

33. Secs. 2, 11, T9S, R8E, Howard Ranch 7.5-minute Quadrangle, Plate 4.

34. Secs. 25, 26, 35, 36, T9S, R8E, Howard Ranch 7.5-minute Quadrangle, Plate 4.

35. Secs. 4, 9, T8S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

36. NE 1/4, SE 1/4, Sec. 32, T7S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

Table 5: Continued.

37. Ne 1/4, SE 1/4, Sec. 20, T7S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

38. SE 1/4, SW 1/4, Sec. 20, T7S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

39. NE 1/4, SW 1/4, Sec. 20, T7S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

40. Secs. 5, 8, 18, T7S, R8E, Newman 7.5-minute Quadrangle, Plate 2.

41. SE 1/4, Sec. 1, T7S, R7E, Orestimba Peak 7.5-minute Quadrangle, Plate 1.

42. SW 1/4, SE 1/4, SE 1/4, Sec. 26, T6S, R7E, Patterson 7.5-minute Quadrangle.

43. Sec. 27, T12S, R9E, Orestimba Peak 7.5-minute Quadrangle, Plate 1.

44. SE 1/4, Sec. 29, T13S, R10E, Ortigalita Peak 7.5-minute Quadrangle, Plate 19.

45. Sec. 20, T11S, R9E, Los Banos Valley 7.5-minute Quadrangle, Plate 13.

46. Secs. 21, 28, T11S, R11E, Charleston School 7.5-minute Quadrangle, Plate 15.

47. Secs. 27, 34, T12S, R9E, Ortigalita Peak 7.5-minute Quadrangle, Plate 19.

Shallowing of such a sea could have resulted from progressive sedimentary infilling of the marine basin, a climatically or tectonically induced eustatic sea level change, or tectonic uplift of the Eocene continental shelf and slope. Progressive filling of a marine basin is not likely in view of the rapid gradation from diatomite to sandstone. The absence of an angular unconformity at or near the contact suggests that local tectonism in the foothill region did not have a significant impact. The marine withdrawl, therefore, may reflect either regional uplift or global sea-level lowering.

Evidence of weathering is common within and on the upper surface of the sandstone of Poverty Flat. A zone of clay-cemented sandstone, approximately 2 to 4 m thick, containing irregular nodules of iron-oxide 3 to 10 cm across, is present 3 to 6 m below the top of the unit and is well exposed on the easterm wall of the California Aqueduct (Figure 10, locality 39, Plate 2). A resistant zone of indurated, hematite-cemented breccia and conglomerate, 2 to 6 m thick, is also present at or near the top of the sandstone of Poverty Flat immediately north of the study area (Figure 10, locality 42).

The sandstone of Poverty Flat is similar in age, lithology, depositional environment and weathering character to the kaolinitic, quartzose sandstone, shale and conglomerate of the Eocene Ione Formation exposed in the foothills of the Sierra Nevada as described by Allen (1929) (J. A. Bartow, personal communication, 1981). The Ione Formation is interpreted as a fluvial, estuarine and shallow-marine deposit derived largely from the Sierra Nevada (Ely and others, 1977, Chapman and others, 1975) and contains several lateritic weathered horizons formed during one or more Tertiary tropical climates (Ely and others, 1977, Singer and Nkedi-Kizza, 1980). The similarity of the Ione Formation and sandstone of Poverty Flat suggests that both units may in part have been deposited along the margin of the Kreyenhagen Sea and that the Ione alluvial plain may have extended across the central San Joaquin Valley in the vicinity of Orestimba Creek. The lenses of predominantly Franciscan derived conglomerate and breccia, however, indicate that portions of the Diablo Range were an eroding highland as early as late Eocene time, and that fluvial deposits derived from this highland locally interfingered with the Ione Formation along the western edge of the alluvial plain.

Valley Springs Formation

The Valley Springs Formation (Piper and others, 1939) in the Orestimba Creek area consists mainly of rhyolitic tuffaceous sandstone, siltstone, and claystone. Less common small lenses of conglomerate, 0.2 to 1 m thick, are also present. Conglomerate clasts are largely well-rounded, radiolarian red chert derived from the Franciscan assemblage, and less common subangular diatomite and sandstone derived from the Kreyenhagen and possibly sandstone of Poverty Flat. These lithologies are well-exposed in Interstate-5 roadcuts (secs 20 and 28, T7S, R8E, Newman 7.5-minute Quadrangle), hillslopes (SW 1/4, sec 6, T7S, R8E) and, north of the study area, along Kern Canyon (SE 1/4, sec 12, T5S, R6E, Solyo 7.5-minute Quadrangle).

The Valley Springs Formation overlies the sandstone of Poverty Flat and is typically overlain by conglomerate and sandstone of the Carbona Formation, although commonly the Carbona is absent or overlain by quaternary alluvium and the unit commonly forms the uppermost portion of the exposed Tertiary section. Local angular discordance of 1^{o} to 4^{o} and relief of 0 to 5 m on the basal contact, combined with the presence of Kreyenhagen and Poverty Flat detritus in the lower section and local deep weathering of the Poverty Flat surface, suggest a probable hiatus and period of erosion separating deposition of the sandstone of Poverty Flat and of the Valley Springs Formation.

Tuffaceous samples from the Valley Springs Formation south of Orestimba Creek (Interstate-5 roadcut Figure 10, locality 37) were analyzed chemically and found to have similar relative proportions of many minor and trace elements with tuffs in the Valley Springs Formation exposed in the western Sierra Nevada (Andrei Sarna-Wojcicki, personal communication, 1981). The similarity of these tuffs suggests a common source terrain for the Valley Springs Formation in the Orestimba Creek area and foothills of the Sierra Nevada. The Valley Springs alluvial-plain flanking the west-central Sierra Nevada (Piper and others, 1939) probably extended across the central San Joaquin Valley and, at least partially, covered the present east-central foothills of the Diablo Range. The Sierra Nevada tuffs yield K/Ar dates ranging from 19.9 to 23.1 my (Dalrymple, 1964) suggesting a probable early Miocene age for the Valley Springs in the Orestimba Creek area.

Carbona Formation of Pelletier, (1951)

The Carbona Formation consists principally of moderately well-bedded, poorly to moderately consolidated gravel, sand, silt and clay. Clasts are dominantly of graywacke with minor red and green, quartz-veined chert, metavolcanics, and serpentinite. These lithologies suggest derivation from the Franciscan and Great Valley rocks of the Diablo Range.

North of Orestimba Creek, these deposits overlie andesitic and tuffaceous sandstone similar in lithology to the Mehrten Formation along the northeast border of the San Joaquin Valley (Piper and others, 1939). Anderson and Pack (1915) originally assigned the clastic rocks of volcanic provenance to the San Pablo Formation and the clastic rocks of Franciscan and Great Valley provenance to the Tulare Formation. Pelletier (1951) later assigned these rocks to the Neroly and Carbona Formations respectively and described a late-Clarendonian-age (10 to 12 m.y.) vertebrate assemblage from the Carbona immediately above the contact. The contact is gradational and is placed at the level where Franciscan detritus exceeds 50% of the total (Raymond, 1969).

On the Tracy, Solyo and Westley 7.5-minute Quadrangles, reconnaissance mapping suggests that the Carbona grades upward into a fine-grained, sparsely diatomaceous clayey silt. The diatom assemblage in this silt (NE 1/4, SE 1/4, sec 20 T2S, R4E, Tracy 7.5-minute Quadrangle, west bank of Delta Mendota Canal) is shown in Table 7 and suggests that the silt accumulated in a late Miocene or early Pliocene (?), slightly alkaline, deep-water lake (J. P. Bradbury, written communication).

Southward, near Orestimba Creek, the mapped thickness of the underlying andesitic and tuffaceous detritus decreases and the thickness of overlying Carbona Franciscan detritus increases (Sonneman, 1958). Recent mapping by J. A. Bartow (personal communication, 1981) indicates that the Neroly Formation pinches out southward near Orestimba Creek possibly as an onlap against a topographic high capped by the older tuffaceous sandstone of the Valley Springs Formation. In this area, deposits of the Carbona Formation dip 5 to 15° northeast approximately concordant to the underlying Valley Springs.

Local relief on the contact, however, locally exceeds 10 m (Figure 10, locality 41, for example) and suggests that erosion of the Valley Springs, possibly removing a thin veneer of Neroly, preceeded deposition of the Carbona.

The Carbona Formation is exposed in the vicinity of Orestimba Creek where it caps many of the low foothills bordering the San Joaquin Valley. It attains a thickness of as much as 80 m and is particulary extensive and well-exposed around Crow Hill in sec 6, T7S, R8E and sec 1, T7S, R7E Orestimba Peak 7.5-minute Quadrangle (plate 1), and on the low hill (El. 477 ft.) adjacent to Interstate-5 immediately south of Orestimba Creek in sec 20, T7S, R8E, Newman 7.5-minute Quadrangle (Plate 2).

Briggs (1953) and Sonneman (1958) correlate the Carbona Formation with the Franciscan detritus of the Oro Loma Formation in the Laguna Seca Hills based on similar stratigraphic position and lithologic character. These deposits are concealed, however, beneath younger deposits between the Laguna Seca Hills and Orestimba Creek and, although they very likely are correlative, the separate formational names are retained for this study.

South of San Luis Creek

Tertiary rocks south of San Luis Creek are best exposed in deep gullies dissecting the Laguna Seca Hills (Figure 9). These rocks conformably overlie the Moreno Shale of the Great Valley Sequence (Briggs, 1953) and include the Paleocene and lower Eocene(?) Tesla Formation (Huey, 1948); the middle and upper Eocene Kreyenhagen Shale (Anderson, 1905); and the Miocene and lower Pliocene(?) Oro Loma Formation (Briggs, 1953). The general lithology, age and distribution of the Tesla Formation and Kreyenhagen Shale are summarized in Table 4. Additional information on the distribution, lithology and age of the Oro Loma Formation has been obtained during this study and is presented in a separated section below.

The sandstone of Poverty Flat and Valley Springs Formation are absent south of San Luis Creek and a major hiatus representing the uppermost Eocene(?), Oligocene, and lower Miocene separates the Kreyenhagen and Oro Loma Formations in the Laguna Seca Hills. Developed on the surface of the Kreyenhagen during this hiatus is a locally well-preserved, strongly-developed buried soil. The soil, recognized here for the first time, provides information and age constraints on geologic events during the hiatus and a discussion of its distribution, characteristics and climatic and tectonic implications is presented following discussion of the Oro Loma Formation.

ORO LOMA FORMATION

Introduction

Stratigraphically overlying the Kreyenhagen Formation in the Laguna Seca Hills is a thick sequence of well-bedded, moderately consolidated gravel, sand, silt and clay named the Oro Loma Formation by Briggs (1953). These deposits differ from older Tertiary deposits in the hills by being the first largely subaerial accumulation of detritus eroded from the Diablo Range. They are lithologically very similar, however, to younger late Cenozoic deposits, and Anderson and Pack (1915), Hall (1963, 1965), Carpenter (1965), Carpenter and Long (1964), and Long and Carpenter (1965) have presented stratigraphic and lithologic evidence correlating them with the upper Pliocene(?) and Pleistocene Tulare Formation (Anderson, 1905). This section describes the distribution and lithology of the Oro Loma Formation in the west-central San Joaquin Valley and presents additional structural, paleontologic, stratigraphic and pedologic information which supports Briggs' (1953) designation of the Oro Loma Formation as a unit separate from the Tulare. Definitive lithologic criteria separating the Oro Loma deposits from the Tulare and younger deposits, however, have not been established.

Previous Literature

In a reconnaissance study of the western San Joaquin Valley, Anderson and Pack (1915) assigned to the Tulare Formation the continental beds stratigraphically overlying the Kreyenhagen Formation in the Laguna Seca Hills because they comprise the youngest deformed continental deposits in the local area (refer to Tulare definition in the "Tulare Formation " section of this report). Briggs (1953), however, separated these deposits from the Tulare Formation on the basis of stuctural and lithologic criteria: (1) "Oro Loma beds are deformed with the bedrock series while the Tulare strata extensively onlap these units." (Briggs, 1953, p. 48), thus indicating angular discordance between the Oro Loma and what he believed to be younger deposits in the Laguna Seca Hills; and (2) Tulare deposits contain horizons of argillaceous limestone, marl and marly silt "... which have no counterpart in the Oro Loma Formation" (Briggs 1953, p. 48-49). Carpenter and Long (1964), Long and Carpenter (1965) and Carpenter (1965) subsequently correlated a silt horizon in the upper Oro Loma with the Corcoran Clay Member of the Tulare Formation based on stratigraphic data from the subsurface of the San Joaquin Valley. This correlation will be addressed in detail in the "Tulare Formation" section of this report where evidence supporting Briggs' separation of the two units will be presented.

Briggs (1953) further divided the deposits overlying the Kreyenhagen Formation along the front of the Laguna Seca Hills, into the underlying "tuffaceous" San Pablo Formation and overlying "non-tuffaceous" Oro Loma Formation. He suggested an upper Miocene and lower Pliocene age for the San Pablo Formation and lower and middle Pliocene age for the Oro Loma Formation based on similar stratigraphic position and lithologic character of the Miocene and lower-Pliocene "San Pablo Formation" (Anderson and Pack, 1915, p. 95-97) north of Quinto Creek. Dibblee (1975), however, could not observe Briggs' field criteria for their separation and grouped Briggs' San Pablo Formation with the Oro Loma Formation. Tuffaceous beds were also not observed during this study and thus all non-marine sediments stratigraphically overlying the marine Kreyenhagen Formation in the Laguna Seca Hills are included in the Oro Loma Formation.

Distribution

The Oro Loma Formation forms a 250 m wide, 10 Km long northwest-trending belt overlying the Kreyenhagen Formation along the eastern front of the Laguna Seca Hills. The belt extends through the Laguna Seca Ranch, Charleston School and Ortigalita Peak NW 7.5-minute Quadrangle (Plates 14, 15 and 20) and the formation is well-exposed in the many gullies that deeply incise the hill front.

The Oro Loma Formation is folded with the older formations and generally dips 25° to 40° northeast and strikes 40° to 50° northwest. The deposits overlie Kreyenhagen diatomite and shale locally deeply weathered to hematite-stained kaolinite. Local angular discordance of as much as 3 degrees with the Kreyenhagen and relief of 3 to 5 m on the contact between the two formations indicate that an interval of erosion and slight tilting probably preceeded deposition of the Oro Loma. The weathered horizon, angular discordance and erosional relief are evident on the hillslopes in the SE 1/4, Sec 1, T12S, R10E, Charleston School 7.5-minute Quadrangle (Plate 15, see also Figure 10, locality 21) and are described further in the "Tertiary Oxisol" section of this report. Briggs (1953) reports that blocks more than 100 m across, as well as pebbles and chips of Kreyenhagen shale are incorporated in the basal Oro Loma, indicating that the Kreyenhagen was eroded by landslides or mud flows and by streams depositing the Oro Loma.

North and south of the Laguna Seca Hills, the formation is overlain by a cover of younger flat-lying beds of coarse sand and gravel. Exposures of the Oro Loma through the surficial cover in these areas are afforded by several deep gullies and quarries (Figure 10, locality 17 for example).

Lithology

The Oro Loma Formation consists entirely of weakly to moderately consolidated gravel, sand, silt and clay. Gravel and sand are predominant commonly forming over 80 percent of an exposure. In general, the proportion of gravel and sand to silt and clay, and the average clast size, increases toward the top of the Formation. Only a 25-m-thick, clayey-silt horizon near the top of the section, interrupts this progression.

Briggs (1915) suggested but did not describe a type section along Oro Loma Creek (SE 1/4 sec 1, T12S, R10E, Charleston School 7.5-minute Quadrangle, Plate 15). Instead he described a section along Rattlesnake Creek approximately 3 Km to the northwest (Briggs 1953, p. 47). Both of these sections are presently very poorly exposed and do not include the upper 30 to 40 m of the formation.

A reference section is therefore described along a small unnamed ravine deeply incised into the Laguna Seca Hills (Table 6). The ravine provides excellent exposures of the entire section and is located in the SE 1/4, sec 35, T11S, R10E, Charleston School 7.5-minute Quadrangle (Figure 10, locality 22) a short 0.5 Km walk southwest from the Mercy Springs Road intersection with Interstate-5.

Table 6: Reference section of the Oro Loma Formation along a small unnamed ravine incised into the Laguna Seca Hills (SE 1/4, SE 1/4, Sec. 35, T11S, R10E; Figure 10, locality 22).

UNIT	LITHOLOGY	THICKNESS (meters)
1	well-bedded, poorly consolidated silt (30 to 40%), fine to coarse sand (20 to 40%) and gravel (10 to 30%). Increasing sand and silt down section. Beds typically 1 to 3 m thick; gravel beds commonly have channeled lower contact, although channels rarely exceed 1 m depth. Silt and sand generally moderately to well sorted, gravel poorly to moderately sorted. Gravel clasts average 1 to 2 cm diameter, up to 8 cm, subangular to subrounded, composed principally of quartzite-veined red chert and graywacke, with less greenstone, gabbro, serpentinite, green and black chert, and volcanic porphyries. Unit is moderately weathered, typically light brown (10YR 5/6).	15
2	Principally moderately consolidated clayey siltstone with increasing fine-sand down section. Siltstone fractures conchoidally and is strongly fissle with long-axis oriented subparallel to bedding. Bedding generally indistinct except in lower 5 m where intercalcated beds of silt and fine-sand, 0.2 to 0.8m thick, are present. X-ray determination of mineralogy provided in Table 7. Silt consists largely of quartz, sodic-plagioclase and less mica, calcic-plagioclase and potash feldspar. Clay is largely montmorillinite (52-56%), kaolinite (8 to 11%) and illite (12 to 15%). Silt is principally light to dark-greenish-gray (5GY 4/2). Upper Miocene to lower Pliocene(?) diatom assemblage present. Abundant, unidentifiable bone fragments of fish are present in the fine-sand. Concordant lower contact with coarse cobble gravel.	21
3	well-bedded, poorly to moderately consolidated gravel (60 to 85%) and medium to coarse sand (15 to 45%). Beds typically 1 to 3 m thick, gravel beds commonly have channeled lower contact. Gravel and sand moderately to well-sorted. Gravel clasts are subangular to well-rounded and are weakly to strongly imbricated. They average 2 to 4 cm diameter, up to 12 cm maximum diameter and consist of lithologies similar to unit 1. Sand beds commonly exhibit faint, low-angle cross-stratification. Sand grains moderately to well rounded, principally lithic fragments (50 to 70%) of similar lithology as clasts, quartz and quartzite (20 to 30%) and feldspar (10 to 20%). Unit contains numerous argillic soil horizons averaging 0.5 to 1 m thick. Soils typically yellowish brown to reddish brown (5YR 5/8) and have excellent clay-skins around clasts and peds. These horizons are typically indurated and form resistant outcrops.	31
4	Poorly bedded, poorly consolidated gravel (30 to 50%), sand (40 to 60%) and silt and clay (5 to 10%). Abundance of sand, silt and clay increases down section. Unit is similar in lithology and sedimentary structures as unit 3, but differs from unit 3 in the absence of strong pedogenic horizons. Deposits are moderately weathered and light brown (10YR 5/6 to 7.5YR 5/6). Silt and clay are generally light gray to dark greenish gray (5GY 4/2).	68
5	Moderately bedded, moderately consolidated gravel (40 to 60%) and sand (40 to 60%). Lithology and sedimentary structures similar to units 3 and 4, but differs from them by containing numerous calcic soil horizons averaging 0.3 to 0.6 m thick. Carbonate typically fills pores and commonly attains a laminar, stage IV structure. Soils are poorly to moderately oxidized (10YR 4/2 to 7.5YR 5/6) although carbonate may mask oxidation. The calcic horizons are strongly indurated and form resistant exposures.	78
6	Poorly bedded, very poorly consolidated, sand (60 to 95%), gravel (5 to 30%) and silt (5 to 10%). Similar lithology and sedimentary structures as units above except clasts are composed principally of graywacke and less common diatomaceous shale. Red chert, greenstone and volcanic clasts are not common. Pedogenic horizons are not evident. Lower 3 m is grayish green (5GY 5/2) silt.	49
	Contact with highly fractured and weathered diatomaceous shale of the Kreyenhagen Formation. Presence of diatomaceous shale clasts in lower Oro Loma and local relief of 1 to 5 m on the contact suggests it is an erosional surface.	

The gravel, sand, silt and clay are moderately to well-bedded. The beds range in thickness from 5 cm to more than 3 m and average 1 to 1.5 m. Beds of gravel and coarse sand are typically thicker, more lenticular and more indurated than the beds of fine and medium sand, silt and clay. Consequently they are generally better exposed than the less consolidated finer sand, silt and clay which tend to be concealed. The beds of gravel and coarse sand generally have channeled bases. Depth of channeling rarely exceeds 0.4 m, however, and thus rarely truncates more than one underlying bed.

The coarse sand and gravel are generally poorly to moderately sorted and clast supported. Clasts are subangular to subrounded with low sphericity. They typically range in size from 0.5 to 20 cm and average 3 to 5 cm; although less common boulders up to 40 cm are also present. They are commonly crudely imbricated suggesting deposition by flowing water. The fine sand, silt and clay are moderately to well-sorted, commonly thinly laminated, and less commonly crudely cross-stratified.

Clast lithologies include a mixture of rock types derived entirely from the Diablo Range. Red and green, radiolarian chert, meta-graywacke and graywacke are predominant. Less abundant black chert, gabbro glaucophane schist, actinolite schist, quartz, volcanic porphyries and metavolcanics are also present. These clasts were derived largely from the Franciscan assemblage in the central Diablo Range which, therefore, probably had structural as well as topographic relief during deposition of the Oro Loma Formation.

Clayey-silt Member

Near the top of the formation a 20- to 25-m-thick horizon of clayey-silt is present. The horizon is present for a lateral distance of over 5 km along the front of the Laguna Seca Hills south of Rattlesnake Creek. It is easily eroded, however, and is generally concealed beneath a cover of colluvium. Present exposures are confined, therefore, to the deeply incised gullies draining the front of the hills in sec 1, T12S, R10E and sec 35, T11S, R10E; Charleston School 7.5-minute Quadrangle (Plate 15). The silt is also well-exposed in the artificial cut behind the Mobil gas station in the SE 1/4, SE 1/4, sec 35 T11S, R10E. Carpenter and Long (1964), Long and Carpenter (1965) and Carpenter (1965) correlated this silt with the Corcoran Clay Member of the Tulare Formation in the subsurface of the San Joaquin Valley, a correlation discussed in detail in the "Tulare Formation" section of this paper.

The clayey-silt is principally light greenish-gray (5GY 4/2 dry), homogeneous and massive. X-ray diffraction analysis indicates the silt faction is principally quartz, sodic plagioclase and potash-feldspar, and the clay is principally montmorillonite with lesser amount of illite and kaolinite, similar to the Corcoran Clay Member of the Tulare Formation (Table 7). Beds of well-sorted, fine quartz sand 0.2 to 0.5 m thick, are intercalated with the silt near the base and contain common unidentified remains of fish.

The clayey silt is sparsely diatomaceous. The diatom assemblage (Table 8) indicates a late Miocene or early Pliocene(?) age for the horizon, and the distribution of modern related species suggests deposition in a relatively

Table 7: X-ray diffraction determination of clay composition for the Oro Loma clayey silt unit and the Corcoran Clay. Sample runs subsequent to: (1) Air drying; (2) Glycolated 70 minutes; (3) Heated at 400°C 70 minutes; (4) Heated at 550°C 60 minutes.

	Type Corcoran Clay (USBR Core Hole 15/14 -15E, Frink and Kues, 1954)	Oro Loma Lacustrine Clay (SE 1/4 SE 1/4 Sec. 35, T11S, R10E)	O'Neill Forebay Corcoran Clay (SE 1/4 NW 1/4 Sec. 18, T10S, R9E) this study
Montmorillinite	30-40% (Beidellite variety)	52-65%	27%
Kaolinite	3-5%	8-11%	10%
Chlorite	2-4%	2-3%	1%
Illite	0%	12-15%	20%
Diatoms	10-15%	0.2%	0%
Quartz, Plagioclase, and mica	24-28%	Present but Undetermined	Present but Undetermined
mixed-layer (principally Illite-montmorillnite)	4-9%(?)	19-22%	42

Table 8: Diatom species recognized from the Oro Loma Formation (upper lacustrine clay, reference section described in text, SE 1/4, Sec. 25, T11S, R10E); and the Carbona Formation (upper lacustrine clay, NE 1/4, SE 1/4, Sec. 20, T2S, R4E, Delta Mendota Canal exposure). Identified by J. Plat Bradbury, of the U.S. Geological Survey, Denver, Colorado.

ORO LOMA FORMATION	CARBONA FORMATION
Cymbella sp.	Coscinociscus sp. (fragments)
Diatoma sp. (?)	Cyclotella Compta
Fragilaria pinnata or lepto stauron	Cymbella mexicana
Gomphonema sp.	Gomphonema grovei
cf. G leifum	Melosira sp.
cf. G. grovei	cf. M. agassizii
cf. G. lingulatum	cf. M. canadensis
cf. G. yatukaensis	cf. M. distans (?)
Melosira sp.	cf. M. paucistriata
cf. M. canadensis	cf. M. praeislandica
cf. M. jouseana	Pinnularia sp.
cf. M. praeislandica	aff. P. Major
	Stephanodiscus sp.
Tetacyclus sp. (?)	S. Astraea
	Aff. S. excentricus

deep, slightly alkaline, warm-water lake (J. Platt Bradbury, written communication, 1981)

Weathering

Numerous buried soils are present in the formation and, with the exception of the clayey-silt unit, the entire sequence is weakly to moderately oxidized. 'Average colors for the deposits range from yellowish-brown (10YR 5/4) to dark brown (7.5YR 4/4). The buried soils include calcic aridisols in the lower part of the formation and argillic ultisols in the upper part (Table 6). The aridisols commonly have tightly cemented petrocalcic horizons with Stage III to IV (Gile et al, 1966) carbonate and are commonly more than 0.5 m thick. The ultisols have argillic horizons as much as 1.5 m thick, with commonly a coarse, angular blocky and prismatic structure and thick continuous clay coatings on clasts and ped faces. The buried soils are typically stripped or truncated by overlying deposits, however, and complete profiles have not been preserved. Each of these soils, therefore, represents a relatively mature development, probably requiring at least several tens of thousands of years to form. The change in soil character implies a probable change in climate from semiarid or arid conditions to more humid, temperate conditions during the time encompassed by deposition of the formation.

Age and Correlation

Age of the Oro Loma Formation is poorly constrained but is probably Miocene to early Pliocene(?) based on the available paleontologic, stratigraphic and structural information. The diatom assemblage in the upper clayey-silt unit in the Laguna Seca Hills suggests a late Miocene or early Pliocene(?) age (J. Platt Bradbury, written communication, 1981) for the uppermost Oro Loma.

Structural evidence, however, suggests that the Oro Loma Formation is older than the Miocene Quien Sabe Volcanics. In the Laguna Seca Hills, the Oro Loma Formation is deformed concordantly with the underlying Cretaceous and Tertiary bedrock. Unconformably overlying the deformed bedrock, are relatively undeformed, flat-lying, basalt outliers of the Quien Sabe Volcanic Group (Figure 10, locality 28). A K/Ar whole rock date on basalt from the base of the outlier is 9.35 $\pm$ 0.1 my old (Garniss Curtis, personal communication, 1981)[1]. The main Quien Sabe Volcanic field west of the study area yields K/Ar dates ranging from 7.5 to 10 my old (Snyder and Dickenson, 1979) indicating that the outlier is coeval with the Quien Sabe Volcanics. The volcanics lie on a gently warped erosion surface cut across the deformed Franciscan assemblage and Great Valley sequence bedrock. Furthermore, clasts in the Oro Loma do not contain fresh, unaltered volcanic lithologies of the Quien Sabe volcanics. These dates, structural and lithologic evidence suggest that deposition of the Oro Loma Formation and subsequent deformation of the foothill belt preceeded Quien Sabe Volcanic activity approximately 9 million years ago.

[1]sample KA-2345; collected by Ross Wagner, 1970;, analysis made by Garniss Curtis, University of California, Berkeley, 1970; recalculated with current IUGS constants by Robert Drake, U.C. Berkeley, 1981; per cent potassium 0.992$\pm$ 0.8, $^{40}Ar^{*}$ 1.61 x 10^{-11} moles/gram, per cent radiogenic argon 44.

The lower age limit of the Oro Loma Formation is very poorly constrained. In the Laguna Seca Hills, the formation overlies the upper Eocene Kreyenhagen Formation. Developed on the Kreyenhagen is a strong buried soil which may have formed during an interval of humid possibly tropical weathering in the late Oligocene (refer to "Tertiary Oxisol" section of this report). The lower age is thus clearly post late Eocene and probably post late Oligocene.

Based on similar stratigraphic position, lithologic character and approximate age, Briggs (1953) and Sonneman (1958) have correlated the Oro Loma Formation with the Carbona Formation north of Orestimba Creek. Pelletier (1951) described a late Clarendonian age (10 to 12 m.y.) vertebrate assemblage from near the base of this formation near Tracy, California. In the Orestimba Creek area, the Carbona rests on the Valley Springs Formation containing Volcanic ash chemically similar to volcanic ash in the eastern San Joaquin Valley dated by Dalrymple (1964) as 19.9 to 23.1 my old. In the Tracy, Solyo, Midway, and Westley 7.5-minute Quadrangles, the upper Carbona progressively becomes a fine-grained, clayey-silt containing a late Miocene or early Pliocene(?) diatom assemblage. (J. P. Bradbury, written communication, 1981).

These data indicate that the Oro Loma Formation may have accumulated during the Miocene and possibly early Pliocene, from about 20 to 5 million years ago. Structural evidence suggests that deposition probably terminated by 9 or 10 million years ago. The numerous buried soils in the unit indicate that although deposition may have encompassed this time interval actual deposition was probably intermittent and was separated by long periods of non-deposition, surface stability and soil development.

South of the study area, equivalent to the Oro Loma Formation may be the unnamed non-marine Tertiary deposits overlying the Kreyenhagen Formation in the Vallecitos area (Dibblee, 1975). Farthur south near Domengine Ranch (T18S, R15E, Domengine Ranch 7.5-minute Quadrangle), these non-marine deposits grade laterally into Miocene and possibly Pliocene marine deposits including the Santa Margarita, Jacalitos and Etchegoin Formations. In these areas, the continental deposits coeval with the Oro Loma Formation may represent a deltaic deposit restricting the northward extension of the late Miocene and Pliocene marine embayment.

Correlations of the Oro Loma Formation with the late Pliocene(?) and Pleistocene Tulare Formation (Anderson, 1905) indicated by Anderson and Pack (1915), Hall (1963, 1965), Long and Carpenter (1963) and Carpenter (1963) in the Laguna Seca Hills, is improbable, given the Miocene and early Pliocene (?) age for the Oro Loma. Division of these units into separate Formations by Briggs (1953) and Dibblee (1975) seems preferable.

Origin

The Oro Loma Formation probably accumulated as a complex of alluvial fans flanking the central Diablo Range. Filled channels, clast imbrication, laminated and cross-stratified bedding, and partial rounding of resistant clasts suggests deposition by flowing water, and the Franciscan-dominated clast lithology suggests derivation from the Central Diablo Range. Because channels rarely cut deeply into underlying beds, deep channel incision probably did not accompany deposition of the alluvial-fans. Lateral continuity of the beds and absence of deep channel incision suggests that the alluvium may have accumulated as rapidly aggrading sheets: coarse-grained deposits may represent migrating constructional lobes of distributary channels on the fan and fine-grained deposits may represent overbank, floodplain alluvium.

The buried soils and weathered horizons indicate prolonged episodes of non-deposition, surface stability and soil development. Lateral continuity of these soils, however, has not been demonstrated and thus the regional extent of deposition and non-deposition is not known.

Deposition of the Oro Loma Formation as an alluvial-fan complex flanking the Diablo Range suggests that the range had considerable topographic, and thus probably structural, relief by Miocene time. The proportionately finer-grained lower section may reflect disagregation and erosion of the less resistant sandstone and shale of the Cretaceous Great Valley Sequence which at one time probably covered the Franciscan core of the Diablo Range. Alternatively the coarsening up-section may reflect progressive uplift of the central Diablo Range from one of low relief, negligible erosion and substantial in situ weathering, to one of high relief, rapid erosion and transport of coarser detritus; or it may reflect the construction of an alluvial plain with sufficient slope necessary to transport coaser detritus.

Deposition of the diatomaceous clayey-silt interrupted the aggradation of alluvial-fan deposits in the late Miocene or early Pliocene(?). The diatom assemblage indicates that the silt accumulated in a relatively deep water, slightly alkaline lake (J. P. Bradbury, written communication, 1981). The thickness and lateral continuity of this unit and the presence of similar lacustrine clayey silts near Tracy suggests that portions of the northwestern San Joaquin Valley had interior drainage during part of the late Miocene or early Pliocene(?). Hence, by late Miocene time, the Diablo Range formed a continuous barrier between the Pacific Ocean and the northern and central San Joaquin Valley. The marine Miocene and Pliocene formations in the Coalinga-Kettleman Hills area (Woodring et al, 1940) however, indicate that a marine embayment extended into the southern San Joaquin Valley throughout this time.

TERTIARY OXISOL

Introduction

The sandstone of Poverty Flat and the Valley Springs Formation are absent in the Laguna Seca Hills, and a major hiatus representing the uppermost Eocene(?), Oligocene, and lower Miocene separates the Kreyenhagen and Oro Loma Formations. Developed on the surface of the Kreyenhagen during this hiatus is a locally well-preserved, strongly-developed buried soil. The soil, heretofore unrecognized as such provides clues to the Tertiary climatic and tectonic history of the west-central San Joaquin Valley as well as to the possible areal distribution of Eocene stratigraphic units in the San Joaquin Valley.

Previous Literature

The Tertiary buried soil was commonly regarded by earlier workers as a depositional unit. Anderson and Pack (1915) and Briggs (1953) assigned the soil to the San Pablo Formation (now Group). Dibblee (1975) included the soil in the Laguna Seca Hills within the basal Oro Loma Formation and Sonneman (1958) included similar weathered horizons in the Orestimba Creek area within the basal Carbona Formation.

Anderson and Pack (1915) probably described a portion of the soil in their description of the basal San Pablo(?) Formation in the Laguna Seca Hills: "One of the most prominent beds in this zone is an indurated greenish clay stained reddish in irregular blotches identical in appearance with the indurated bed near the base of the San Pablo(?) Formation near Orestimba Creek." In both areas, I believe they are referring to the lower horizons of the soil developed on what is here interpreted to be the Kreyenhagen Formation and sandstone of Poverty Flat, respectively.

Distribution

The best preserved and exposed outcrop of the soil is on the north wall of a large gulley draining the front of the Laguna Seca Hills 3 km north of Laguna Seca Creek (Charleston School 7.5-Minute Quadrangle, Plate 15, Figure 10, locality 21), where it is developed on the Kreyenhagen Formation containing marine diatoms of middle and late Eocene age (John Barron, written communication, 1981) and is overlain by the Oro Loma Formation containing freshwater diatoms of late Miocene or early Pliocene(?) age (J. P. Bradbury, written communication, 1981).

Possible poorly-preserved remnants of the soil crop out in isolated exposures in the Laguna Seca Hills and near Orestimba Creek. Near Orestimba Creek, the soil may be correlative with the weathered horizons, discussed earlier, buried within and on the surface of the sandstone of Poverty Flat (Figure 10, localities 39 and 42), which contains pelecypod molds of late Eocene or early Oligocene (?) age (Ellen Moore, written communication, 1981) and is overlain by tuffaceous sandstone correlated with the Valley Springs Formation of early Miocene age. In the Laguna Seca Hills, isolated exposures of the soil occur along the Kreyenhagen-Oro Loma contact (for example SW 1/4, NW 1/4, sec 7, T12S, R11E; and Sw 1/4, sec 1, T12S, R10E, Charleston School 7.5-minute QuadranglePlate 15).

At other exposures of the stratigraphic horizon at which the soil should be present, it may not have developed or, more likely was removed by erosion before deposition of younger formations. In the Laguna Seca Hills, for example, the surface of the soil is everywhere eroded and the soil is truncated laterally by deposits of the Oro Loma Formation. The lower beds of the Oro Loma commonly contain large blocks of Kreyenhagen diatomite more than 100 m across (Briggs, 1953), indicating substantial erosion of the Kreyenhagen which probably removed the soil over many areas.

Description

The thickest section of the soil that has escaped erosion is that 3 km north of Laguna Seca Creek where it is about 15 m thick and consists of two relatively distinct units: (1) an upper, friable silty clay; and (2) a lower, indurated sandy clay. These units dip 35° to 40° northeast parallel to the bedding of underlying and overlying rocks and are exposed laterally for approximatèly 300 m along strike.

The upper silty clay is approximately 3 to 5 m thick and ranges from dark purplish red (5R 3/8 to 5RP 4/2) near the top to dark red and yellowish red (10R 4/8 to 2.5YR 5/8) near the base (Figure 11). The color probably reflects the abundance of iron-oxide, principally hematite, in the zone. Granule and pebble-size iron-oxide concretions are also sparsely present near the upper surface. The zone lacks sedimentary structures, organic matter, carbonate, and strong development of peds. Weak, fine granular structure, however, is common. Little vegetation, other than sparse grass, grows on its well-exposed outcrop, suggesting that it may have been leached of soluble nutrients. Quantitative chemical analyses, however, have not been completed to support this interpretation. The unit has a sharp upper contact with the Oro Loma Formation and is abruptly underlain by the lower indurated, sandy clay. Because of its friable nature, the unit was commonly removed by erosion before deposition of the Oro Loma Formation or was deeply gullied along its exposure and subsequently buried beneath a colluvial cover. Gentle relief of 0-3 m (over a distance of 100 m) on the upper contact, suggests that it was partly eroded prior to deposition of the Oro Loma and that the preserved thickness of the zone is less than that of the original profile.

The lower, indurated sandy clay unit is approximately 8 to 10 m thick and ranges in color from nearly white to greenish-gray (N9 to 5GY 6/1). X-ray diffraction analysis indicates that the clay is dominantly kaolinite (J. A. Bartow, personal communication, 1981). The sand is medium to coarse grained and consists largely of quartz. The quartz sand grains are typically suspended in and cemented by the kaolinite clay. Irregular nodules of iron-oxide, as much as 25 cm across, and extremely resistant to weathering, are randomly distributed through it (Figure 12). Their color ranges from red (10R 4/6) to yellowish-red (5YR 4/6). Rare lenses of bright-red silty-clay, less than 0.5 m thick and similar to the upper red silty-clay unit, are present within the lower unit and are parallel to bedding in the underlying Kreyenhagen Formation. The sandy-clay unit grades downward into unweathered Kreyenhagen diatomite. The unit is generally resistant to erosion and commonly forms bold ridges or ledges (Figure 13). It is probably this horizon which Anderson and Pack (1915) described and which forms isolated exposures in the Laguna Seca Hills and possibly near Orestimba Creek.

The dark red clay and underlying sandy clay are interpretd to be the remnants of a thick Tertiary oxisol. Criteria indicative of the extensive weathering and leaching required for development of an oxic profile include: thickness of the profile, the massive character and general absence of internal bedding or depositional features in both units, the concentration of ferric-oxides, including uniformally disseminated hematite in a clay rich matrix in the upper unit and iron-oxide nodules in the lower unit, absence of organic matter, dearth of sand-size mineral grains except quartz, distribution of the quartz grains in a clay matrix dominated by kaolinite and the lack of

Figure 11: Upper unit of Tertiary oxisol developed on the upper Eocene Kreyenhagen Formation in the Laguna Seca Hills. The upper unit is truncated and overlain by the Miocene Oro Loma Formation. Colors range from dark purplish-red (5RP 4/2) near the top to yellowish-red (2.5YR 5/8) near the base of the upper unit. Vegetation is generally absent from exposures of the soil, suggesting that the soil has been leached of nutrients (Figure 10, locality 21).

Figure 12: Lower unit of the Tertiary oxisol preserved in the Laguna Seca Hills. The unit consists principally of indurated greenish-gray to grayish-white kaolinite. Irregular nodules of iron oxide are extremely resistant to erosion and typically weather out from the surface. The nodules average 10 to 15 cm across with maximum diameters of 25 cm (Figure 10, locality 21).

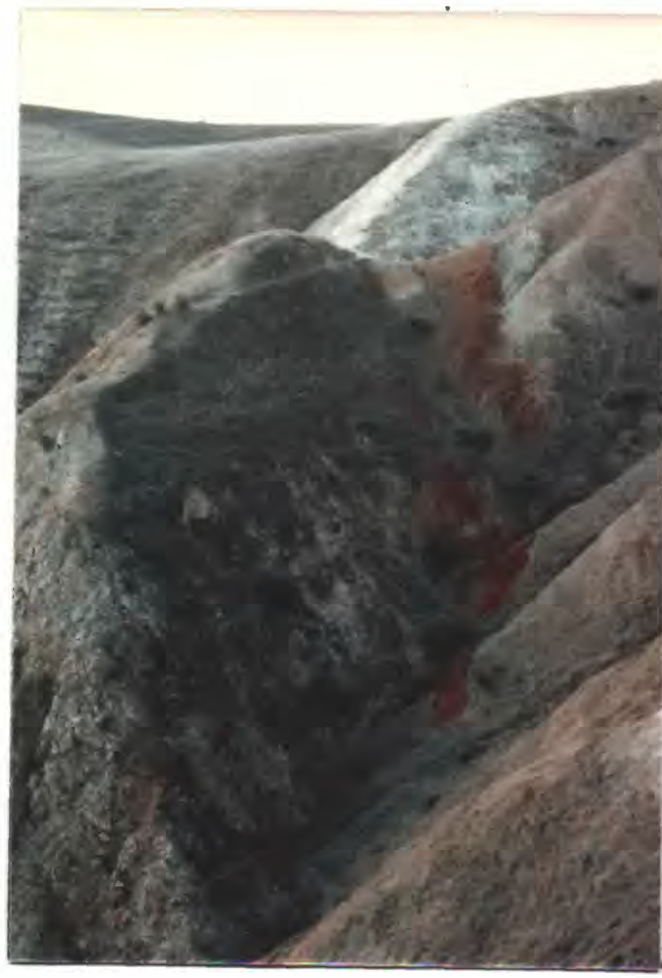

Figure 13: Tertiary oxisol preserved in the Laguna Seca Hills. The soil dips 35° to 40° northeast and strikes 40° to 50° northwest parallel to bedding in the underlying Kreyenhagen Formation and overlying Oro Loma Formation and is preserved laterally along strike over 300 meters. The upper vividly red, iron oxide-rich horizon grades downward into a resistant horizon of kaolinite-cemented fine sand with irregualr nodules of iron oxide. The upper horizon, also shown on Figure 11, is friable and susceptible to deep gulleying (Figure 10, locality 21, view looking northwest).

soluble nutrients as indicated by the sparse vegetation. Based on these criteria, the soil meets the requirements of an oxic horizon as defined by the soil survey staff (Soil Survey Staff, U.S. Department of Agriculture, 1975).

Age

Age of the soil is poorly known and is inferred indirectly from the stratigraphic and paleoclimatic evidence. In the Laguna Seca Hills area the soil is developed on the Kreyenhagen diatomite containing late Eocene diatoms (J. A. Barron, personal communication, 1981) and is overlain by the middle to late Miocene Oro Loma Formation. In the Orestimba Creek area possible remnants of the soil are developed on the late Eocene to lower Oligocene (?) sandstone of Poverty Flat and are overlain by the Valley Springs Formation, which in the foothills of the Sierra Nevada contains volcanic ash beds dated by the K/Ar method as 19.9 to 23.1 m.y. old (Dalrymple, 1964).

Warm periods indicative of the tropical conditions required to produce the soil can be inferred from the paleoclimatic record. Ingle and others (1976) and Savin and others (1975) provide marine paleontologic and oxygen isotope data indicating that warm, probably tropical conditions prevailed in North America during the Paleocene, early to middle Eocene and again during the late Oligocene and middle Miocene. Wolfe (1978) provides paleobotanical evidence supporting a major warm interval during the middle Eocene and less extensive warm intervals during the late Oligocene and middle Miocene. Only the late Oligocene warm period is consistent with the available stratigraphic age limits, thus indicating that the soil probably formed approximately 23 to 28 m.y. ago.

Correlation

In appearance, stratigraphic position, approximate age and degree of development the soil strongly resembles the iron-rich oxisol developed on the Eocene Ione Formation. The Ione oxisol is exposed in isolated outcrops in the eastern San Joaquin Valley and is described by Ely and others (1977) and Singer and Nkedi-Kizza (1980). These studies have discussed the detailed mineralogic and chemical properties of the profile, compared it with modern soils of similar development, and described the regional occurrence of the soil in the eastern San Joaquin Valley. In these areas the Ione soil is typically overlain by the early Miocene Valley Springs Formation. Age of the upper Ione Formation, however, is poorly known. If the Ione is as old as middle Eocene, the soil developed on it many have formed during the middle Eocene warm periods. Consequently, the age of the Ione soil may be greater than that of the soil developed on the Kreyenhagen Formation, hence correlation of these two soils is tenuous.

Climatic Implications

A thick oxic soil-profile dominated by kaolinite as the principal clay mineral strongly suggests intense weathering under warm, humid tropical conditions (Singer and Nkedi-Kizza, 1980). Oxisols are currently developing only near equatorial areas which have around 25° C average annual temperature and more than 50 inches (125 cm) annual precipitation (Abbot and others, 1975, Soil Survey Staff, U.S. Department of Agriculture, 1975). Intense leaching and eluviation is required and pronounced fluctuations between wet and dry seasons enhance their formation. In tropical rain forests bacterial action prevents the accumulation of humus even though considerable vegetation is present (Pettyjohn, 1966).

Singer and Nkedi-Kizza (1980) indicate that a climate similar to the present San Joaquin Valley's will not form an oxisol, even over a long period of time. They suggest that surface water penetration, even under very wet years, would not be of sufficient depth required to produce such a thick weathered oxic horizon. Marchand and Allwardt (1981) have shown that 1 to 2 million year old surfaces in the San Joaquin Valley develop soils with iron and silica hardpans rather than oxic horizons leached of silica. It is suggested, therefore, that the late Oligocene climate of the San Joaquin Valley during development of the soil was similar to that of the hot, humid areas found within 20 to 30° latitude of the modern equator; markedly different from what the Valley has experienced since.

PRE-LATE CENOZOIC STRUCTURE

The Diablo Range is essentially a faulted anticline whose structural development directly reflects the interaction of the Pacific, North American and Farallon Plates during the late Mesozoic and Cenozoic (Page, 1981). Three key elements in the structural evolution of the range include: (1) the accumulation and structural juxtaposition of the Franciscan assemblage and Great Vallèy Sequence; (2) anticlinal deformation of this rock complex, and (3) vertical and lateral displacement of the anticline along high-angle faults. Figure 14 is a diagrammatic cross section of the Diablo Range illustrating the general structure of the range.

(1) In the late Mesozoic and early Cenozoic, subduction of the Farallon Plate beneath the North American Plate produced a trench at the present site of the Diablo Range and a volcanic arc in the Sierra Nevada (Hamilton, 1969 and 1978; Atwater 1970). The age, lithologic character and stratigraphic relations of the Franciscan assemblage and Great Valley Sequence, discussed earlier, suggest that they accumulated in an active trench and a coeval forearc basin, respectively (Hamilton, 1978; Blake and Jones, 1981). These two rock assemblages have been structurally juxtaposed and are everywhere separated by the Coast Range Thrust (Blake and others, 1970) or by younger faults. The thrust may represent the former zone of late Mesozoic subduction or subsequent underthrusting of the Franciscan assemblage below the Great Valley Sequence during the late Mesozoic or early Cenozoic (Page, 1981).

(2)Anticlinal deformation of this thrust complex in the Paleogene has produced the present structural configuration of the Diablo Range. The anticline trends northwest and generally governs the geographic distribution of bedrock lithologies in the range. Deep erosion of the anticline has generally exposed an elliptical core of the Franciscan assemblage, tectonically flanked on nearly all sides by steeply dipping Great Valley Sequence and, locally, younger Tertiary rocks (Anderson and Pack, 1915, Page, 1981). Isolated remnants of the Great Valley Sequence and its basal ophiolite locally overlie the Franciscan assemblage in the central Diablo Range attesting to the original continuity of the Great Valley Sequence thrust sheet over the range (Page, 1981, diagrammatically illustrated on Figure 14). Projection of bedding attitudes in the Great Valley Sequence exposed at the surface in the east-central foothills of the Diablo Range are generally sufficient to clear the crest of the Diablo Range. The present elevation of the range, therefore, can in large part be attributed simply to the anticlinal deformation.

Age and stratigraphic constraints provided by the Oro Loma Formation indicate that the principal episode of anticlinal deformation occurred in the late Miocene. As described earlier, the continental sands and gravels of the Oro Loma Formation probably accumulated on an alluvial apron flanking the central Diablo Range in the Miocene. Bedding in the Oro Loma is subparallel with underlying Eocene rocks indicating that anticlinal deformation did not significantly effect the foothill belt between the late Eocene and late Miocene, although older Tertiary and Cretaceous rocks, are progressively more deformed with age suggesting that the Diablo Range may have been deformed in the earlier Tertiary. Rocks of the Cretaceous Panoche Formation, for example, locally attain attitudes of 80 to 90° in the Wisenor Hills (sec 16, T13S,

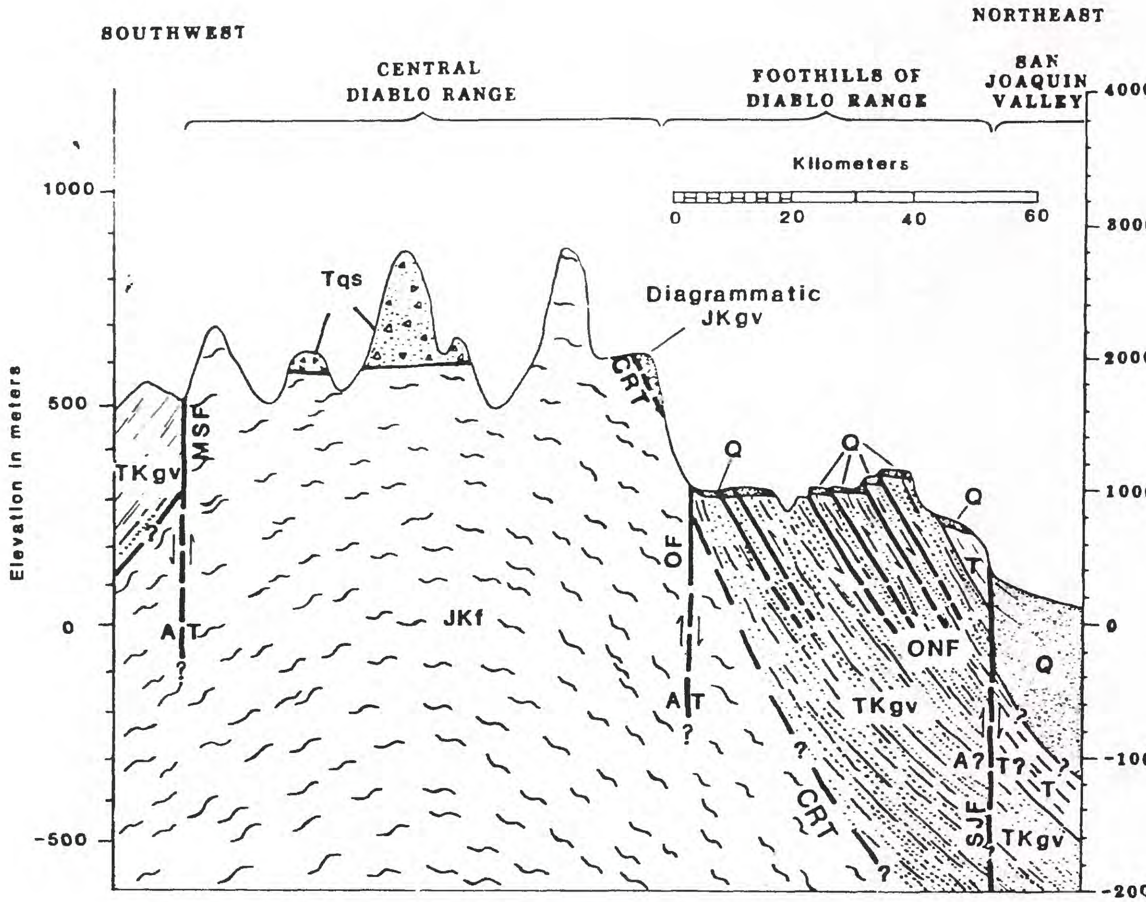

Figure 14: Generalized cross section of the Diablo Range at approximately latitude 36° 50' illustrating the pertinent lithologic and structural features of the central Diablo Range and eastern foothills. Q - Late Cenozoic alluvium; Tqs - Quien Sabe Volcanics; T - undifferentiated Tertiary marine and nonmarine rocks; Jkf - Franciscan assemblage; Tkgr - Great Valley Sequence; JKgr - diagrammatic outlier of the basal ophiolite and lower beds of the Great Valley Sequence; MSF - Madrone Springs and related faults; OF - Ortigalita Fault; ONF - O'Neill Fault System; SJF - San Joaquin Fault System; CRT - Coast Range Thrust.

R10E, Laguna Seca Ranch 7.5-Minute Quadrangle). This pre-late Eocene deformation may have produced the Eocene sandstone of Poverty Flat.

Following deposition of the Oro Loma Formation, deformation tilted the foothill belt up to attitudes of 45°. A minimum age for this deformation is provided by the Quien Sabe Volcanic group. An undeformed, relatively flat-lying outlier of the Quien Sabe Volcanic Group unconformably overlies the tilted bedrock series immediately south of San Luis Reservoir (Figure 10, locality 28). As described earlier, a whole rock potassium-argon date on a basalt flow from the base of this outlier is 9.35± 0.1 m.y. (Garniss Curtis, personal communication, 1981) indicating that deposition of the Oro Loma and post-Oro Loma deformation of the foothill belt probably culminated prior to the late Miocene.

These general age and stratigraphic relations imply that the principal period of anticlinal deformation occurred in the Miocene after deposition of the Oro Loma Formation and prior to eruption of the Quien Sabe Volcanics. The abundance of coarse Franciscan detritus in the Oro Loma and Carbona Formations, however, indicates that the Franciscan assemblage was widely exposed in the central Diablo Range by Miocene time. Widespread erosion of the Franciscan in the Miocene prior to deformation of the Oro Loma Formation adequately explained by the principal period of deformation.

(3)Northwest-trending, high-angle faults have vertically and laterally displaced the limbs of the Diablo Range anticline. These faults include the Ortigalita-Tesla Fault system on the eastern flank, among others. They commonly form the contact between the Franciscan assemblage and Great Valley Sequence (Figure 14) as well as the physiographic contact between the central Diablo Range and bordering foothill provinces (Figure 5). Locally, thousands of meters of basal Great Valley Sequence rocks may be hidden in the down-thrown side of the fault (Briggs, 1953; M. C. Blake personal commun., 1981) and many previous workers have attributed the present relief of the Diablo Range to vertical displacement on these faults during the Pliocene and Pleistocene (Taliaferro, 1948; Briggs, 1953; Page, 1981; among others).

Although the Ortigalita Fault exhibits evidence of Neogene activity, the topographic position and age of the Quien Sabe volcanics suggests that the major episode of vertical displacement culminated prior to the late Miocene. These faults therefore, may have produced the Miocene Diablo Range which provided the Franciscan detrital source for the Oro Loma and Carbona Formations. The main Quien Sabe volcanic field lies west of the Ortigalita Fault in the central Diablo Range and yields potassium-argon dates ranging from 7.5 to 10 m.y. (Snyder and Dickenson, 1979). The Quien Sabe volcanic outlier south of San Luis Reservoir composed of basalt flows from the main Quien Sabe field lies east of the Ortigalita Fault and yields a potassium-argon date of 9.35± 0.1 m.y. (Garniss Curtis, personal communication, 1981). The base of these two volcanic units lies at a similar elevation (about 1600 feet) indicating that any vertical displacement on the Ortigalita fault culminated prior to eruption of the Volcanics in the late Miocene. If post-late Miocene vertical displacement is suggested, restoration of the displacement would place the basalt flows of the outlier at a higher elevation than their probable source. Later Neogene activity is evident however, along these faults and is discussed in the "Late Cenozoic Structure" section of this report.

During the late Miocene and Pliocene, the uplifted and tilted foothill belt was eroded and planed down to a graded condition with the San Joaquin Valley Floor. Parts of the late Miocene Quien Sabe Volcanics, such as the Basalt Hill outlier, were laid down during this time in stream channels graded to the San Joaquin Valley floor. In the Pliocene and Quaternary, the Tulare Formation (Anderson, 1905) and younger deposits, the principal subject of this investigation, were deposited in part on a piedmont alluvial-plain over this erosional surface.

LATE CENOZOIC GEOLOGY

STRATIGRAPHY

Introduction and Depositional Environment

Late Cenozoic deposits in the west-central San Joaquin Valley and adjacent foothills of the Diablo Range consist entirely of weakly consolidated to unconsolidated gravel, sand, silt and minor clay. The deposits range greatly in grain size and texture, suggesting that they may have accumulated in a variety of environments. To facilitate presentation of a late Cenozoic stratigraphy for these deposits, a discussion of depositional environments in the San Joaquin Valley and the geomorphic terms used to describe them is necessary.

Following the terminology of Thornbury (1969, p. 271) and Gile and others (1981, p. 27), the study area is divided into three prinicipal areas of deposition: (1) the basin-floor of the San Joaquin Valley, (2) the piedmont alluvial-plain of the western San Joaquin Valley and (3) the foothills of the Diablo Range (Figure 15). The present distribution of these environments coincides with the distribution of the floodbasin, alluvial-plain and foothills geomorphic provinces discussed earlier on pages 6 through 10. Table 9 briefly describes the principal environmental facies: alluvial fans laid down by fluvial and mudflow processes on the piedmont alluvial-plain; riverine, flood-basin, paludal and lacustrine deposits on the basin floor; stream channel and floodplain deposits on erosional surfaces in the foothills; and locally, eolian deposits on the piedmont alluvial-plain and basin floor.

Piedmont Alluvial-Plain

Late Cenozoic deposits on the piedmont alluvial-plain are interpreted to have accumulated on a complex of coalescing alluvial-fans similar to the fans that line the west side of the valley today (described in detail by Bull 1964a,b). Most deposits exhibit sedimentary structures indicative of deposition from or reworking by flowing water. There structures include poorly to well-defined clast imbrication, channeled contacts, laminated bedding, grain supported matrix and more rarely low-angle cross-stratification. Interfingered with and locally overlying these deposits near the range front are poorly sorted, poorly stratified deposits containing matrix-supported boulders commonly exceeding 0.5 m in long-dimension. These are interpreted as mudflow deposits.

The fluviatile and mudflow deposits consist entirely of detritus shed from the Diablo Range or reworked from older deposits of similar provenance. Clast lithologies include graywacke, metagraywacke, quartz-veined red and green chert, and some glaucophane schist and actinolite schist characteristic of the Franciscan assemblage; graywacke, minor shale, conglomerate and black chert from the Great Valley Sequence; minor greenstone, serpentinite, and gabbro from the Franciscan assemblage or basal ophiolite of the Great Valley Sequence; diatomaceous shale from the Kreyenhagen Shale and locally the Moreno Shale; and, in places, andesite, basalt and some rhyolite from the Quien Sabe Volcanics.

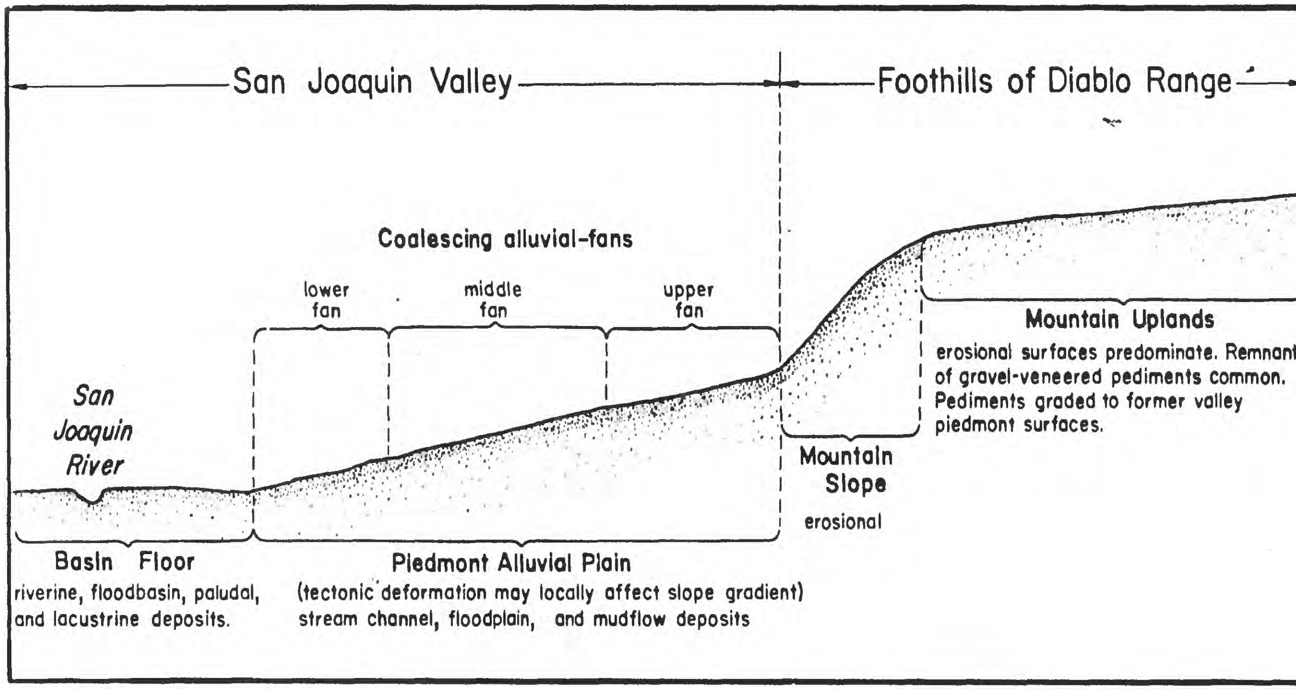

Figure 15: Diagrammatic landform profile of the west-central San Joaquin Valley and foothills of the Diablo Range illustrating landform terminology used in the text. Areas of deposition and erosion are indicated. Deposits characteristic of each landform are described in the text and summarized on Table 8.

DEPOSITIONAL ENVIRONMENT		GRAIN SIZE, SEDIMENTARY STRUCTURES AND GEOMETRY	LITHOLOGY OF CLASTS
Pediment		Moderately to well sorted, poorly bedded, coarse sand and gravel. Shale fragments commonly angular to subangular; All other clasts are typically subangular to well-rounded; Clasts average 4 to 6 cm in diameter, 30 cm maximum diameter, commonly imbricated. Deposits veneer erosional surfaces of of low relief carved over Tertiary and Cretaceous bedrock but commonly attain a thickness of over 10 m in channes cut in underlying bedrock.	Clasts composed principally of graywacke, quartzite-veined red and green radiolarian chert, and less greenstone, gabbro, diatomaceous shale, black chert, glaucophane schist, and actinolite schist Locally andesite, basalt and rhyolite are a major component.
PIEDMONT PLAIN	Upper and Middle Fan	Poorly to well sorted, poorly to well bedded, commonly laminated coarse-sand and gravel. Clasts typically subangular to sub-rounded, average 2 to 4 cm diameter, 30 cm maximum diameter, commonly imbricated. Low-angle cross stratification occassionally present, channeled basal contact over fine sand and silt lower fan facies common. Gravel beds typically lenticular with channeled base. Locally grades upward into poorly-sorted, unbedded unstratified coarse-sandy gravel. Clasts average 1 to 6 cm diameter, up to 1 m maximum diameter	Clasts lithologically similar to pediment clast lithologies.
	Middle and Lower Fan	Moderately to well sorted, moderately to well bedded, laminated fine sand, silt, and clayey-silt. Laminae typically 0.2 to 5 cm thick.	Pebbles and sand grains principally varicolored lithic fragments with subordinate quartzite and/or quartz and minor glaucophane. Lithics primarily red chert, meta-volcanic and sandstone and minor blueschist and greenschist.
FLOODBASIN		Moderately to well sorted gravel, fine to coarse sand, silt and less clay. Moderately bedded, commonly laminated. Channel facies extensive in transverse section, typically forming "shoe-string" bodies deeply incised into underlying deposits.	Sand composed principally of quartz and feldspar with less mica and lithic fragments. Granules and pebbles principally. lithic-granite, diorite and monzonite common with less metamorphic. Near confluence of valley trunk stream with Coast Range streams an admixture with varicolored lithic fragments is common. Lithics include red and green chert greenstone, basalt, and sandstone
EOLIAN		Very well-sorted fine and medium sand, bedding indistinct, commonly cross-stratified. Sand grains principally subangular subrounded. Dune-like morphology not apparent in available exposures.	Grains composed principally of quartz with less plagioclase and mica. Quartz commonly myrmekitic with undulatory extinction under polarized light. Minor varicolored lithic grains present. Glaucophane not present.

Table 9: Texture and lithology of deposits accumulating in the west-central San Joaquin Valley and bordering foothills of the Diablo Range.

The piedmont alluvial-plain slopes moderately to gently (18m/km to 2m/km) from the mountain front to the nearly flat basin floor. The gradient decreases downslope, and abrupt changes in gradient may result at the intersection of alluvial-fans of different age or alluvial fans of similar age laid down by streams with different channel gradients (Bull, 1964a). The slope is dominantly to the northeast, perpendicular to the range front and valley axis. These fans are arbitrarily divided into three segments: the upper, middle and lower-fan (Figure 15).

The alluvial-fan deposits range from poorly to well bedded and from coarse to fine grained. Beds of poorly to moderately sorted coarse gravelly sand and sandy gravel are interpreted to be upper and middle-fan channel deposits. They are typically massive, lenticular and can not be traced laterally. Planer beds of fine to medium sand and some silt are commonly intercalated with the coarser beds and are interpreted to be sheetflow deposits (Davis, 1938) on the upper and middle-fan. Thick sections of laminated, well sorted fine sand and silt, in the absence of beds of coarser-grained detritus, are interpreted to be middle and lower-fan sheetflow deposits.

Similar alluvial-fan deposits are accumulating today in the western San Joaquin Valley along streams and gullies draining the Diablo Range Alluvial-fans from the major Diablo Range drainages consist mainly of fluviatile deposits and typically have very gently sloping surfaces. Fans emanating from the short, ephemeral foothill-front drainages consist largely of mudflow deposits and have steeply sloping surfaces. Combined, these fans form today's piedmont alluvial-plain of the western San Joaquin Valley which includes 60 to 70 percent of the valley floor in the study area.

Basin Floor

The basin floor is situated in the valley axis between the piedmont alluvial-plains of the western and eastern San Joaquin Valley (Figure 5). The basin is essentially level with very gentle slopes, 0.5 m/km to 1m/km, oriented northwesterly parallel to the long axis of the valley. Late Cenozoic deposits accumulating on the basin floor consist principally of laminated, well bedded, well sorted arkosic sand and silt with lesser amounts of clay and gravel. The sand and gravel are interpreted to have been deposited in or near channels of the axial streams of the valley, and the silt and clay to have been deposited on the adjoining plains when the streams overflowed their banks. The terms "riverine" and "flood basin" are used to describe these deposits.

Lithologically, the alluvium is nearly identical with the arkosic sediment currently transported by the rivers draining the Sierra Nevada. Quartz and feldspar are dominant minerals; mica and rock fragments of granitic and multicolored metamorphic and volcanic lithologies are also common. Stream bank exposures and data obtained from shallow augering during this study indicate that the beds of laminated fine-sand and silt are planar but are truncated laterally and overlain abruptly by beds of coarse sand and gravel. The coarse beds are thick, lenticular, of short extent and grade upward into the beds of fine sand and silt. These stratigraphic relations are interpreted to reflect migration and incision of the San Joaquin River and its sloughs into floodbasin deposits across the basin floor.

Laminated beds of well-sorted clayey silt, silty clay and clay are sparsely interbedded with the riverine and floodbasin deposits. They contain sparse mollusc shell-fragments and diatoms and are interpreted as paludal, oxbow-lake, pond or lacustrine deposits on the basin floor of the San Joaquin Valley. The diatomaceous Corcoran Clay Member of the Tulare Formation (Frink and Kues, 1954), for example, represents a major period of lacustrine deposition in the valley.

Toward the mountain front, the western edge of these basin floor deposits interfingers with the fluviatile and mudflow deposits of the piedmont alluvial-plain. In surface exposures and auger cuttings these deposits are easily distinguished based on color as well as their contrast in detrital composition. The piedmont alluvial-plain deposits are typically brown or yellowish-brown (10YR and 2.5Y hues) whereas the basin floor deposits are generally blue, green or gray (5G, 5GY, 10G, 5B, 5BG and N hues, also Meade, 1967).

The color contrast probably reflects the oxidized state of the sediments. The major foothill streams and gullies tributary to the alluvial-fans flow only during the rainy season and commonly only for short periods following rainstorms. After leaving the mountain front and flowing onto the piedmont alluvial-plain, they are never in complete hydraulic continuity with the water table (Meade, 1967). Discharge from the streams either infiltrates the unconsolidated fan deposits to the water table or evaporates from the surface. Most of the sediments, consequently, remain unsaturated and subject to oxidation between the time they are deposited and the time they are buried below the water table and hence exhibit brown and red colors characteristic of ferric iron.

The water table beneath the basin floor, however, is close to the land surface, and basin deposits are consequently generally saturated. The common preservation of plant remains, presence of authigenic sulfides in many cores (I.E. Klein, unpublished data, 1954, Meade 1967) and unoxidized state of the sediment suggest that the basin floor deposits have never been subjected to continued aeration and oxidation, and thus that the water table of the basin floor has always approached the land surface in late Quaternary time; hence they exhibit the blue-green and gray colors characteristic of ferrous iron.

Foothills of the Diablo Range

The foothills of the Diablo Range are dominated by past and present erosional surfaces particularly south of San Luis Reservoir. Remnants of gravel-veneered pediments, probably graded to former valley piedmont alluvial-plains, are preserved across the summits of the hills, and many broad, terraced, stream valleys have been cut into the hills (stream valleys are shown in Figure 3). Stream channel and floodplain deposits are common in these valleys and in many cases represent aggradational events on earlier cut surfaces. Channel deposits include poorly to moderately sorted, poorly bedded coarse sandy gravel and coarse gravelly sand. Clasts are typically imbricated and their long axes are typically oriented downstream. Floodplain deposits include moderately to well sorted, moderately bedded coarse gravelly sand, medium to fine sand, and silt. Longitudinal gradients of stream terraces and pediments typically converge downstream and are everywhere steeper than gradients of the present piedmont alluvial-plain of the western San Joaquin Valley.

Eolian Deposits

Deposits of very well sorted fine and medium sand with common high-angle cross-stratification (Figure 16) underlie and locally may interfinger with the lower piedmont-plain and possibly floodbasin fluviatile deposits. The sand is composed principally of quartz, with minor weathered plagioclase, and biotite. The quartz grains commonly exhibit a myrmekitic intergrowth with plagioclase and have undulatory extinction under polarized light suggesting a plutonic source. Varicolored Coast Range lithic fragments are less abundant and heavy minerals characteristic of the Diablo Range such as glaucophane are not present. The sand is thus interpreted to result from eolian reworking of alluvium derived from the Sierra Nevada. The sand is well exposed along Interstate-5 between Orestimba and Quinto Creeks (Figure 10, localities 33, 35, and 40).

Blissenbach (1954) reported that eolian deposits, in general, are commonly incorporated into the toes of alluvial-fans in semi-arid and arid environments. Marchand and Allwardt (1981) suggested that eolian reworking commonly accompanies and immediately follows glacial outwash deposition in the eastern San Joaquin Valley prior to surface stabilization of outwash fans by vegetation. Atwater (1982) has recognized at least two late Pleistocene periods of eolian reworking of glacial outwash from the Sacramento-San Joaquin Delta into the northwestern San Joaquin Valley. Winds blowing from the north or down-valley from the northwest, therefore, may have transported the Sierran sand from the basin floor, from the eastern San Joaquin Valley or from the Sacramento-San Joaquin Delta. The eolian sand observed between Orestimba and Quinto Creeks lies immediately west of the Merced River glacial outwash fan. A large area of eolian sand bearing the Delhi soil series (Arkley, 1954) is present north and south of the Merced River and is wind reworked glacial outwash alluvium (Marchard and Allwardt, 1981). The eolian sand between Orestimba and Quinto Creeeks is probably a westward extension of this vast dune field.

Facies and Geomorphic Relationships

The stratigraphic divisions recognized in this report commonly encompass two or more depositional facies. Figure 17 is a schematic block diagram illustrating the interpreted distribution of facies within a single stratigraphic unit. From the basin floor to the mountain front, each unit generally consists of fine to coarse-grained floodbasin and riverine deposits, locally interfingered with and overlain by fine-grained, laminated middle and lower alluvial-fan deposits, overlain and commonly channeled into by upper-fan coarse-sand and gravel (Figure 18). Locally, the eolian sand interfingers with and underlies the lower-fan deposits, and mudflow deposits interfinger with and overlie the upper-fan deposits. Facies relations between the eolian sand and basin floor deposits have not been observed.

The complete sequence of facies is not exposed in a single outcrop and Figure 17 is a composite of many isolated exposures supplemented by auger borings. The generalized vertical and lateral facies relationships, however,

Figure 16: Cross-bedded, well sorted fine to medium sand in the lower portion of the upper member of Los Banos alluvium. The sand is principally quartz with less abundant plagioclase and sparse mica, with very little admixture of multicolored detritus from the Diablo Range, suggesting that the sand is largely wind reworked alluvium from the Sierra Nevada. Pen is 14 cm long. (east-facing Interstate-5 roadcut immediately north of Quinto Creek (SE 1/4, Sec. 4, T8S, R8E)).

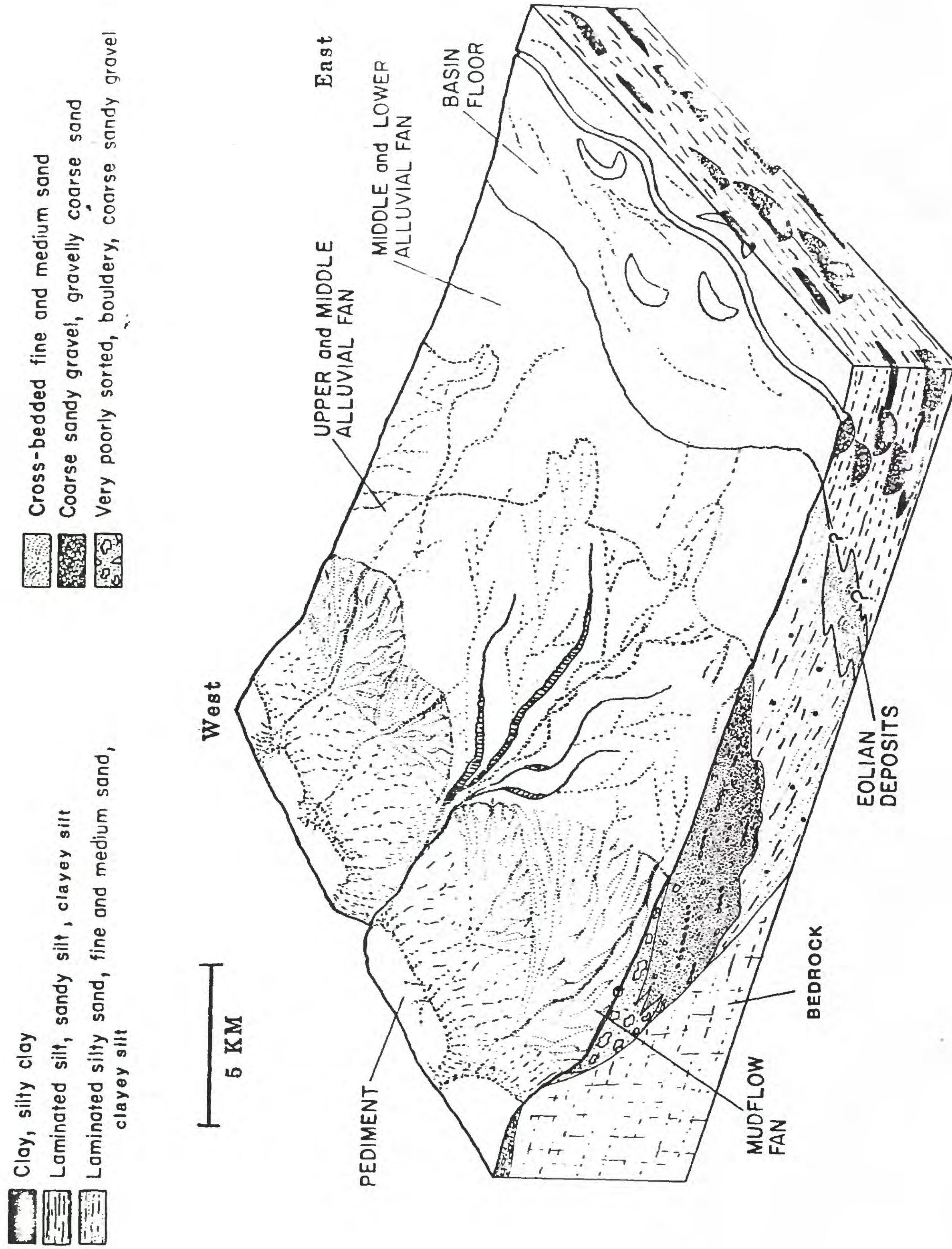

Figure 17: Diagrammatic section illustrating the vertical and lateral facies relationships within one stratigraphic unit. The block diagram is a composite of numerous exposures. Refer to Table 9 and text for discussion of facies and lithologies.

Figure 18: Coarse sandy gravel of the upper alluvial-fan facies channeled into middle and lower fan silt and fine sand containing abundant white nodules of calcium carbonate (Interstate-5 exposure, SW 1/4, Sec. 9, T10S, R9E; Plate 7).

The complete sequence of facies is not exposed in a single outcrop and Figure 17 is a composite of many isolated exposures supplemented by auger borings. The generalized vertical and lateral facies relationships, however, suggest that each alluvial unit represents a progradation of Coast Range alluvial fans over the San Joaquin Valley basin floor accompanied by and followed by mudflow deposition near the valley margin.

The distribution of these facies reflects the distribution of physiographic provinces in the study area. Coarse-grained stream valley and alluvial-fan deposits predominate within and near the front of the foothills of the Diablo Range, while fine-grained outer-fan and floodbasin deposits predominate towards the basin floor. Arkosic basin floor deposits, for example, have not been observed within or near the front of the foothills in the study area.

The geomorphic and pedologic character of these deposits and their surfaces are diagrammatically illustrated in Figure 19. Near the foothill front, younger deposits are typically inset into older deposits forming a sequence of "nested" alluvial-fans. Mountainward these nested fan-deposits commonly merge with a sequence of inset stream terraces and valley fills. This physical continuity is best illustrated along Little Panoche Creek, Los Banos Creek and north of the study area, along Corral Hollow and Hospital Creek. As do most terraces (Gilbert, 1877), these stream terraces probably reflect periods of floodplain-forming lateral stream corrasion followed by intervals of stream incision. In the study area, the two highest terraces commonly merge imperceptably with gravel-veneered erosional surfaces, or pediments, carved across the crest of the foothills. As will be discussed, these pediments appear to represent extensive periods of lateral stream corrasion rather than headward erosional retreat of a former range front.

Valleyward, each younger alluvial-fan deposit commonly spreads out over the preexisting alluvial-fan. The sequence of nested alluvial-fans near the mountain front thus merges with a sequence of superimposed alluvial fans towards the valley axis (Figure 19). Soils developed on the nested-fan and stream terrace surfaces near the valley margin can occasionally be traced by means of surface exposures and drill holes into buried soils developed on the buried alluvial-fan surfaces. The profile development of or preservation of the buried soils typically decreases downfan and seldom are buried soils recognized in drill holes on the lower alluvial fans.

Soils formed on the fan and terrace surfaces progressively increase from little or no development on the youngest inset deposits to strongly developed on the older, higher surfaces. Table 10 lists the U.S. Department of Agriculture (USDA) soil series most commonly mapped on the stratigraphic units recognized for these deposits and summarizes the characteristic properties of these soil series. Figure 20 illustrates the actual geomorphic distribution of these soils on the stratigraphic units. A representative soil developed on each unit is described in the individual discussion of stratigraphic units. In general, soil-profile thickness, thickness of the B_t horizon, degree of carbonate accumulation (Gile and others, 1965, Bachman and Machette, 1977), ped development, clay accumulation, and soil redness (Munsell) all increase with age (Table 10).

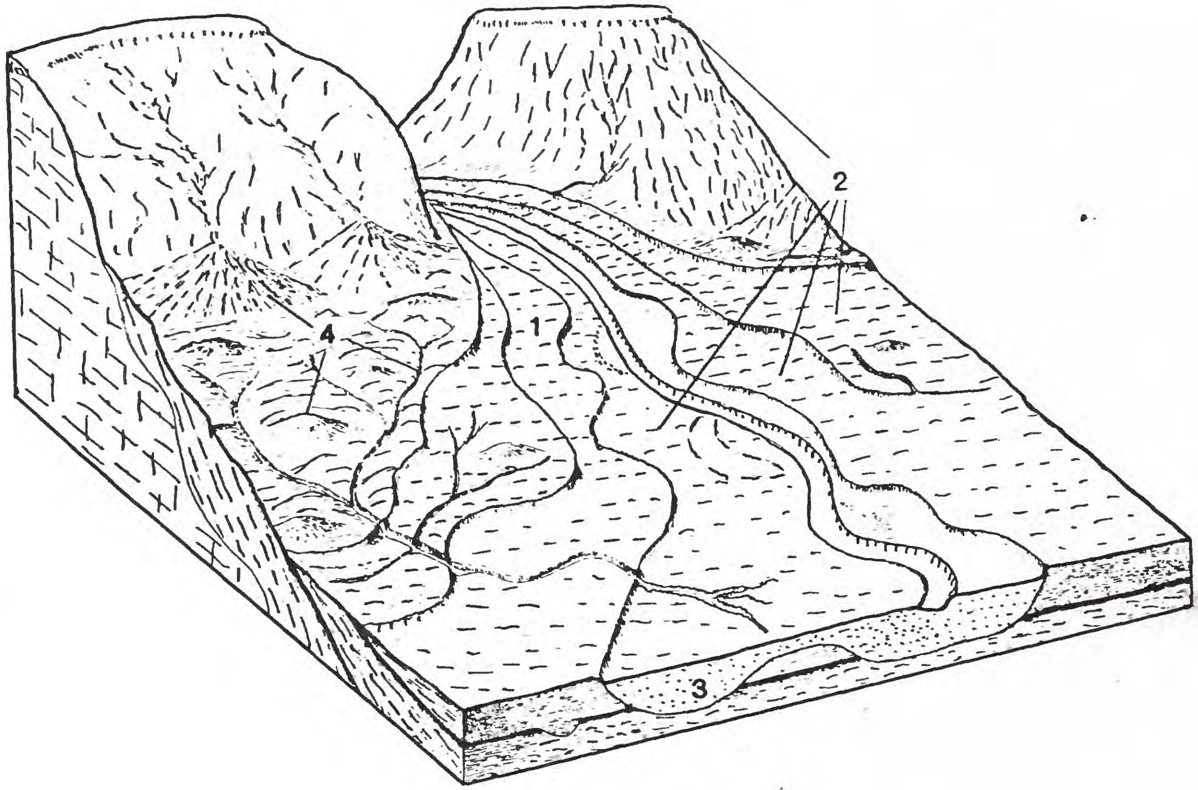

Figure 19: Geomorphic character of late Cenozoic deposits in the west-central San Joaquin Valley. The deposits form a sequence of inset alluvial-fans and stream terraces mountainward, which merge valleyward with a sequence of overlapping alluvial-fans. The youngest deposits are shown in yellow and the oldest deposits are shown in red. Relative age criteria used to divide and map these deposits include: (1) relative topographic position in a sequence of inset alluvial-fans or stream terraces; (2) relative degree of soil-profile development, which increases from little or no development on deposits adjacent to the trunk stream to very strongly developed on high terraces and pediment surfaces; (3) superpositon in a vertical sequence indicated by buried soils or erosional unconformities; and (4) relative degree of surface modification, including development of microrelief, erosional dissection, and subsequent depositon.

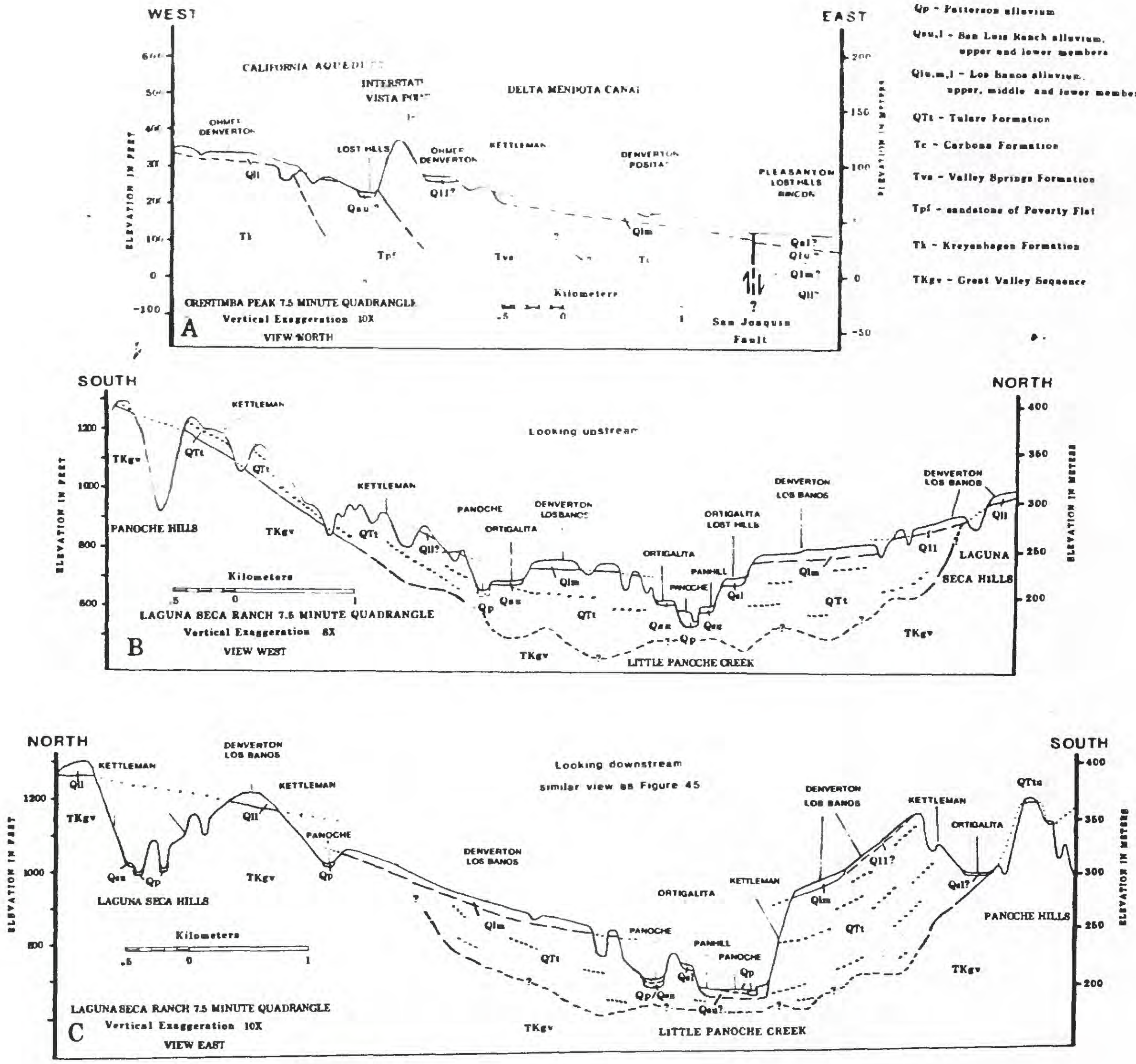

Figure 20: Detailed geologic sections near Orestimba and Little Panoche Creeks showing the character of late Cenozoic deposits in the foothills of the Diablo Range, and the relation of soils to stratigraphic units and geomorphic surfaces. Soil series names are in capitals above the ground surface. Stratigraphic units are shown generally below ground surface. Refer to text for descriptions of the soils and of the stratigraphic units. The cross sections are located on the Laguna Seca Ranch and Orestimba Peak 7.5-minute Quadrangles (Plates 1 and 18).

Table 10: Comparison of soil properties for characteristic soil series developed on late Cenozoic deposits in the west-central San Joaquin Valley. Properties listed represent typical values summarized largely from Soil Conservation Service Soil Series descriptions (Cole and others, 1943, 1948, 1952; Harradine, 1950; Harradine and others, 1956; Isgrig, 1969; McLaughlin and Huntington, 1968) and National Cooperative Soil Survey records (Davis, California). Stage of carbonate accumulation (Gile and others, 1965), color, and horizon thicknesses for soils developed on Los Banos and Tulare alluvium are determined mainly through field observation. Mottles and coatings on ped faces commonly have redder hues and brighter chromas than typical soil color.

Parent Material	Units on which soil is formed	Typical Soil Series	Approx. depth to C horizon (m)	Mean thickness of B horizon (cm)	Mean thickness of Bt horizon (cm)	Most representative continuous moist color of subsoil (Munsell)
	Patterson	Panoche, Mocho	0.0 to 0.6	0	0	2.5Y 5/2 to 10YR 5/3
	upper San Luis Ranch	Sorrento, Panhill,	0.3 to 1.0	0 to 60	0 to 40	10YR 3/2 to 10YR 5/3
Coarse-grained alluvial-fan and terrace deposits	lower San Luis Ranch	Lost Hills, Pleasanton, Ortigalita	0.8 to 1.7	20 to 115	20 to 60	10YR 4/3 to 7.5YR 4/4
	upper Los Banos	Herdlyn, Los Banos, Denverton, Positas	1.0 to 2.4	25 to 130	25 to 100	7.5YR 4/3 to 5YR 3/4
	middle and lower Los Banos	Los Banos, Denverton, Positas	1.5 to 3.0	25 to 200	25 to 150	7.5YR 4/4 to 5YR 3/6
	Tulare (relict)	Los Banos, Positas, Kettleman	1.4 to 4.0	100 to 300 +	100 300 +	5YR 4/4 to 2.5YR 3/5
	Tulare (residual)	Kettleman	0.4 to 1.5	0 to 20	0	10YR 4/2 to 10YR 4/4
Fine-grained lower alluvial-fan deposits	Patterson	Levis, Oxalis, Willows	0.5 to 1.2	0	0	5Y 4/2 to 2.5Y 4/3
	upper San Luis Ranch	Rossi, Volta, Orestimba	1.3 to 1.8	40 to 115	20 to 40	2.5Y 4/4 to 10YR 4/2
	Dos Palos (channel)	Columbia	0 to 0.4	0	0	2.5Y 4/3 to 10YR 4/3
Floodbasin deposits (arkosic parent material)	Dos Palos (floodplain)	Temple, Merced, Sacramento	0.5 to 1.3	0 to 110	0 to 20	2.5Y 4/4 to 10YR 3/1
	Modesto Formation Marchand and Allwardt, 1981)	Fresno, Waukena	0.5 to 1.5	15 to 100	15 to 60	2.5Y 5/4 to 10YR 4/4

Table 10: Continued.

Typical Carbonate accumulation	Clay and iron oxides in best developed subsoil horizon	Dry Consistency of subsoil	Dry structure in best developed subsoil horizon
None to stage 1, disseminated, filament.	none evident	Firm to slightly hard	Massive, granular or weak, fine subangular-blocky.
Stage 1 and 2 disseminated soft masses and nodular.	None to thin, discontinuous coatings on ped faces and pores.	Slightly hard to hard	Massive granular or weak, coarse subangular-blocky.
Stage 2 soft masses, nodula.	Moderate to thin discontinuous to nearly continuous coatings on ped faces and large clasts. Pores partially filled.	Hard to very hard	Moderate, fine to medium subangular-blocky and weak fine prismatic.
Stage 2 and 3, nodular, massive.	Common, thick continuous coatings on ped faces and clasts. Pores partially filled.	Hard to very hard	Weak, coarse prismatic breaking into subangular-blocky, or coarse subangular-blocky.
Stage 2 and 3, nodular, massive	Common, thick continuous coatings on ped faces and clasts. Pores nearly filled	Hard to very hard	Strong, coarse prismatic breaking into angular blocky
Stage 1 to 4, disseminated to laminar depending on topographic position.	Thick, continuous coatings on peds and clasts. Pores nearly filled or filled, slickensides common.	Hard to very hard	Strong, coarse prismatic, breaking into subangular- or angular blocky.
Stage 1 to stage 2; disseminated, nodular.	None to thin, discontinuous coatings on peds and clasts.	Slightly hard to hard	Weak, fine prismatic breaking into weak, fine subangular-blocky and granular.
None to Stage 1, disseminated, rare nodules.	None evident	Very hard	Strong, coarse prismatic and and subangular-blocky in lower A horizon.
Stage 2, soft masses and nodular.	Thin, continuous on peds. Pores partially filled.	Very hard	Moderate, medium subangular-blocky and moderate medium prismatic.
None to Stage 1, finely disseminated.	None evident	Slightly hard	Weak, fine granular.
Stage 1 to 2, disseminated, nodular, soft masses.	None to thin, discontinuous coatings on peds and pores.	Hard	Weak medium subangular-blocky to to moderate, coarse prismatic.
Stage 2 and 3, nodular, massive.	Thin continuous and discontinuous coatings on peds. Pores partially filled.	Hard to very hard	moderate, medium subangular blocky to strong, coarse prismatic.

Mapping Criteria and Methods of Preparing the Geologic Map

Mapping Criteria

Late Cenozoic deposits are divided into stratigraphic units and mapped primarily on the basis of relative age deciphered from geomorphic and pedologic criteria. These criteria are diagrammatically illustrated in Figure 19. Geomorphic criteria include: (1) relative topographic position in a sequence of inset stream terraces or nested alluvial fans (Figure 21); (2) truncation or incision of one alluvial fill by another; (3) relative degree of surface modification, including erosional dissection (Figure 22), development of "gilgai" microrelief from the expansion and contraction of montmorillinitic soils, and biologic modification such as development of "mima-mound" microrelief (Arkley and Brown, 1954; Page and others, 1977). Pedologic criteria include: (1) contrasting degree of soil development on depositional surfaces under similar conditions of parent material, relief, climate, vegetation and drainage; and (2) cross-cutting soil patterns resulting from a younger deposit overlying or truncating an older deposit (Figure 23). In addition, stratigraphic superposition indicated by buried soils or erosional unconformities (Figure 24) becomes an important mapping criterion away from the mountain front where younger fan deposits commonly overlie older fan deposits.

These criteria are largely objective but each criterion by itself does not define a mappable geologic unit. Combined, however, they provide distinct relative age separation of a mappable sequence of deposits. Frye and Leonard (1954) and Leopold and Miller (1954) discuss problems associated with this method of mapping and correlating alluvial deposits and suggest methods to overcome them. Some of the more difficult problems to interpret, for example, include unpaired terraces, strath terraces and exhumed surfaces or soils. These problems are commonly encountered in the west-central San Joaquin Valley and have been treated carefully.

Geologists formally define several broad categories of stratigraphic units, including rock-stratigraphic, bio-stratigraphic and chrono-stratigraphic divisions (U.S. Geological Survey, 1974, American Commission on stratigraphic nomenclature, 1970; Hedberg, 1976). The criteria discussed above, however, do not conform to the guidelines for recognition of these formal stratigraphic divisions. The general absence of absolute (numerical) age control and lack of fossils in the late Cenozoic deposits in the western San Joaquin Valley precludes the use of bio-stratigraphic or chronostratigraphic terms; and rock-stratigraphic terms are avoided because the lateral and vertical facies variation in lithology within units generally exceeds lithologic variation between units, precluding the use of lithology as a principle mapping criterion. Except for the previously defined Tulare Formation (Watts, 1896, Anderson, 1905), informal names are adopted for the stratigraphic units. The widely used numerical system of labelling Quaternary alluvial units is avoided because it implies correlations from region to region that are not necessarily justified.

Figure 21: Terraces and pediments along Little Panoche Creek. Lower surfaces are younger than higher surfaces illustrating relative age based on topographic position. The highest surface is a broad pediment of regional extent throughout the foothills of the east-central Diablo Range. (View west from NE 1/4, Sec. 36, T13S, R10E; Laguna Seca Ranch 7.5-minute Quadrangle, Plate 1, Figure 10, locality 8).

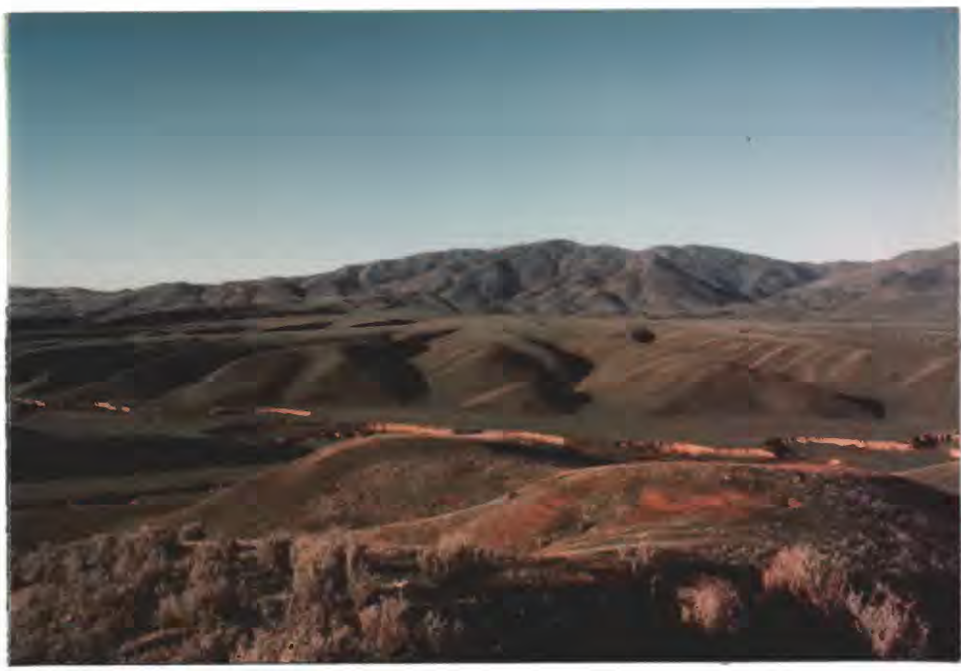

Figure 22: Relative age indicated by relative degree of surface dissection. A terrace of the middle member of Los Banos alluvium along Little Panoche Creek is deeply dissected by gullies graded to a relatively undissected Holocene floodplain underlain by Patterson alluvium. Late Holocene stream incision through the floodplain by Little Panoche Creek is evident in the foreground (view west from SW 1/4, SW 1/4, Sec. 11, T14S, R10E, Mercey Hot Springs 7.5-minute Quadrangle, Figure 10, locality 9).

Figure 23: Relative age of alluvial deposits indicated by relative degree of soil profile development. On the left, a young, light-brown soil is developed on Patterson alluvium adjacent to an older reddish-brown soil developed on the lower member of San Luis Ranch alluvium. The younger alluvium debouched from the small gulley in foreground and overlies the older alluvium along this soil contact. The California Aqueduct and Interstate-5 are present in the background. View east from foothill front of Laguna Seca Hills across San Joaquin Valley from SE 1/4, SE 1/4, Sec. 29, T12S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 1, Figure 10, locality 17.

Figure 24: Relative age indicated by stratigraphic superposition. Superposition is generally indicated by erosional unconformities or buried soils. On the Little Panoche Creek alluvial fan, for example, younger deposits of the lower member of San Luis Ranch alluvium overlies a buried soil developed on older deposits of the upper member of Los Banos alluvium. The top of the buried soil is about 15 cm above the head of the hammer. The hammer handle is 30 cm long (Figure 10, locality 16).

Methods

The late Cenozoic deposits were initially divided into stratigraphic units based on topographic position and surface modification interpreted from aerial photographs and large-scale topographic maps with five-foot and ten-foot contour intervals. The geomorphic surface-character of each unit was noted and the soil series most commony developed on unmodified surfaces was determined from USDA soil survey maps (Cole and others, 1943, 1948, 1952; Harradine, 1950; Harradine and others, 1956; Isgrig, 1969; and McLaughlin and Huntington, 1968).

The preliminary stratigraphic divisions were subsequently modified during field examination of natural and artificial exposures, including streambanks, gulley-walls, and roadcuts as well as depositional surfaces unaltered by man. The geological character of each unit (thickness, lithology, sedimentary structures) and stratigraphic relationships between units were noted. Degree of soil development was estimated from color, ped-structure, clay-skin development on ped faces, pebble margins, pores, and fractures, stage of carbonate development (Gile and others, 1965, Bachman and Machette, 1977) and the thickness of profiles.

Wherever possible, units were correlated from drainage to drainage and fan to fan by physical continuity. These correlations were made entirely by field or air-photo observation. Where the deposits lack such continuity at the surface, sequences established independently in individual drainages were correlated by comparison of soil-profile development and position in a relative topographic sequence. Bilzi and Ciolkosz (1977), Birkeland (1978), Schlemon and Begg (1975), Marchand and Allwardt (1981) and Gile and others (1981), for example, have successfully used soil development to divide and correlate Quaternary deposits. The available absolute age control (Table 12), however, is not sufficient in the west-central San Joaquin Valley to conclusively demonstrate temporal equivalence of the discontinuous alluvial units from drainage to drainage

Many of the original geomorphic and pedologic features of the late Cenozoic deposits have been modified or destroyed by cultivation in the San Joaquin Valley. Tilling, fertilizing, ripping and irrigating commonly modify their character; and leveling and grading typically destroy the original topography and soil profile. Air-photos and soil surveys made after intensive cultivation reflect these agricultural practices and can not always be used to interpret the late Cenozoic geology. Air-photos and soil surveys made prior to cultivation were therefore used in areas strongly affected by these practices.

STRATIGRAPHIC DIVISIONS

Introduction

Late Cenozoic deposits in the west-central San Joaquin Valley and adjacent foothills of the Diablo Range are divided into five stratigraphic units based primarily on geomorphic and pedologic criteria. In order of decreasing age, these are the Tulare Formation (Watts, 1894, Anderson 1905) of late Pliocene(?) and Pleistocene age, and the informally named Los Banos alluvium of middle and late Pleistocene age, San Luis Ranch alluvium of late Pleistocene and early Holocene age, and Patterson alluvium and Dos Palos alluvium of Holocene age. The lithology distribution and modification of these units are summarized in Table 11. The Los Banos and San Luis Ranch alluvium are further divided into three and two members, respectively. Each of these members ranges in thickness from less than 1 m up to 15 m and thus represents, at least in part, a distinct period of aggradation.

Together, these units underlie all of the west-central San Joaquin Valley and large portions of the bordering foothills of the Diablo Range. Figure 25 illustrates the general distribution of the units in the study area and Figure 26 diagrammatically illustrates the geomorphic character of the units along streams draining the Diablo Range. Figure 20 shows several geologic sections illustrating the distribution of soils on the stratigraphic units and geomorphic surfaces.

The stratigraphic units are Quaternary in age, although the Tulare Formation may in part extend into the upper Pliocene. Table 12 is a compilation of the available radiometric age dates from the western San Joaquin Valley. A discussion of these dates and the paleontologic, pedologic, paleomagnetic, structural and stratigraphic age control for the stratigraphy is presented separately for each unit.

Figure 27 shows the proposed stratigraphy and its inferred correlation with late Cenozoic alluvial deposits elsewhere in California, with the marine oxygen isotope record (Emiliani, 1978), and with the Sierra Nevada glacial record (Blackwelder, 1931; Curry, 1969; Wahrhaftig and Birman, 1965; Sharp and Birman, 1963, and Sharp, 1972). Definite time boundaries are not shown because: (1) lack of sufficient age control; (2) probable presence of significant depositional hiatuses of unknown duration between most of the depositis; (3) lack of diagnostic vertebrate fauna and uncertainty of correlation of terrestrial vertebrate "ages" with the marine faunal "ages"; and (4) extreme difficulty in precisely coordinating the terrestrial alluvial events with the climatic record as recorded in the marine oxygen isotope data (Emiliani, 1978). Resolution of these age and correlation problems awaits further research and development of more applicable late-Cenozoic dating techinques.

Table 11: Summary of the lithology, distribution and surface modification of late Cenozoic deposits in the west-central San Joaquin Valley and bordering foothills of the Diablo Range.

UNIT	AGE	DISTRIBUTION	LITHOLOGY	MODIFICATION
Dos Palos alluvium	Holocene	Underlies a continuous, northwest-trending belt from 1 to 25 km wide in the valley axis between the Coast Range and Sierra Nevada piedmont alluvial plains (Figure 25).	Unconsolidated, moderately to well sorted gravel, sand, silt, and clay. Principally micaceous arkose derived from the Sierra Nevada. Clasts are subrounded to well rounded, average 0.5 to 1 cm diameter, and are chiefly granitic. Metamorphic and volcanic clasts are typically subordinate but are common near the confluence of Coast Range streams and the San Joaquin River where multi-colored lithics predominate. Fine-grained beds are typically laminated and laterally continuous. Coarse-grained beds are lenticular, cross-stratified and have channeled lower contacts.	Generally unweathered and undissected. Deposits are grayish green (5GY and 5G hues) and are poorly drained, typically bearing alkali rich, moderately to poorly developed soils (Table 10).
Patterson alluvium	Holocene	Within the foothills, underlies present stream channels and low bordering terraces inset into terraces of San Luis Ranch alluvium. The alluvium also forms extensive valley fills up to 7 m thick in Panoche Valley, Little Panoche Valley, and Carrisalito Flat. Within the San Joaquin Valley, the alluvium occupies small, steep-walled valleys incised into older alluvium near the fan-apex and a thin, "tear-drop" shaped veneer over older deposits farther down fan (Figure 25).	Unconsolidated, poorly to well sorted gravel, sand, silt, and minor clay. The alluvium is derived entirely from the Diablo Range or is reworked from older alluvial deposits. Clasts include quartzite-veined red and green chert, metagraywacke, and minor greenstone, gabbro, serpentinite and blueschist from the Franciscan assemblage or basal ophiolite of the Great Valley Sequence; graywacke and minor shale and black chert from the Great Valley Sequence; basalt, andesite, and rhyolite from the Quien Sabe Volcanics; and diatomite from the Kreyenhegen shale and Great Valley Sequence. Clasts are generally subangular to sub-rounded, crudely imbricated, and range greatly in size up to 1 m diameter, averaging 3-6 cm. Fine-grained beds are generally laterally continuous, laminated, and average 0.5 to 1 m thick. Coarse-grained beds are lenticular, cross-stratified, average 1 to 2 m thick, and generally have channeled lower contacts. Cross-stratified beds of well sorted eolian sand are locally interbedded with the less sorted deposits.	Generally unweathered and undissected, although "fan-head trenching" (Bull, 1964) is common on smaller fans. Original sheetwash morphology is common. "Mima-mound" or "gilgai" microrelief is absent. Deposits are brown to yellowish-brown (5Y, 2.5Y and 10YR hues) and bear weak, thin A-C or A-Cox-C soil profiles (Table 10).
San Luis Ranch alluvium	late Pleistocene and early Holocene	Within the foothills, underlies well-preserved, low and intermediate stream terraces inset into terraces of Los Banos alluvium and the Tulare Formation. In Little Panoche Valley, Panoche Valley, and Carrisalto Flat, also forms extensive valley fills greater than 5 m thick veneered by Patterson alluvium. The terraces merge downstream with alluvial fans in the San Joaquin Valley. The fans occupy broad, shallow valleys cut into Los Banos alluvium at the fan-head, and open down-fan onto broad alluvial sheets veneering the Los Banos alluvium and, in turn, veneered by Patterson alluvium (Figure 25).	Unconsolidated, poorly to well bedded gravel, sand, silt and minor clay. The deposits are similar in composition and texture, and exhibit similar sedimentary structures as deposits of Patterson alluvium.	Generally unweathered to slightly weathered and slightly to moderately dissected with local relief of 5 to 20 m. Large unmodified surfaces are common between gullies. "Mima-mound" or "gilgai" microrelief is slightly to moderately developed on many original surfaces. The deposits are brown to reddish-brown (10YR and 2.5Y hues) and bear weakly to moderately developed azonal and zonal soils (Table 10).
Los Banos alluvium	middle and late Pleistocene	Veneers remnants of broad, extensive pediments carved across the crest of the foothills and, locally, poorly preserved high terraces along the larger foothill streams. Remnants of the pediments are discontinuously preserved in a northwest-trending belt ranging in width from 5 to 20 km (Figure 25). The terraces and pediments grade valleyward into alluvial fans. The fans are locally preserved and exposed near the valley margin but are everywhere overlain by younger deposits toward the valley axis.	Unconsolidated, poorly to well bedded, gravel, sand, silt and minor clay. The deposits are similar in composition and texture, and exhibit similar sedimentary structures as deposits of Patterson alluvium and San Luis Ranch alluvium.	Slightly to moderately weathered and moderately to strongly dissected resulting in a relief of low, rolling hills between steep-walled canyons. Where unmodified for agriculture, a well-developed, pronounced "mima-mound" or "gilgai" microrelief is common. The deposits are brown to reddish-brown (10YR hues) and bear moderately to strongly developed zonal soil profiles (Table 10).
Tulare Formation	late Pliocene and Pleistocene	At one time formed a continuous sheet of coalescing alluvial-fan deposits up to 120 m thick over the foothills, thickening eastward into the San Joaquin Valley. Remnants are locally preserved over the crest of the Panoche Hills south of the study area, along the valley margin north of San Luis Reservoir, and in several restricted foothill valleys in the southwestern part of the study area (Figure 25). The deposits are everywhere overlain by younger deposits in the San Joaquin Valley.	Weakly to moderately consolidated, poorly to well bedded, gravel, sand, silt, and minor clay. The deposits are similar in composition and texture, and have similar sedimentary structures as deposits of Patterson, San Luis Ranch, and Los Banos alluvium.	Deeply weathered and dissected with local relief up to 150 m. Little, if any of the original depositional surface remains. Argillic and calcic soils with thick zonal profiles have developed on relict and eroded surfaces (Table 10). The deposits range in color from gray to brown to red (5Y, 10YR, 7.5YR and 5YR hues).

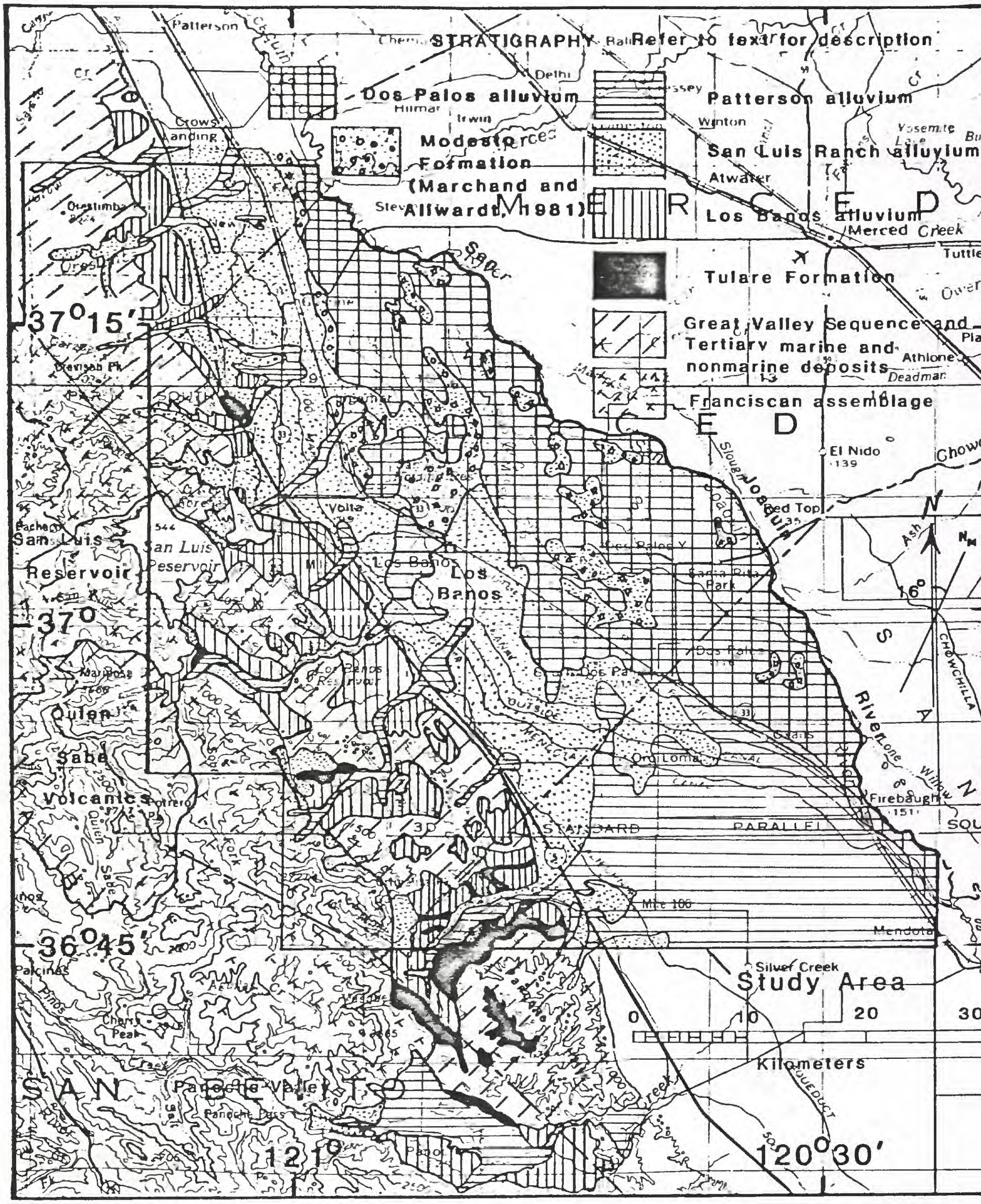

Figure 25: General distribution of late Cenozoic deposits in the west-central San Joaquin Valley and bordering foothills of the Diablo Range.

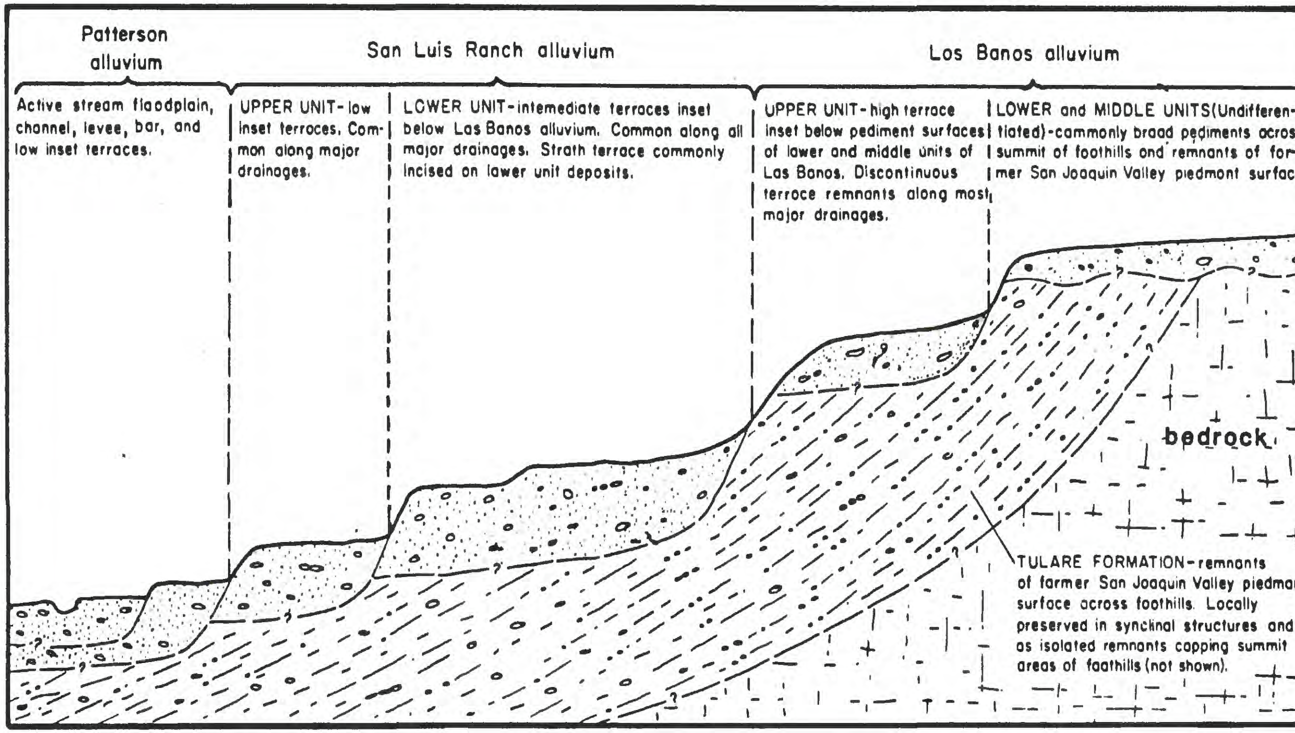

Figure 26: Diagrammatic cross-section of a foothill stream valley and bordering hills illustrating the geomorphic character of stratigraphic units within the foothills of the Diablo Range.

Table 12: Continued.

Age In Years	Method	Latitude North	Longitude West	7.5 Minute Quadrangle	Depth In Meters	Map Unit	Laboratory Number	Remarks Detrital Charcoal	Reference
81,661 ± 2,000	Uranium[1] Series	36°37'15"	120°34'00"	Monocline Ridge	15	Ql_u-Qs_1(?)	—	Equus sp. tooth fragments; from USBR core hole 15/13-16N. Above soil(?) horizon separating Los Banos and San Luis Ranch alluvium.	Analysis by E. L. Begg, U. C. Davis oral communication. Submitted by N. Prokopovich, USBR
95,167 ± 1,623	Uranium[1] Series	37°43'30"	120°31'23"	Midway	?	Ql_u	—	Bison sp. bone fragments. Depth below ground surface unknown. Veneer of QS_1 (Ambrose soil) channeled into underlying Tulare Formation.	Analysis by E.L. Begg, U.C Davis This study
112,000 ± 14,000	Uranium[1] Series	37°3'37"	121°1'25"	San Luis Dam	2	Ql_u	U-3	Groundwater carbonate concretion from fracture in clayey silt unit near O'Neill Forebay (Corcoran Clay?). Provides maximum limiting age for overlying veneer of Los Banos alluvium.	USBR O'Neill Forebay Trench Study (1980), Preliminary Report.
160,000 ± 5,000	Uranium[1] Series	37°3'55"	121°1'30"	San Luis Dam	Surface	Ql_u	U-2	Groundwater(?) calcareous crust at surface of clayey silt unit O'Neill Forebay (Corcoran Clay?). Provides maxium limiting age for overlying veneer of Los Banos alluvium.	USBR O'Neill Forebay Trench Study (1980) Preliminary Report.
250,000	Uranium[1] Series	36°45'35"	120°49'30"	Laguna Seca Ranch	12-15	QTt	—	Equus sp. bone fragments. Upper beds of Upper Tulare Formation.	Analysis by E. L. Begg, U. C. Davis, This study.
615,000 ± 31,000	K-Ar	--	--	Lanes Bridge	—	QTt(?)	--	Sanidine from pumice clasts, in Friant ash. Ash overlies Corcoran clay in San Joaquin Valley subsurface.	Dalrymple, 1980 Janda, 1965

[1]Uranium-thorium disequillibrium series dates on vertebrate bones requires burial of the bone and subsequent incorporation of uranium transported in solution. Thorium is relatively insoluble and not easily transported in solution. The dates, therefore, are minimum ages for the sample dependent on the rate of burial and depth to groundwater. In arid and semi-arid regions lacking near-surface groundwater, slower migrations of uranium in meteoric waters result in mean residence times of uranium within fossils to be less than the total elapsed time (Hansen and Begg, 1970).

Table 12: Continued.

Age In Years	Method	Latitude North	Longitude West	7.5 Minute Quadrangle	Depth In Meters	Map Unit	Laboratory Number	Remarks Detrital Charcoal	Reference
81,661 ± 2,000	Uranium[1] Series	36°37'15"	120°34'00"	Monocline Ridge	15	Ql_u-Qs_1(?)	—	Equus sp. tooth fragments; from USBR core hole 15/13-16N. Above soil(?) horizon separating Los Banos and San Luis Ranch alluvium.	Analysis by E. L. Begg, U. C. Davis oral communication. Submitted by N. Prokopovich, USBR
95,167 ± 1,623	Uranium[1] Series	37°43'30"	120°31'23"	Midway	?	Ql_u	—	Bison sp. bone fragments. Depth below ground surface unknown. Veneer of QS_1 (Ambrose soil) channeled into underlying Tulare Formation.	Analysis by E.L. Begg, U.C Davis This study
112,000 ± 14,000	Uranium[1] Series	37°3'37"	121°1'25"	San Luis Dam	2	Ql_u	U-3	Groundwater carbonate concretion from fracture in clayey silt unit near O'Neill Forebay (Corcoran Clay?). Provides maximum limiting age for overlying veneer of Los Banos alluvium.	USBR O'Neill Forebay Trench Study (1980), Preliminary Report.
160,000 ± 5,000	Uranium[1] Series	37°3'55"	121°1'30"	San Luis Dam	Surface	Ql_u	U-2	Groundwater(?) calcareous crust at surface of clayey silt unit O'Neill Forebay (Corcoran Clay?). Provides maxium limiting age for overlying veneer of Los Banos alluvium.	USBR O'Neill Forebay Trench Study (1980) Preliminary Report.
250,000	Uranium[1] Series	36°45'35"	120°49'30"	Laguna Seca Ranch	12-15	QTt	—	Equus sp. bone fragments. Upper beds of Upper Tulare Formation.	Analysis by E. L. Begg, U. C. Davis, This study.
615,000 ± 31,000	K-Ar	—	—	Lanes Bridge	—	QTt(?)	—	Sanidine from pumice clasts, in Friant ash. Ash overlies Corcoran clay in San Joaquin Valley subsurface.	Delrymple, 1980 Janda, 1965

[1]Uranium-thorium disequillibrium series dates on vertebrate bones requires burial of the bone and subsequent incorporation of uranium transported in solution. Thorium is relatively insoluble and not easily transported in solution. The dates, therefore, are minimum ages for the sample dependent on the rate of burial and depth to groundwater. In arid and semi-arid regions lacking near-surface groundwater, slower migrations of uranium in meteoric waters result in mean residence times of uranium within fossils to be less than the total elapsed time (Hansen and Begg, 1970).

Table 12: Radiometric ages of late-Cenozoic deposits in the west-central San Joaquin Valley.

Age In Years	Method	Latitude North	Longitude West	7.5 Minute Quadrangle	Depth In Meters	Map Unit	Laboratory Number	Remarks	Reference
2850 ± 100	^{14}C	36°35'30"	120°49'00"	Panoche	4	Qp	Beta 2345	Detrital Charcoal; provides maximum age for aggradation of broad valley fill in Panoche Valley.	This report
2415 ± 190	^{14}C	37°06'00"	121°2'00"	San Luis Dam	0.5	Qp	Bete 1602	Gastropod shell; dates Holocene terrace along San Luis Creek.	This report
200 ± 70	^{14}C	36°35'40"	120°46'00"	Panoche	3-3.5	Qp	Beta 2616	Detrital charcoal from laminated silt horizon; provides maximum age for aggradation of overlying fine to coarse sand.	This report
3330 ± 60	^{14}C	37°32'06"	121°07'05"	Brush Lake	6.2	Qd	Beta 2788	Detrital wood from contact of channel arkosic sand overlain by flood-basin silt.	B. F. Atwater and W. R. Lettis 1981, unpublished
1110 ± 50	^{14}C	37°32'11"	121°06'35"	Brush Lake	3-5	Qd	Beta 2786	Detrital charcoal; Cross bedded, arkosic sand. East Bank San Joaquin River.	B. F. Atwater and W. R. Lettis, 1981, unpublished
8230 ± 80	^{14}C	37°33'30"	121°07'02"	Brush Lake	5.5	Qd	Beta 2787	Wood; detrital (?) at contact of channel gravel with Coast Range detritus overlain by San Joaquin River arkosic sand and oxbow silt.	B. F, Atwater and W. R. Lettis 1981, unpublished
Preliminary 16,000	Uranium[1] Series	37°21'37"	121°10'03"	Orestimba Peak	4 - 6	Qs_u	—	Equus sp. bone fragments; south wall Crow Creek. Underlies buried soil capped by Holocene deposits.	Analysis by E. L. Begg, U. C. Davis This study
22,670 ± 200	^{14}C	36°45'22"	120°18'56"	Mendota Dam	11	QSu	USGS 1201	Wood; Contact of arkosic silt abruptly overlain by arkosic sand. Provides maximum limiting age for flood-plain silt deposit. No pedogenesis observed.	This report
28,200 ± 330	^{14}C	36°44'50"	120°19'39"	Tranquillity	15	Qs	USGS 1197	Detrital wood; less than 2 cm maximum dimension. Top of fining upward sequence.	This report
29,970 ± 250	^{14}C	36°44'50"	120°19'39"	Tranquillity	15	Qs	USGS 1198	Disseminated organic matter in silt. Top of fining upward sequence.	This report
31,300 ± 650	^{14}C	36°43'45"	120°21'53"	Tranquillity	17	Qs	USGS 1200	Decomposed roots and detrital (?) plant fragments; from arkosic silt and sand. Provides maximum limiting age for probable buried land surface (soil?).	This report
43,800 + 1,700 − 1,400	^{14}C	36°43'45"	120°21'53"	Tranquillity	17	Qs_1	USGS 1199	Detrital wood; in arkosic silt and sand overlain by by Coast Range fine sand USGS 1200 dates the contact surface.	This report

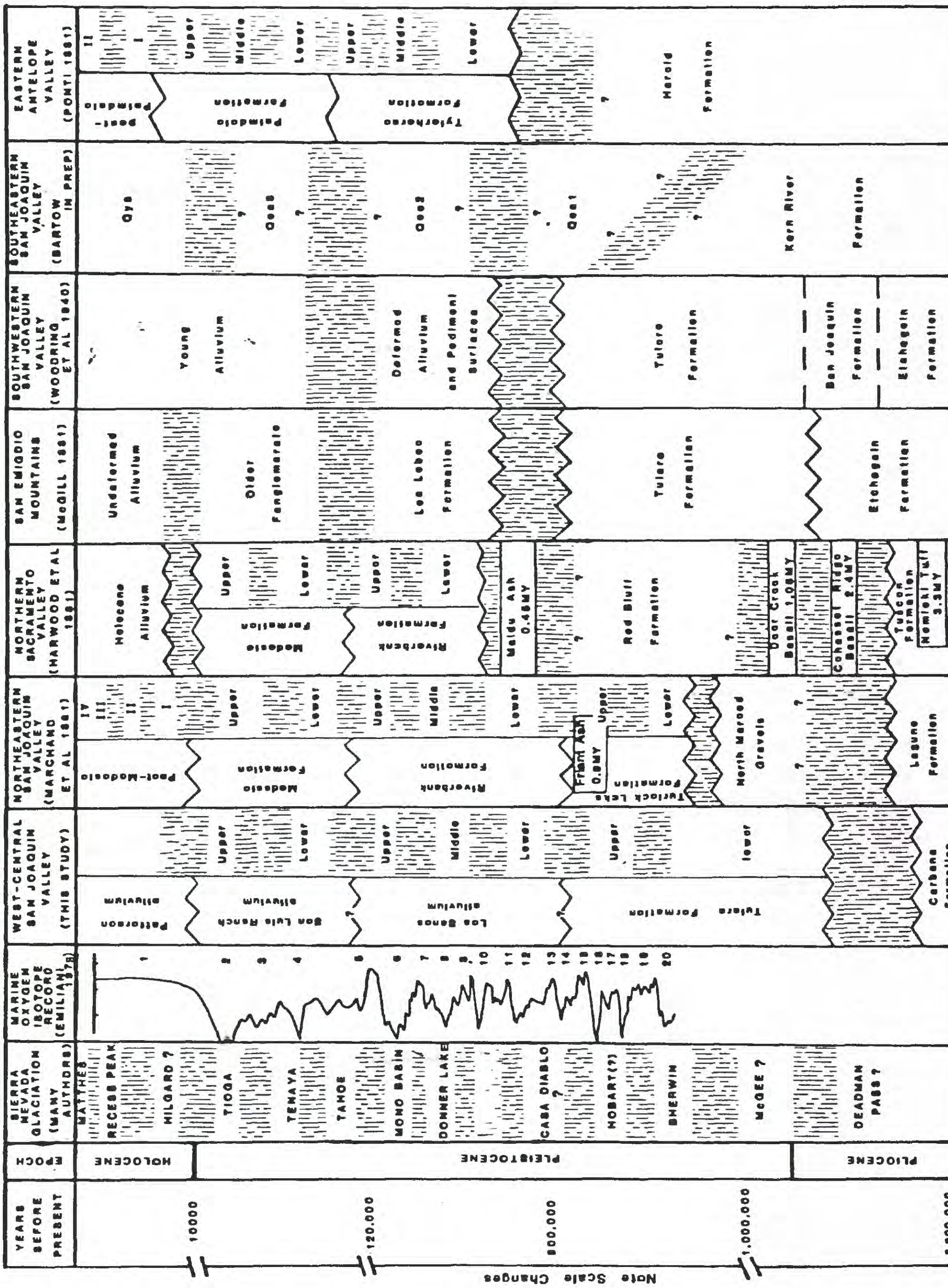

Figure 27: Correlation chart of Late Cenozoic stratigraphies from several areas of California and relation to the marine oxygen isotope record and glacial events in the Sierra Nevada. For a summary of previous stratigraphic nomenclatures see Marchand and Allwardt (1981). Vertical pattern indicates a hiatus in deposition and probable soil development on stable surfaces. Contacts between units are solid if abrupt and well constrained, dashed if gradational, and jagged if pooly constrained.

TULARE FORMATION

Definition and General Description

The Tulare Formation is a continental deposit of unconsolidated, moderately to well-weathered gravel, sand, silt and clay. In the west-central San Joaquin Valley, the Tulare includes deformed Pliocene(?) and Pleistocene deposits demonstrably younger than alluvium of the Miocene and Lower Pliocene(?) Oro Loma and Carbona Formations, based on paleontologic and structural criteria, and older than Los Banos alluvium based on stratigraphic superposition and geomorphic and pedologic criteria. The Tulare is discontinuously preserved in the foothills of the Diablo Range but forms a thick unit in the subsurface at the San Joaquin Valley where it contains the Corcoran Clay as a widespread member (Davis, 1958; Frink and Kues, 1954).

In the west-central San Joaquin Valley, the Tulare is interpreted to be a deformed and eroded complex of coalescing alluvial-fans flanking the central Diablo Range. Sedimentary structures, including channeled contacts, imbrication of clasts, laminated bedding, and cross-stratification, and buried soils and oxidized horizons are common, suggesting that the deposits accumulated largely by fluvial processes under subaerial conditions. Coarser-grained beds are interpreted as channel and levee deposits and finer-grained beds are interpreted as floodplain deposits. Eolian deposits are locally preserved north of Quinto Creek (Figure 10, locality 33). The lacustrine Corcoran Clay is widespread in the valley subsurface but has not been observed in surface exposures.

Exposures of the Tulare probably represent remnants of a once-continuous sheet of alluvium extending eastward from embayments within the central Diablo Range across the foothills to the San Joaquin Valley, where the Formation attains its greatest thickness and is everywhere overlain by younger deposits. The distribution of this sheet suggests that the Tulare alluvial-fan complex accumulated on a San Joaquin Valley floor that extended across the foothills to the margin of the central Diablo Range. Subsequent uplift of the foothills has locally deformed the Tulare, and erosion has removed most of the formation.

Previous Literature

The Tulare Formation was originally informally defined as the deformed, continental deposits in the Kettleman Hills by Watts (1894, p. 55-57) who measured a stratigraphic section from the Kettleman Hills and collected a freshwater mollusc assemblage from its basal lacustrine beds identified by Cooper (1894, p. 167-169) as Pliocene in age. Lohman (1938) subsequently studied a freshwater diatom assemblage from these basal beds and agreed with Cooper's designation of a Pliocene age for the base of the Formation.

The formation was formally named Tulare, however, by F. M. Anderson (1905, p. 181-182) who defined it as a "freshwater deposit of unconsolidated gravel, sand and clay exceeding 1000 feet thick and resting conformably on the San Joaquin Clay in the Kettleman Hills." He doubtfully assigned it to the Pliocene and reported exposures at intervals along the southwest border of the San Joaquin Valley, although a type locality was not then designated.

Arnold and Anderson (1910) subsequently redefined the Tulare as a continuous succession of "little consolidated gravel, sand and clay, with occassional indurated beds of marl and limestone" which "conformably overlies the marine Echegoin Formation and whose summit is considered to be the highest bed markedly displaced from its original attitude by uplift." Inherent in this definition, therefore, are structural criteria for defining the required extent of deformation. In 1940, Woodring and others (p. 13-17), prepared several detailed stratigraphic columns for the Tulare exposed in the Kettleman Hills and suggested a type locality of the western flank of North Dome, although no specific locality was designated.

Lacking a well-described type locality, the Tulare Formation has been correlated instead on structural and generalized lithologic criteria. Regional correlation of the Tulare Formation has therefore been difficult because the timing and the style of structural deformation changes considerably over short distances in the southwestern and western San Joaquin Valley. Nevertheless, the name has been extended by general consent rather than by demonstrated equivalence or physical continuity, to the San Joaquin Valley subsurface, where it contains the Corcoran Clay (Frink and Kues, 1954), and to the series of deformed continental beds, both conformably and unconformably overlying the older Tertiary and Cretaceous bedrock, along the entire western margin of the San Joaquin Valley (Anderson and Pack, 1915). Included are numerous deposits subsequently determined to be temporally, lithologically, pedologically and structurally distinct from the Tulare deposits recognized in the Kettleman Hills.

In the west-central San Joaquin Valley, for example, Anderson and Pack (1915) included in the Tulare Formation both the strongly deformed Oro Loma Formation overlying the Eocene Kreyenhagen Formation in the Laguna Seca Hills and the slightly deformed continental deposits in the Little Panoche Valley and Panoche Hills. Briggs (1953) subsequently separated the Oro Loma and Tulare Formations primarily on the basis of structural criteria. He concluded that the Oro Loma deposits are deformed with the bedrock series while the Tulare deposits lie unconformably across the eroded edge of the folded Tertiary and Cretaceous bedrock. Pelletier (1951) and Sonneman (1958) made a similar separation of Anderson and Pack's (1915) Tulare Formation north of Quinto Creek. They called the deposits deformed with the bedrock series the Carbona Formation and restricted the term "Tulare" to the slightly deformed deposits unconformably overlying the deformed bedrock.

In a geologic compilation of the Ortigalita Peak 15-minute Quadrangle, Dibblee (1975) adopted Brigg's interpretation and restricted the Tulare Formation to the slightly deformed deposits unconformably overlying the Cretaceous and Tertiary bedrock. Dibblee (1975) and Briggs (1953) also separated the Tulare and Oro Loma deposits partly on lithologic criteria in that the upper Tulare beds contain strongly developed, carbonate cemented "marl and limey" horizons while corresponding upper Oro Loma beds do not. Briggs' point is well taken because the carbonate horizons in the upper Tulare represent pedogenic calcic aridisols formed in a semi-arid or arid climate and, although the upper Oro Loma deposits do contain pedogenic horizons, they are argillic ultisols formed in a more temperate climate. A climatological argument for separation of the two units may therefore also be invoked.

Distribution

The Tulare Formation forms a thick, extensive body of alluvium in the San Joaquin Valley subsurface which thins westward against the valley margin (plates 25A and B) providing rare exposures at the valley surface. In the study area, these exposures are best preserved as a thin, deformed alluvial apron fringing the northeastern flank of the Panoche Hills (Laguna Seca Ranch and Hammonds Ranch 7.5-minute Quadrangles, Plates 20 and 21, Figure 10, locality 15).

The Tulare attains its greatest exposed thickness and preservation, however in the restricted foothill valleys of the Diablo Range. In Carrisolito Flat, Little Panoche, and Los Banos Valleys, deformed Tulare deposits as much as 120 m thick (Figure 10, locality 7) unconformably overlie the Cretaceous Great Valley Sequence (Figure 20). Buried bedrock hills of the Panoche Formation (Figure 10, localities 6, 10 and 13) indicate that the Tulare deposits bury a former erosional surface in the foothills with relief of more than 60 m. In these basins, the Tulare is commonly the "bedrock" into which younger, alluvium-veneered stream terraces are cut (Figures 20 and 26). In Los Banos Valley, the Tulare deposits form an embayment into the central Diablo Range across the Ortigalita fault (Figure 10, locality 25), indicating that there has been no uplift of the range along this fault since deposition of the Tulare Formation.

Other remnants of the Tulare Formation are preserved on the north flank of the Wisenor Hills, on the crest of the Panoche Hills, and immediately north of Quinto Creek (Figure 10, localities 4, 19, 33 and immediately southwest of locality 29). On the north flank of the Wisenor Hills the deposits are deeply weathered, dip northward from 4° to 18°, and are as much as 30 m thick. North of Quinto Creek, the Tulare deposits dip as much as 16° to 20° to the southeast and are more than 200 m thick (Figure 28). At the crest of the Panoche Hills south of the study area, flat-lying, deeply weathered Tulare deposits up to 50m thick unconformably overlie deformed Great Valley Sequence rocks (Mercey Hot Springs 7.5-minute Quadrangle, Figure 10, locality 4).

Lithology

The Tulare Formation consists primarily of weakly consolidated, moderately to well bedded gravel, sand, and silt with minor amounts of clay. In Little Panoche Valley, Los Banos Valley, and the Panoche Hills, beds of fine to coarse sand and silt predominate while lenses of pebbly coarse sand and sandy gravel are less common and randomly distributed through the section. Gravel typically caps the surface in these areas although this may, in part, be lag gravel. This random intercalation of beds contrasts with the succession of bedding north of Quinto Creek (Figure, 10 locality 33), where the exposed section of the Tulare consists of cross-bedded, well sorted fine and very fine sand, overlain by beds of laminated silt and sand, overlain in turn by beds of coarse gravelly sand and sandy gravel.

Clast lithologies indicate deriviation of the alluvium from the Diablo Range. Lithologies include metagraywacke, quartz-veined red and green chert and minor amounts of greenstone, gabbro, serpentinite, glaucophane schist and actinolite schist, all derived from the Franciscan assemblage and

Figure 28: Tilted gravelly coarse sand beds of the Tulare Formation north of Quinto Creek. Beds strike N45o to 55oE and dip 18oSE on the southeast flank of a possible late Quaternary fold (Interstate-5 exposure, Figure 10, locality 33).

basal ophiolite of the Great Valley Sequence; basalt, andesite, and some rhyolite derived from the Quien Sabe Volcanics; and nonschistose graywacke and minor shale and black chert possibly derived from the Great Valley Sequence. The relative proportion of these lithologies, however, ranges greatly, reflecting proximity to the source bedrock. In Los Banos Valley, for example, basalt and andesite comprise 70 to 80 percent of the clasts because a major portion of the drainage basin of Los Banos Creek is underlain by the Quien Sabe Volcanics. An exception, however, occurs north of Quinto Creek (Figure 10, locality 33) where red chert comprises 75 to 85 percent of the Tulare clasts. The draithe Great Valley Sequence; basalt, andesite, and some rhyolite derived from the Quien Sabe Volcanics; and nonschistose graywacke and minor shale and black chert possibly derived from the Great Valley Sequence. The relative proportion of these lithologies, however, ranges greatly, reflecting proximity to the source bedrock. In Los Banos Valley, for example, basalt and andesite comprise 70 to 80 percent of the clasts because a major portion of the drainage basin of Los Banos Creek is underlain by the Quien Sabe Volcanics. An exception, however, occurs north of Quinto Creek (Figure 10, locality 33) where red chert comprises 75 to 85 percent of the Tulare clasts. The drainage basin of Quinto Creek is underlain principally by sandstone and shale of the Great Valley Sequence and sandstone clasts comprise 80 to 90 percent of post-Tulare deposits laid down by Quinto Creek. The Tulare in this area may have been deposited by a stream whose drainage system extended well into the central Diablo Range underlain by the Franciscan assemblage.

Clasts derived from younger Tertiary rocks are not evident in the exposed sections of the Tulare Formation, because the exposures lie west of the Tertiary section towards the source terrain. Ira E. Klein (1954, unpublished U. S. Bureau of Reclamation report), however, has reported the presence of diatomite clasts from the Kreyenhagen Formation in core samples of the Tulare Formation in the San Joaquin Valley subsurface.

Clasts in the Tulare Formation are subangular to subrounded, crudely imbricated and range greatly in average and maximum clast size. North of Quinto Creek, for example, the chert clasts average 1 to 2 cm diameter with a maximum size of 7 cm. In Los Banos Valley, the volcanic clasts average 6 to 8 cm diameter and commonly exceed 50 cm in maximum size. In general, however, the average clast size ranges from 2 to 5 cm in diameter, varying in average size between beds and decreasing in average size toward the San Joaquin Valley indicating that clast size is largely determined by distance from the source and stream competence rather than by in situ physical or chemical weathering of the bedrock.

The gravel and coarse sand beds are typically lenticular, faintly cross bedded and difficult to trace laterally. These beds average 1 to 2 m thick and commonly have channeled lower contacts. The beds of well-sorted fine sand, silt, and clay average 0.5 to 1 m in thickness and are commonly well stratified, internally laminated and laterally continuous.

Surface Modification

The top of the Tulare Formation approximates a former extensive depositional surface which probably extended over the foothills region, in large part unrelated to the present drainage system. Deformation and subsequent erosion, however, have significantly modified the upper surface so that little if any of the original depositional surface remains, and fan-forms are not evident from the topography or distribution of outcrops. Uplift of the Panoche Hills, Wisenor Hills and Laguna Seca Hills, for example, warped the surface, and the deposit has been largely removed. The closest approximation of an original surface is probably on the extensive outcrops south of the study area on Marl Ridge at the crest of the Panoche Hills (Mercey Hot Springs 7.5-minute Quadrangle, Figure 10, locality 4).

Deep weathering, probably contemperaneous with depostion, characterizes the entire sequence. Beds display variegated colors from red and brown to blue and gray indicating various states of oxidation. Bold bluffs of brightly colored Tulare deposits can be seen from Little Panoche Road near Mercy Hot Springs (Figure 10, localities 5 and 7). Clay skins around clasts and lining and filling pores are ubiquitous. Indurated beds cemented by iron oxides and/or calcium carbonate are also common and may indicate that intervals of non-deposition and subaerial exposure allowed soils to form during accumulation of the formation. One particularly well-developed laminar carbonate horizon (Stage IV, Gile and others, 1967) lies 5 to 10 m below the surface in the Tulare deposits capping the Panoche Hills (Figure 10, locality 4). If pedogenic, the carbonate suggests that a major depositional hiatus, possibly on the order of 10^6 years interrupted deposition of the Tulare Formation in this area. Alternatively, the carbonate may have precipitated from groundwater within a single depositional unit.

Soils developed on the surface of the Tulare Formation include the Positas, Los Banos, Kettleman, Danville, Alturas, Altamount, Danville, Keefers, Linne and Contra Costa series (Cole and others, 1943. 1948, 1952; Isgrig, 1969; Harradine, 1950; Harradine and others, 1956; McLaughlin and Huntington, 1968). Because erosion has removed all or most of the original depositional surface, relict soils are rare and the soils observed have developed on younger surfaces cut into the Tulare. These soils, therefore, are typically much younger than the age of the deposit and were commonly classed as "bedrock" or "residual" soils by the early soil surveys in the area. Of these, the Positas (Mollic Palexeralf), Los Banos (Mollic Haplargid), and Kettleman (Typic Haplorthent) series are most common and their characteristic properties are shown in Table 10.

The Positas soil series, a red (2.5YR to 5YR hues), montmorillinitic soil described below, is the most well-developed soil preserved on the Formation. The thick argillic B-horizon exhibits thick, continuous clay films and coarse, prismatic ped structure. It is well-exposed in stream cuts along Los Banos Creek in Los Banos Valley (Figure 10, locality 26).

Positas Soil Series

Ap--0 to 20 cm; brown (10YR 5/3) gravelly loam, dark brown (7.5YR 3/3) moist; massive with weak horizontal partings in the top few inches; hard, friable, nonsticky and nonplastic; many very fine roots; many very fine pores; medium acid (pH 6.0); abrupt smooth boundary; (15 to 50 centimeters thick).

A2--20 to 26 cm; similar to above in all respects except color valus are nearly 1/2 chip higher; abrupt smooth boundary; (5 to 15 centimeters thick).

B21t--26-51 cm; reddish brown (5YR 4/3) clay, dark reddish brown (5YR 3/3) moist; strong coarse prismatic structure; extremely hard, extremely firm, sticky and very plastic; few very fine roots along structure faces; few very fine tubular pores; thick continuous dark reddish gray (5YR 4/2) clay films on faces of peds and nearly filling pores; common slickensides; slightly acid (pH 6.5); gradual smooth boundary; (20 to 30 centimeters thick).

B22t--51 to 74 cm; reddish brown (5YR 4/4) dry and moist, clay; strong coarse prismatic structure; extremely hard, extremely firm, sticky and very plastic; few very fine roots along structure faces; few very fine tubular pores; thick continuous clay films on faces of peds and nearly filling pores; common slickensides; moderately alkaline (pH 8.0); abrupt smooth boundary; (20 to 30 centimeters thick).

B31t--74 to 100 cm; brown (7.5YR 5/5) clay loam, brown (7.5YR 4/4) and yellowish red (5YR 4/6) moist; strong medium angular blocky structure; very hard, firm, sticky and plastic; few very fine roots; few very fine tubular pores; moderately thick continuous yellowish red (5YR 5/5) clay films on faces of peds and lining pores; common fine (1 to 2 mm) black stains on faces of peds; very weakly calcareous; moderately alkaline (pH 8.0); gradual smooth boundary; (20 to 35 centimeters thick).

B32t--100 to 130 cm; light yellowish brown (10YR 6/5) clay loam, brown (10YR 5/3) and yellowish red (5YR 4/6) moist; strong medium angular blocky structure; very hard, firm, sticky and slightly plastic; few very fine roots; few very fine tubular pores; moderately thick continuous yellowish red (5YR 4/6) clay films on peds and lining pores; common fine black stains on faces of peds; very weakly calcareous; moderately alkaline (pH 8.0); gradual smooth boundary; (25 to 45 centimeters thick).

IIC--138 to 152 cm; light yellowish brown (10YR 6/5) very gravelly sandy clay loam, yellowish brown (10YR 5/4) moist; few yellowish red (5YR 4/6) dry and moist, coatings; massive; slightly hard, friable, nonsticky and nonplastic; moderately alkaline (pH 8.0)

Type Location: Approximately 6 miles northwest of Patterson, Stanislaus county, California. In Almond orchard, NW 1/4, sec 2, T5S, R7E. (McLaughlin and Huntington, 1968)

National Cooperative Soil Survey, Department of Agriculture.

The Kettleman Soil Series, described below, is the most commonly mapped residual soil on the Tulare Formation in the foothills of the Diablo Range. It has a very thin, weakly developed A-C profile. The A horizon is typically pale brown (10YR 6/3), loamy and calcareous and the C horizon is yellowish brown (10YR 6/4) and strongly calcareous.

Kettleman Soil Series.

A11--0 tp 26 cm Pale brown (10YR 6/3) loam, brown (10YR 4/3) when moist; moderate fine granular structure; slightly hard, very friable, slightly sticky, slightly plastic; abundant very fine and fine roots; few very fine and fine tubular pores, common very fine and fine interstitial pores; moderately alkaline, slightly effervescent; gradual smooth boundary. 10 to 25 centimeters thick.

A12--26 to 57 cm Pale brown (10YR 6/3) loam, brown (10YR 4/3) when moist; weak medium subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; abundant very fine and fine roots; many very fine, fine and medium tubular pores; moderately alkaline, strongly effervescent; gradual smooth boundary. 20 to 40 centimeters thick.

C1--57 to 105 cm Light yellowish brown (10YR 6/4) loam, dark yellowish brown (10YR 4/4) when moist; weak coarse subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; plentiful very fine and fine roots; common very fine and fine tubular pores; few fine flecks of lime, moderately alkaline, strongly effervescent; gradual wavy boundary. 25 to 45 centimeters thick.

C2--105 to 130+ cm Light yellowish brown (10YR 6/4) loam, dark yellow brown (10YR 4/4) when moist; weak medium subangular blocky structure; slightly hard, very friable, slightly sticky, slightly plastic; few very fine and fine tubular pores; few fine flecks of lime; moderately alkaline, violently effervescent; gradual irregular boundary. 10 to 30 centimeters thick.

Type Location: South of Panoche Valley, southeastern San Benito County, California, NW 1/4, sec 28, T16S, R11E (Isgrig, 1969).

National Cooperative Soil Survey, Department of Agriculture.

Age of the Tulare Formation

The age of the Tulare Formation in the west-central San Joaquin Valley is uncertain but is considered to be Pliocene(?) and Pleistocene based on structural and stratigraphic relationships and meager paleontologic, paleomagnetic and radiometric age information. The Tulare deposits exposed in Little Panoche, Los Banos and Carrisolito Flat valleys overlie eroded, deformed Cretaceous and Tertiary bedrock including the late Miocene and early Pliocene(?) Oro Loma Formation. The Tulare is, in turn, overlain by deposits of Los Banos Alluvium in Little Panoche Valley, Los Banos Valley, Carrisalito Flat and the San Joaquin Valley whose age may be as great as 535,000 years (refer to "Los Banos alluvium" age discussion).

Horse bones and teeth collected from several localities and identified by C. A. Repenning of the U.S. Geological Survey, Menlo Park (written communication, 1980) suggest an Irvingtonian or younger age (less than 1.9 my) for most of the Tulare Formation. Tooth fragments of *Equus* cf. *E. scotti* Gidley have been recovered from the lower Tulare beds exposed along Little Panoche Creek (Laguna Seca Ranch 7.5-Quadrangle, Plate 1, Figure 10, locality 8); a very well preserved tibia of *Equus scotti* has been recovered from the cross-bedded, fine sand north of Quinto Creek (Howard Ranch 7.5-minute Quadrangle, Plate 4, Figure 10, locality 33); and fragments of *Equus* sp. tibia have been recovered from the upper Tulare beds exposed along Little Panoche Creek (Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20, Figure 10, locality 7). These latter bones have been dated by the Uranium-Thorium disequillibrium series method providing a minimum age of greater than 250,000 years for the upper Tulare (Table 12, E. L. Begg, personal communication, 1980).

Results of a paleomagnetic investigation of the Tulare section exposed along Little Panoche Creek (Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20 Figure 10, locality 8, suggest that a paleomagnetic reversal exists between 30 and 35 m below the upper ground surface (1100 foot contour) or approximately 35 to 40 m below the top of the Tulare Formation. The reversal persists over 15 m to the base of the esposure. Based on the consistency of the reversal and the available age constraints of greater than 250,000 years and less than 1.9 my, the reversal is believed to correspond with the Matuyama geomagnetic reversal and the boundary to be the Bruhnes-Matuyama interpreted to be 0.73 $\pm$ 0.2 my old by Davis and others (1977). The remnant magnetization was measured in samples from four reduced clayey-silt horizons. The clayey-silts are waterlaid, free of carbonate and manganese or iron hydroxides. Samples were collected by W. R. Lettis and analyzed by J. W. Hillhouse of the U.S. Geological Survey, Menlo Park (J. W. Hillhouse, written communication, 1981). The magnetic directions of these samples were stable during alternating-field demagnetization indicating that meaningful, not random, magnetic directions were present.

Assuming the uppermost Tulare is as young as 550,000 years, the deposits above the reversal accumulated at a minimum depositional rate of 24 to 27 cm/1000 years. This rate is consistent with rates of deposition from the San Joaquin Valley where deposits overlying the Corcoran Clay have accumulated as rapidly as 38 cm/1000 years over a duration of 600,000 years (refer to "Late Cenozoic Structure" section).

Corcoran Clay Member of the Tulare Formation

Description and Distribution

The Corcoran Clay is a formally designated Member of the Tulare Formation in the subsurface of the San Joaquin Valley (Davis, 1958, p. 121). The Corcoran Clay is a widespread, nearly homogeneous, greenish-blue to bluish-gray, well-sorted silty clay and clayey silt with an increasing proportion of silt and fine sand towards its lateral margins. It ranges in thickness between 5 m to 50 m and extends continuously beneath at least 12,500 km^2 of the San Joaquin Valley (Croft, 1972). Diatoms are abundant within the clay but decrease in abundance toward the margins (Lohman, 1954; Frink and Kues, 1954). Beds of silt and well-sorted fine sand commonly bearing fish scales are present in the lower section, especially near the margins of the clay (I. E. Klein, unpublished U.S. Bureau of Reclamation report, 1954).

The marked lateral continuity, very fine-grained texture, and presence of diatoms and fish remains clearly indicate a lacustrine rather than floodbasin or paludal environment of deposition. The clay thus represents a major departure from the alluvial, paludal, floodbasin and eolian late Cenozoic depositional history of the San Joaquin Valley. The blue and green colors of the clay suggest either a reducing environment of deposition consistent with the bottom of a lake where decaying organic matter can support anaerobic bacterial activity, or diagenesis.

Its unique occurrence, widespread extent and fine-grained texture make the clay an important stratigraphic marker as well as a prominent aquiclude in the subsurface of the San Joaquin Valley. Consequently, the clay has been the subject of many geologic and hydrologic investigations, which are summarized below. Many of the subsurface stratigraphic correlations and calculations of Quaternary sedimentation and deformation rates presented in this report are based on the distribution of this clay in the north-central San Joaquin Valley. Its distribution in the north-central valley is illustrated on two cross-valley sections (Plates 25A and B) and on a contour map of the surface of the Corcoran Clay (Figure 29). The general distribution of the Corcoran throughout the San Joaquin Valley is shown on contour maps by Croft (1972). Figure 29 is a generalized contour map based on well and test core information as shown. Many wells and test cores in the valley, however, do not penetrate the Corcoran Clay, or if they do, very few provide sufficient paleontologic or lithologic information to identify a clay unit as the Corcoran Clay. Consequently, insufficient data are available to accurately construct a more detailed contour map of the Corcoran Clay than is shown and many small structures including faults and folds, are difficult to detect

Previous Literature

The Corcoran Clay was first recognized, named and described by Frink and Kues (1954) who correlated it in cores beneath several thousand square kilometers of the San Joaquin Valley and described a type section in the U.S. Bureau of Reclamation core hole 15/14-15E. Its known lateral extent was subsequently greatly extended by Davis and others (1959), who called it the "Diatomaceous Clay" because of its well known diatomaceous character, and by Croft (1967, 1968, and 1972), who correlated it with his "E-Clay" in the

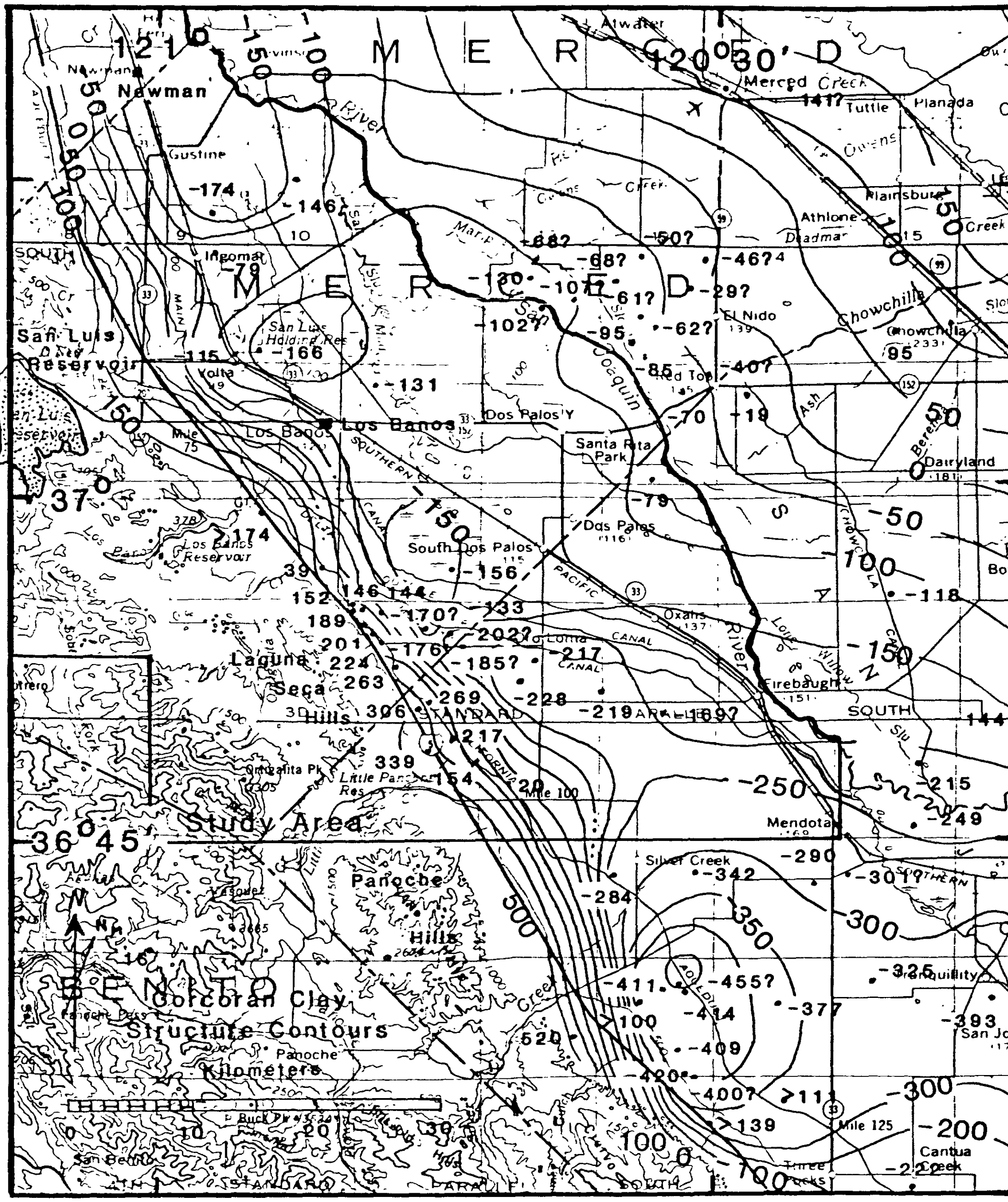

Figure 29: Structure contour map of the Corcoran Clay member of the Tulare and Turlock Lake Formations in the northern San Joaquin Valley. Contours indicate the altitude in feet of the top of the clay and illustrate the general distribution and deformation of the clay in the north-central San Joaquin Valley. Contour interval is 50 feet, except east of Panoche Hills where 100 foot contours are shown. Depth to the clay is listed adjacent to drill holes in the valley. Queried depths are from water wells. Core holes are shown on Plate 24 and reference data are given in Appendix 1.

southern San Joaquin Valley. Other studies which provide isopach and structure contour maps on the distribution of the clay include those by Croft and Gordon (1964), Davis and others (1964), Davis and Poland (1957), Wood and Davis (1959), Hilton and others (1963) Wood and Dale (1964), and Miller and others (1971).

X-ray diffraction analysis of the Corcoran Clay indicates a clay mineralogy dominated by montmorillinite, beidellite variety, with minor kaolinite and chlorite (Table 7). The analysis is from the type section (core hole 15/14-15A) at a depth of 720 feet, by W. C. Schieltz (1952, unpublished U.S. Bureau of Reclamation Memorandum no. 52-19) and reported by Frink and Kues (1954). It is not known if this represents the general mineralogy of Corcoran Clay throughout its entire widespread subsurface extent. The silt fraction of the clay is micaceous suggesting a Sierran contribution to the clay (Frink and Kues, 1954).

Paleontology and Conditions of Deposition

Diatoms from several U.S. Bureau of Reclamation core holes have been examined by K. E. Lohman of the U.S. Geological Survey (1954, unpublished memorandum to the U.S. Bureau of Reclamation). The assemblage of 113 species identified by Lohman is shown in Table 13. Lohman's interpretation is that the diatoms lived in a large, shallow, freshwater lake with possible local brackish water conditions. He suggested that a fluctuating volume of water in a shallow lake would produce the dominantly freshwater character of the lake during high lake levels, and the brackish water conditions when the lake level was low and the concentration of salts was at a maximum.

The diatom content ranges from sparse (less than 1%) near the top and bottom of the clay to abundant (10 to 15%) in the middle of the clay (Frink and Kues, 1954). The diatom content decreases laterally toward the margins where the clay is typically non-diatomaceous (Frink and Kues, 1954).

Pollen from the Corcoran Clay indicates that local swamp and grassland conditions probably bordered the lake with stands of pine, fir and juniper in the surrounding hills or mountains. Visual approximation of pollen percentages at a depth of 279.5 feet in core hole 26/23-22C by Linda Heusser (written communication, 1976; reported in Davis and others, 1977) include pine, fir and juniper types (30 to 50%), oak (1 to 2%), alder (1%), spruce (1%), hemlock (1%), cattail (20 to 50%), grasses (8 to 10%), sedges (5%) and herbs (5%). Water algae and fern spores are also abundant. Pollen identified by H. P. Hansen (written communication, 1953; reported by Frink and Kues (1954) from a two-foot-thick bed of peat overlying the clay in core hole 15/16-12 are principally pine, fir, grasses, and composites. Willow and cottonwood pollen and varieties of fern spores are also present. Oak pollen was not reported.

These approximations of pollen abundances do not conclusively indicate climatic conditions at the time the Corcoran Clay accumulated. Except for the sparse spruce and hemlock pollen, all of these taxa are found today in the Diablo Range or in the central and southern Sierra Nevada. Spruce and hemlock have their habitats farther north and suggest cooler temperatures, although even during glacial conditions the geographic range of spruce probably did not extend far south into California. Eolian transport or perhaps misidentification of these sparse pollen grains may be indicated. The relative

Table 13: Diatom species recognized in core samples of the Corcoran Clay Member of the Tulare and Turlock Lake Formation. Sample localities are listed on the following page. Identified by K. E. Lohman (1954) of the U.S. Geological Survey.

U.S.G.S. DIATOM LOCALITY NO.

	3291	3292	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942
Actinocyclus sp.	R						F								M
Actinoptychus senarius Ehrenberg					R								R		M
n. sp. A														R	M*
Amphicampa eruca Enrenberg	F	F							R						F
Amphora ovalis Kutzing	F	R	R	R	F		R	R		F					F
sp.			R	R	R		R		R						
Caloneis cf. C. permagna (Bailey) Cleve										R					B
trinodis (Lewis) Meister	C	F													BF
Cocconeis placentula Ehrenberg		R			R						F				BF
Coscinodiscus n. sp. A.											R				M*
sp. (fragments)	R	F		R	R	R	R	R					R	R	M
Cyclotella n. sp. A.					A				C		F	R		R	*
n.sp. B.					A				C		C			R	*
sp.			R												
Cymatopleura solea (Brebisson) Wm. Smith										R	R				F
Cymbella cf. C. alpina Grunow				R											F
aspera (Ehrenberg) Cleve	R	F								F					F
cuspidata Kutzing		R								R					F
mexicana (Ehrenberg) Cleve	R	R				R	R		R	F					F
tumida (Brebisson) van Heurck		R													F
turgida (Gregory) Cleve	R	R								F	F			R	F
ventricosa Kutzing	R				F				F						F
n. sp. A.					F						R				*
sp.				R	R								R		
Diploneis ovalis (Hilse) Cleve		R			R										BF
cf. D. ovalis (Hilse) Cleve							R								BF
smithii (Brebisson) Cleve	R	F										R			MB
Epithemia argus (Ehrenberg) Kutzing			R												BF
intermedia Fricke									R						BF
turgida (Ehrenberg) Kutzing	F	F	R		F			R	F	F			R		BF
zebra (Ehrenberg) Kutzing	F	F	R							R					BF
zebra var. porcellus (Kutzing) Grunow	R	R									R				BF
qebra var. porcellus (Kuntzig) Grunow	R	R								F	F				BF
Eunotia formica Ehrenberg	F	R	R										R		F
indica Grunow	F	F							F	F	R				
monodon Ehrenberg									R						F
pracrupta var. pidens (Wm. Smith) Grunow	R														F
robusta var. diadema (Ehrenberg) Ralfs	R														F
rostellata Hustedt												R			*
cf. E. Serpentina Ehrenberg		R										R			*
serpentina var. transylvannica (Penocsek) Hustedt	R					R	R	F	R	R					*
sp.								R							F
tenella (Grunow) Hustedt												R			
Fragilaria cf. F. Alternata Frenguelli									F	R	R				F
pinnata Ehrenberg										F					F
sp.		R								F	R				
Gomphoneis herculena (Ehrenberg) Cleve	R				R	R									F
Gomphonema constructum var. capitatum (Ehrenberg) Grunow	R														F
grovei M. Schmidt		F	R		F		R		R	F	F				*
intricatum Kutzing											R			R	F
turris Ehrenberg															F
ventricosum var. ornata Grunow									R						F

Table 13: Continued

	U.S.G.S. DIATOM LOCALITY NO.														
	3291	3292	3930	3931	3932	3933	3934	3935	3936	3937	3938	3939	3940	3941	3942
Gyrosigma spencerii var. nodiferum (Grunow) Cleve		F							R		R				BF
sp.										R					
Hantzschia amphioxvs (Ehrenberg) Grunow									F					R	B*
sp.									R	R				R	
Liradiscus ovalis Greville								F							M*
Melosira cf. M. ambigua (Grunow) Muller									R	R					F*
distans var. lirata (Ehrenberg) Bethge	F	F	R	C			C	C	F		R				F
granulata (Ehrenberg) Ralfs				R	F		F	F	R	R					F
granulata var. angustissima Muller													F		F
granulata var. procera (Ehrenberg) Grunow							F								F
cf. M. islandica Muller	C	F	F	R	R			R			R	R			F
italica (Ehrenberg) Kutzing	F	R			R			R					R		F
cf. M. solida Eulenstein		R													*
undulata (Ehrenberg) Kutzing					R	R	F		R	R	R		R	R	BF
n. sp. A	C	C	C	F		A	C	F	F	F	F			F	*
n. sp. B			F	R	F	A		R	F	A	A	C		C	*
sp.							R		F						
Navicula americana Ehrenberg		R								R					F
bacillum Ehrenberg									R						F
cuspidata Kutzing	R	R							R						F
gastrum Ehrenberg		R	R	R		F			R	F	R				F
kotschyi Grunow										R					F
placentula (Ehrenberg) Kutzing				R			R		R						F
reinhardtii Grunow					R					R					F
tuscula (Ehrenberg) Kutzing									F						F
cf. N. viridula Kutzing										R					F
n. sp. A.	R	F			F		R		F	F	F		R		*
Nitzschia granulata Grunow									F						M
cf. N. Kutzongiana Hilse									R						B
tryblionella Hantzsch									F						B
sp.	R	R								R				B	
Opephorn martyi Heribaud		R								R			R		F
n. Sp. A.	R	R													*
sp.		R													F
Pinnularia borealis Ehrenberg							R								F
brevicostata Cleve		R							R						F
dactylus Ehrenberg									R						F
hemiptera (Kuntzing) Cleve					R										F
major (Kuntzing) Cleve											F			R	F
viridis (Nitzsch) Ehrenberg		F								R					F
viridis var. sudetica (Hilse) Hustedt									R						F
sp.	R	R		R									R	R	
Pyxilla gracilis Tempere and Forti								R							M*
Rhoicosphenia curvata (Kutzing) Grunow	R						R			R					F
Rhopalodia gibba (Ehrenberg) Muller					R										BF
Stauroneis ancops Ehrenberg	R	R		R						R					F
Stephanodiscus astraea (Ehrenberg) Grunow	F	C		C	A	R	A	F	C	F	F	R	R	F	MB
astraea var. minutula (Kuntzing) Grunow				F				F	F			R		F	
carconensis Grunow					R		F				R				*
carconensis var. minor Grunow		F	F		F			C	F	F	F			R	*
carconensis var. pusilla Grunow										R					*
niagarae Ehrenberg	F	C	C	A	A				F	C				F	F
niagarae var. magnifica Fricke	R	F	A					C		F					*
n. sp. A		F						F		F	R				*
Stephanopyxis grunowii Grove and Sturt								R							M*
Surirella cf. S. Lineraris Wm. Smith									F						R
n. sp. A		R	R		F	R	F	F		R	R		R		*
sp.			R	R											
Synedra capitata Ehrenberg										R					F
ulna (Nitzsch) Ehrenberg		R			R										F
Xanthiopyxis sp.								R							M

Table 13: Continued

3291. Delta-Mendota Canal, San Joaquin Valley, Calif. 447 + 25. Center line 6' below grade Diatomacenes coast silt. Coll. Parry Reiche, Jan. 16, 1948.

3292. Delta-Mendota Canal, San Joaquin Valley, Calif. 337 + 00. Sec. 18, T. 2 S., R. 4 E., Coll. Parry Reiche, Jan. 16, 1948.

3930. Northwesternmost well in trough." Sec. 21, T. 8 S., R. 10 E., MDB&M, Merced Co., Calif. Depth 292 ft. Coll. U.S.B.R., 1950.

3932. U.S.B.R. core sample from 0.8 mi. E and 0.97 mi. N of SW cor. Sec. 35, T. 13 S., R. 15 E., MDB&M, Tulare Co., Calif. Depth 602 ft. Coll. U.S.B.R., 1950, # 32.

3933. U.S.B.R. core sample from 0.1 mi. E and 0.75 mi. N of SW cor. Sec. 35, T. 13 S., R. 15 E, MDB&M, Fresno Co., Calif. Depth 433 ft. Coll. U.S.B.R., 1950, # 1.

3934. U.S.B.R. core sample from 0.1 mi. E and 0.75 mi. N of SW cor. Sec 35, T 13 S., R 15 E, MDB&M, Fresno Co., Calif. Depth 452 ft. Coll. U.S.B.R., 1950, # 2.

3935. U.S.B.R. core sample from 0.5 mi E. and 0.75 mi. N of SW cor. Sec. 8, T. 20 S., R. 23 E., MDB&M, Tulare Co., Calif. Depth 399.2 ft. Coll. U.S.B.R., 1950, # 24.

3936. U.S.B.R. core sample from 0.70 mi. E and 0.10 mi. N of SW cor. Sec. 23, T. 15 S., R. 12 E., MDB&M, Fresno Co., Calif. Depth 287.1 ft. Coll. U.S.B.R., 1950, # 3.

3937. U.S.B.R. core sample from 0.30 mi. E and 0.94 mi. N of SW cor. Sec. 12, T. 15 S., R. 16 E., MDB&M, Fresno Co., Calif. Depth 507.0 ft. Coll. U.S.B.R., 1950, # 4.

3938. U.S.B.R. core sample from 0.41 mi. E and 0.18 mi. N of SW cor. Sec. 36, T. 18 S., R. 22 E., MDB&M, Tulare Co., Calif. Depth 342.0 ft. Coll. U.S.B.R., 1950, # 18.

3939. U.S.B.R. core sample from 0.19 mi. E and 0.15 mi. N of SW cor. Sec. 19, T. 19 S., R. 22 E., MDB&M, Tulare Co., Calif. Depth 398.5 ft. Coll. U.S.B.R., 1950, # 20.

3940. U.S.B.R. core sample from 0.1 mi. E and 0.99 mi. N of SW cor. Sec. 31, T. 21 S., R. 24 E., MDB&M, Tulare Co., Calif. Depth 364.2 ft. Coll. U.S.B.R., 1950, # 25

3941. U.S.B.R. core sample from 0.80 mi. E and 0.97 mi. N of SW cor. Sec. 33, T. 23 S., R. 23 E., MDB&M, Tulare Co., Calif. Depth 497.0 ft. Coll. U.S.B.R., 1950, # 30.

3942. U.S.B.R. core sample from 0.01 mi. E and 0.99 mi. N of SW cor. Sec. 28, T. 25 S., R. 23 E., MDB&M, Kern Co., Calif. Depth 268.5 ft. Coll. U.S.B.R., 1950, # 40.

abundance of pine and fir to oak pollen, and the complete absence of Artemisia sp. (sagebrush) pollen, however, suggests that the climate may have been cooler than at present. Adam and others (1981), for example, show that high frequencies of oak relative to pine pollen correspond to warm conditions at Clear Lake, California, and the low frequencies of oak relative to pine pollen correspond to cold periods. Because of the more than 12,500 km^2 area of the lake in which the Corcoran Clay was deposited, the pollen record preserved represents the integrated vegetation of a large surrounding region, including the cooler high Sierra where pine and fir stands are common even during interglacial conditions.

The freshwater diatom assemblage (Table 13, Lohman, 1954) and extensive lateral continuity of the Corcoran Clay under the valley floor (Croft, 1972) indicate that the clay accumulated in a broad fresh-water lake covering most of the present area of the San Joaquin Valley. The clay is typically bluish-green and commonly laminated suggesting that reducing, quiet conditions probably prevailed on the lake bottom. Unoxidized carbonaceous matter, including possible rootlets, are common in cores penetrating the margins of the clay indicating that shallow water, possibly swamp conditions bordered the lake. The abundance of Typha (cattail) pollen and fern spores in the clay and associated peat beds, discussed earlier, supports the existence of shallow water swampy conditions bordering the lake.

Beds of well sorted fine sand are common near the base and margins of the clay (I. E. Klein, 1954, unpublished U.S. Bureau of Reclamation data). These sand beds probably represent nearshore beach or sand-bar deposits produced by waves or longshore currents reworking deposits introduced by the tributary streams and rivers. Locally, the clay thins over topographic highs suggesting that the lake inundated a prior topography without reducing it to a smooth plain by wave erosion. In the Chowchilla area, for example, Helley (1967) indicated that the clay buries a topography with 2 to 5 m local relief and, in part, rests directly on a well-developed buried soil not removed by wave action. Transgression without modification of pre-existing deposits may result if wave energy is entirely expended on the lake bottom or on a dense shore vegetation, and not on the lake margins. The surrounding marsh vegetation could have protected the lake margins from erosion. Alternatively, as Zenkovich (1967, p. 203) indicated a sandy bottom with a gradient of less than 0.0125 (about 12m/km) to a depth of 3m will dissipate all the wave energy without the formation of breakers and very likely result in an aggradational rather than a degradational shoreline. This interpretation suggests that the lake in which the Corcoran Clay was deposited may have been as shallow or shallower than 3m at a distance 240m from shore. The slope of less than 12 m/km compares favorably with present slopes of the valley floor, about 0.5 to 1 m/km for the basin floor and 2 to 18 m/km (averaging 6 to 8 m/km) for the piedmont alluvial-plain (Table 1).

Fluctuations in the size of the lake are indicated by oxidized horizons and dessication features towards the perimeter of the clay. Oxidized silt and sand beds are particularly evident in core holes 9/15-33A and 10/14-18E through the western margin of the clay and suggest probable subaerial exposure. Brecciation and high-angle slickensided joints and fractures are common in many core holes (I. E. Klein, 1954, unpublished U.S. Bureau of Reclamation report) and suggest intermittent wetting and drying of the montmorillinitic clays prior to their burial. A fluctuating lake size supports Lohman's (1954) suggestion that a fluctuating volume of water in a shallow lake produced local brackish water conditions. In the southwestern San Joaquin Valley, the Corcoran Clay bifurcates into two thick, continuous horizons separated by sand (Croft, 1972) suggesting either two major expansions and one contraction during the life of the lake or progradation of a deltaic sand facies into the southwestern part of the lake..

At its maximum extent, the lake probably did not extend beyond the present valley margin. The Corcoran Clay progressively thins from about 50 m thick near the valley axis to less than 5 m thick near the valley margin and is not preserved in the foothills of the Diablo Range or Sierra Nevada, although it may have been removed from the foothills by erosion or be present in an unrecognized sand or silt facies. The increase in silt, sand and carbonaceous matter, and decrease in diatom content, toward the margin of the clay also suggests proximity of the former lake margin.

Subsurface and Surface Correlation of the Corcoran Clay

Subsurface correlations of the Corcoran Clay have been based principally on its diatomaceous character. In many wells and cores, however, diatom information is not available and correlation is generally accomplished by E-log comparison, color and texture of the clay, and stratigraphic position. Correlations based on these criteria are difficult and in many cases speculative.

In many core holes an ash layer 10 $\pm$ 10 cm thick is present within the Corcoran Clay (Plate 24; I. E. Klein, 1954, unpublished U.S. Bureau of Reclamation report). The ash probably represents a single volcanic air-fall event and thus provides a valuable internal marker bed for correlation of the clay. The ash bed is shown on Plate 25A in core hole 13/15-35. Davis and others (1977) retrieved samples of this ash from core hole 26/23-22C near Bakersfield and X-ray flourescence analysis of rubidium, strontium and zirconium contents by Robert Drake (written communication, 1974, reported by Davis and others, 1977) indicates a chemical composition similar to the Bishop Tuff erupted 725,000 to 740,000 years ago (Dalrymple, 1980; Izett and others, 1976) from the Long Valley Caldera in the southeastern Sierra Nevada. More recently, Sarna-Wojcicki and others (1980) examined the minor and trace element chemistry of this ash in the U.S. Bureau of Reclamation core hole 23/23-33A and concluded it to be the Friant Pumice, a close relative to the Bishop Tuff erupted about 615,000 years ago (Janda, 1965; Dalrymple, 1980), possibly during a resurgent eruption of the Long Valley Caldera (Bailey and others, 1976; refer to "Subsurface" section of this report for further discussion of the Friant Pumice.

Very few surface exposures of the Corcoran Clay have been reported. In the eastern San Joaquin Valley, Marchand and Allwardt (1981, p. 34) speculate that the Corcoran Clay might be correlative with the fine-grained laminated silts and clayey silts in the lower portion of the upper member of the Turlock Lake Formation, but offer no documentation. In general, however, subsurface projections of the clay do not approach the surface in the eastern San Joaquin Valley (Plates 25A and B) and surface exposures are not likely.

In the western San Joaquin Valley, however, the Corcoran Clay does approach the surface near the Valley's margin (Plates 25A and B, Figure 27) where deep artificial and natural cuts through overlying younger alluvium may expose the clay. A gravel quarry at the mouth of Los Banos Creek (Figure 10, locality 24,) exposes a bluish-green non-diatomaceous clayey silt at its base approximately 12 to 15 m below ground level, and Carpenter (1965) reports a non-diatomaceous blue clay at the base of the California Aqueduct excavation in sec. 28, T12S, R11E. West of Los Banos, a bluish-green clayey silt is exposed in Interstate-5 roadcuts (Figure 10, locality 31) and along the southeastern margin of O'Neill Forebay (Figure 10, locality 29), and is correlated with the Corcoran Clay by Prokopovich (1973) and Herd (1979a). A uranium-thorium disequillibrium series date on groundwater nodules from the clay at O'Neill Forebay yielded an age greater than 370,000 years B.P. (T. V. Ku, unpublished O'Neill fault trench exploration data, U.S. Bureau of Reclamation, 1980). X-ray diffraction analysis of the clay (Table 7) indicates a similar clay mineralogy to that of the type Corcoran Clay.

These and twenty-three other exposures of clay and silt beds within the Tulare Formation along the valley margin were examined microscopically for volcanic ash and diatoms. None were observed preventing conclusive correlation of the subsurface Corcoran Clay with the clays exposed at the valley margin in the west-central San Joaquin Valley.

Based on the texture, color, presence of fish-bearing sand beds and subsurface projection of the Corcoran Clay in core holes, Hall (1963, 1965), Carpenter (1965), Carpenter and Long (1964), and Long and Carpenter (1965) correlated the Corcoran Clay with the sparsely diatomaceous clayey-silt of the Oro Loma Formation in the Laguna Seca Hills. These authors thus argued for the stratigraphic equivalence of the Tulare and Oro Loma Formations, supporting Anderson and Pack's (1915) original interpretation.

Paleontologic, structural and stratigraphic data obtained during this study, however, indicate that the clayey-silt unit of the Oro Loma Formation and the Corcoran Clay Member of the Tulare Formation are not correlative. (1) The subsurface Corcoran Clay thins from over 50 m thick in the valley axis to less than 12 m thick at the valley margin near the Laguna Seca Hills (Plate 25B), while the clayey-silt in the upper Oro Loma is 20 to 22 m thick--an abrupt thickening not present elsewhere in the Corcoran Clay (Plates 25 A and B). (2) Late Pleistocene vertical offset of greater than 125 m (refer to "Late Cenozoic Structure" section of report) along the range front San Joaquin Fault system (Herd, 1979b) has occurred in this area since the Corcoran Clay was deposited. Removal of this offset produces clear stratigraphic separation of the Oro Loma clayey-silt unit from the Corcoran Clay Member of the Tulare Formation. (3) Diatoms from these two units suggest different ages and somewhat different depositional environments. Diatoms from the Corcoran Clay (Table 13) are indicative of a late Pliocene(?) or Pleistocene, shallow, freshwater lake (Lohman, 1954), while diatoms from the clayey-silt unit of the Oro Loma Formation are indicative of a late Miocene or early Pliocene(?), deep, slightly alkaline lake (J. Platt Bradbury, written communication, 1981). The diatoms in the silty-clay, however, are sparse and commonly have broken and corroded margins permitting the possibility of reworking from older sediments into a silty, non-diatomaceous facies of the Corcoran Clay. The absence of other late Miocene lacustrine deposits in the surrounding region to provide a source, and the consistent representation of extinct species and lack of more modern varieties of the Corcoran Clay makes this interpretation unlikely.

Age of the Corcoran Clay

Radiometric and paleomagnetic data from the subsurface of the San Joaquin Valley indicate that the Corcoran Clay Member of the Tulare Formation accumulated approximately 615,000 to 740,000 years ago. In the eastern San Joaquin Valley, the clay is believed to conformably underlie the Friant Pumice Member of the Turlock Lake Formation (Marchand and Allwardt, 1981; Janda and Croft, 1967; Frink and Kues, 1954; refer to "Subsurface Stratigraphy" section of this report for description of the pumice). Sanidine from the pumice near the Town of Friant, California, was dated by potassium-argon as 615,000 ± 22,000 years B.P. (recalculated to current I.U.G.S. constants by Dalrymple, 1980; refer to Janda, 1965, for locality information and original dates). Core holes in Madera County, however, show that, although the Corcoran Clay underlies the main body of the ash, the uppermost beds of the clay contain from 2 to 30% Friant Pumice ash shards (Plates 25A and B). Sarna-Wojcicki and others (1980), on the basis of chemistry, have also correlated the Friant pumice with the thin 10 ± 10 cm ash beds observed within the Corcoran Clay in core holes near Bakersfield. These data indicate that the uppermost Corcoran Clay probably post-dates eruption of the Friant Pumice 615,000 years ago but that the main body of the clay accumulated prior to eruption of the pumice.

Investigations by Davis and others (1977) and Kukla and Opdyke (1975) have shown that a paleomagnetic reversal, probably corresponding to the Bruhnes-Matuyama geomagnetic boundary, immediately underlies the Corcoran Clay in core hole 26/23-22C. Age of the reversal is based principally on the age of the Bishop ash which lies immediately above the reversal in the southeastern Sierra Nevada. Dalrymple (1980) reports a potassium-argon age of 725,000 ± 15,000 years and Izett and others (1976) report a fission-track age of 740,000 ± 50,000 years for the Bishop ash. These data, therefore, place approximate age brackets of 615,000 to 725-740,000 years for accumulation of most of the Corcoran Clay.

Origin of the Corcoran Clay

The Corcoran Clay Member of the Tulare Formation accumulated in a freshwater, probably shallow lake occupying most of the San Joaquin Valley at its maximum (Frink and Kues, 1954; Lohman, 1954; Croft, 1972; Davis and others, 1959). Several hypotheses have been advanced to explain the origin of the clay; the goal of each being to produce a closed basin throughout the San Joaquin Valley capable of enclosing a large, fresh water lake (see Davis and others, 1959, for review). These hypotheses typically invoke a climatic and/or tectonic event impeding northward drainage of the lower San Joaquin River.

Climatic hypotheses include the folowing: (1) an interglacial rise in sea level induced eastward retreat of the Sacramento-San Joaquin Delta and subsequent impoundment of the lower San Joaquin River drainage; and (2) glacial-age growth of the Cosumnes, Mokelumne, Stanislaus and Tuolumne River fans constricted the northern San Joaquin Valley basin floor and ultimately dammed northward drainage of the lower San Joaquin River.

Problems with these climatic hypotheses, however, include: (1) the lack of similar, extensive lake deposits in the stratigraphic record produced during the later glacial periods; (2) glacial-outwash fans from the Kings, Joaquin, and Merced Rivers, as large or larger than the Mokelumne and Cosumnes, did not have a significant impact on the aerial distribution of the lake (Figure 26, Croft, 1972). The Corcoran Clay extends virtually undeflected beneath the present-day toes of these fans; and (3) judging from the marine oxygen isotope record, the age range of the clay may span at least two glacial cold stages.

Tectonic hypotheses generally involve the timing of deformational events in the Coast Ranges of California. Uplift of the southern Coast Ranges probably blocked the Coalinga and San Benito marine outlet sometime in the early or middle Pleistocene, while offset along the San Andreas and related faults may not have opened the Carquinez Strait or Golden Gate until 600,000 years ago. The timing of these events, however, is very uncertain. Judging by the distribution of paleocurrents in the Paso Robles Formation (Galehouse, 1967), the San Benito and Coalinga outlet probably closed much earlier in the Pleistocene than 740,000 years ago. Although removal of displacement along the San Andreas and Hayward faults, using geologically reasonable sliprates, allows closure of both the Carquinez Strait and Golden Gate by 600,000 years ago, if the bay outlets were closed during the early Pleistocene, the question of why the Corcoran Clay did not form until 740,000 years ago remains a significant problem. Alternatively, if the Carquinez Strait or Golden Gate were open prior to 740,000 years ago, displacement along the San Andreas or Hayward faults may have temporarily juxtaposed a topographic high across one or both of these outlets impeding drainage from the Great Valley during the time required.

An alternative hypothesis to the climatic and tectonic models above, is the interaction between rates of sedimentation and subsidence in the San Joaquin Valley. As long as sedimentation equals or exceeds subsidence, subaerial exposure will prevail on the valley floor. If, for some reason, deposition fails to keep pace with subsidence, a closed basin will result similar to the present southern San Joaquin Valley. Marine waters will not invade the valley through the straits previously mentioned as long as the valley remains above sea level or a structural sill or topographic high in the straits separates the valley from the ocean. Because the Corcoran clay is thickest where it is farthest below the valley surface (Plates 25A and B), the structural and topographic axes of the valley probably coincided during accumulation of the clay. Such a coincidence is unlikely when the rate of sedimentation equals or exceeds the rate of subsidence because in this case the position of the topographic axis is governed principally by the contrast in rates of sedimentation from the adjacent Sierra Nevada and Coast Ranges. Previous positions of the topographic axis are reflected by the distribution of Sierran and Coast Range alluvium in the valley subsurface and have rarely coincided with the structural axis. See Plates 25A and B. Further discussion of subsidence and sedimentation rates and their affects on the geography of the valley is presented in the "Subsurface Stratigraphy" section of this report). Because the two axes probably coincided during accumulation of the Corcoran Clay, the rate of sedimentation probably did not equal or exceed the rate of subsidence in the valley at that time.

Possible scenarios for the origin of the lake, therefore, may simply involve either decreasing the rate of sedimentation and/or increasing the rate of subsidence in the valley. Such a change in rates can result either from a climate change favorable to increasing vegetation cover and thus stabilizing the surrounding hillslopes and thus decreasing stream sediment yields to the valley, or greater tectonic downwarping of the San Joaquin Valley. A climatic model for changing the rates of sedimentation in the valley is presented in the "Depositional Model" section of this report. However, because the clay is unique in its extent below the San Joaquin Valley, a greater rate of subsidence about 700,000 to 600,000 years ago is more likely to have caused the lake than a model dependent on glacial-interglacial fluctuations.

Correlation of the Tulare Formation

Pliocene and Pleistocene deposits of principally fluvial origin are common in California, particularly the southern Coast Ranges. The Tulare Formation is, at least in part, coeval with the Santa Clara Formation in the San Franciscan Bay Region, the Livermore gravels of Livermore Valley, the San Benito gravels south of Hollister, the Paso Robles Formation in the Salinas Valley Region, the Peckham gravels of Lieth (1949) near Quien Sabe Peak, the Harold Formation in Antelope Valley area, the upper Laguna Formation(?), North Merced Gravel and Turlock Lake Formation northeast of the San Joaquin River, the Kern River Formation east of Bakersfield and the Red Bluff Formation in the Sacramento Valley. Based on the presence of the Friant Pumice and/or Bishop ash (Sarna-Wojcicki and others, 1980), the Tulare is also, at least in part, coeval with the deformed Bautista beds west of the Salton trough in the Anza-Borrego area, the Santa Barbara Formation in the Ventura basin, and Pleistocene lacustrine beds in the Lake Tecopa area of southeastern California.

LOS BANOS ALLUVIUM

Definition and General Description

Los Banos alluvium is the informal name given to the unconsolidated deposits of gravel and sand covering broad areas of the foothills of the Diablo Range, that are demonstrably younger than the Tulare Formation and older than San Luis Ranch alluvium based on stratigraphic superposition and pedologic (Table 10) and geomorphic criteria. Los Banos alluvium is generally less deformed and weathered than alluvium of the Tulare Formation. Within the foothills, the deposits commonly lap onto or veneer the Tulare Formation--in particular immediately south of Little Panoche Creek, north of Quinto Creek and in Carrisalito Flat (Figure 10, localities 12, 20 and 33)--and are inset into by deposits of San Luis Ranch alluvium (Figures 20 and 26). Valleyward, the deposits are everywhere overlain by younger San Luis Ranch and Patterson alluvium.

Within the foothills, most of the Los Banos alluvium veneers broad pediments carved across the crest of the hills. Remnants of the pediments are preserved discontinuously through the study area from south of Little Panoche Creek to north of Orestimba Creek (Figure 25). The surfaces are continuous with terraced deposits of sand and gravel bordering many of the major Diablo Range drainages and merge eastward with thick, unconsolidated deposits of gravel, sand, silt and clayey silt in the San Joaquin Valley. The name is thus proposed to include both the pediment veneer deposits as well as the thick unconsolidated deposits on the San Joaquin Valley and foothill stream valleys.

The foothill pediments include the extensive pediments carved across the Laguna Seca Hills north of Little Panoche Creek (Figure 25 and 31). Hall (1963) referred to these surfaces as the "Las Aguilas Land Surface" because early Spanish settlers termed the area "El Camino de Las Aguilas" or "Road of the Eagles". This name is not adopted for the deposits veneering the surface, however, because no geographic locality is present in the area under that name.

Los Banos alluvium is interpreted to be a complex of alluvial deposits laid down on former piedmont alluvial plains of the western San Joaquin Valley. Sedimentary structures, including channeled contacts, laminated bedding, clast imbrication and abrupt lateral changes in grain size and degree of sorting strongly indicate deposition by fluvial processes. Deposits in the San Joaquin Valley are thus interpreted to be coalescing alluvial-fans on the former piedmont plain, while the terraced deposits bordering the major Diablo Range drainages are interpreted to be remnants of former stream floodplains formed by lateral erosion. Because the pediment deposits exhibit all of the above sedimentary structures and are laterally continuous with the alluvial-fan and stream terrace deposits, the pediments are interpreted to be formed by extensive lateral stream planation rather than by headward erosional retreat of a former range front. If so, they are thus coeval with the alluvial-fan and stream deposits and represent major segment of the former piedmont alluvial plain.

Based principally on relative topographic position, Los Banos alluvium includes deposits veneering at least two and possibly three distinct former alluvial plains of regional extent. These deposits are informally designated the upper, middle, and lower members of Los Banos alluvium. The older two members are generally well preserved and very extensive regionally, while the youngest member is generally poorly preserved and generally underlies restricted stream terraces along major Diablo Range drainages.

Previous Literature

Previous geologic work on post-Tulare deposits in the western San Joaquin Valley is limited to a few pioneering regional and local studies. These investigations are summarized here for the Los Banos alluvium as well as the younger San Luis Ranch and Patterson alluvial units to be discussed later.

Arnold and Anderson (1910) first recognized prominent paired alluvial terraces younger than the Tulare Formation along streams draining the Coast Ranges. Their photograph (page 40a) of Zapato Creek shows a sequence of five terraces above the Holocene floodplain. They indicated that the highest of these terraces merges with an extensive alluvial surface preserved across the crest of the foothill belt in the Coalinga area. Anderson and Pack (1915) subsequently described the regional occurrence of paired terraces along streams draining the eastern flank of the Diablo Range north of the Coalinga area.

In 1951, McGill described alluvial deposits and landforms in the southwestern San Joaquin Valley and San Emigdio Mountains. His stratigraphic units are listed in Figure 27. He named the slightly deformed, post-Tulare deposits preserved along streams draining the San Emigdio Mountains the Los Lobos Formation. Undeformed alluvium post-dating the Los Lobos Formation he informally designed as "Older alluvium" if preserved as elevated terraces, and "younger alluvium" if essentially unweathered and unmodified.

Previous studies which propose informal divisons of late Cenozoic deposits in the west-central San Joaquin Valley include those by Green and Cochran (1958) and Herd (1979a). Green and Cochran divided the unconsolidated deposits into deformed alluvium of the Tulare Formation and undeformed "older" and "younger" post-Tulare alluvium. Patterson alluvium and the upper member of the San Luis Ranch alluvium defined in this study are included in their "younger" alluvium. The Los Banos alluvium and lower member of San Luis Ranch alluvium are included in their "older" alluvium. Their Tulare Formation encompasses portions of the continental deposits mapped in this study as Los Banos alluvium, the Pliocene(?) and Pleistocene Tulare Formation and Miocene and Pliocene(?) Oro Loma Formation.

Herd (1979a) mapped unconsolidated late Cenozoic deposits along a portion of San Luis Creek in the vicinity of O'Neill Forebay. Based on pedologic and geomorphic criteria, he informally recognized a five-fold division; from youngest to oldest, Qa, QOa_1, QOa_2, QOa_3, and the Tulare Formation. In this study, Los Banos alluvium includes most of Herd's Tulare and QOa_3, the members of San Luis Ranch alluvium resemble QOa_2 and QOa_1 and Patterson alluvium resembles Qa.

Bedrock studies in the west-central San Joaquin Valley by Leith (1949), Briggs (1953), Sonneman (1958), Dibblee (1975) and Payne (1951) have typically grouped Los Banos alluvium with the Tulare Formation and Patterson and San Luis Ranch alluvium as undifferentiated Quaternary alluvium or younger terrace deposits. Anderson and Pack (1951), however, included most of the Los Banos alluvium veneering pediments in the foothills of the Diablo Range in their Pleistocene "terrace deposits".

Subsurface studies in the San Joaquin Valley by Page and LeBlanc (1969), Hotchkiss and Balding (1971), Croft (1968, 1972) and Miller, Green and Davis (1971), among others, have typically grouped Los Banos alluvium with the Tulare Formation or, along with Patterson and San Luis Ranch alluvium, with undifferentiated Quaternary alluvium.

Distribution

Los Banos alluvium veneers remnants of at least two ancient pediments in the foothills of the east-central Diablo Range (Figure 31). These surfaces are discontinuously preserved in a northwest-trending belt ranging from 5 km in width north of Orestimba Creek to 20 km in width between Little Panoche and Ortigalita Creeks (Figure 25; see Figure 3 for localities). They truncate steeply dipping beds of the Panoche, Moreno, Laguna Seca, Tesla, Kreyenhagen and Oro Loma Formations south of San Luis Creek and of the Tesla, Domengine and Kreyenhagen Formations, sandstone of Poverty Flat, and Valley Springs and Carbona Formations north of Quinto Creek.

The veneer of alluvium is generally less than 4 m thick (Figure 32). Locally, however, the veneer is 8 to 12 m thick and may represent former stream channels incised into underlying bedrock during formation of the pediment (Figure 10, locality 38 for example, Newman (7.5-minute Quadrangle, Plate 2). The veneer of alluvium generally grades laterally into stream

Figure 31: Distant view of pediments of Los Banos alluvium carved over the Laguna Seca Hills north of Little Panoche Creek. Little Panoche Creek crosses from left to right in the middle foreground. Higher pediment on left is the lower member of Los Banos alluvium, lower pediment on right is middle member of Los Banos alluvium. Light brown soil in foreground is developed on the upper member of San Luis Ranch alluvium; reddish brown soil north of Little Panoche Creek is developed on the lower member of San Luis Ranch alluvium (view N30oW from Sec. 25, T13S, R11E).

Figure 32: Pediment veneer of sandy gravel channeled into Tertiary bedrock in the foothills of the Diablo Range near Orestimba Creek. The veneer merges valleyward with terrace and alluvial fan deposits of the lower member of Los Banos alluvium. The gravel includes locally derived, angular, white clasts of Kreyenhagen diatomite and large brown clasts of sandstone of the Tulare or Carbona Formation, and more distantly derived or reworked well-rounded clasts of the Franciscan assemblage. The presence of channeling, clast imbrication and detritus from a distant source indicates, at least in part, fluvial development of the pediment rather than headward erosional retreat of a former mountain front. Shovel handle is 50 cm long (Newman 7.5-minute Quadrangle, Plate 2, SW 1/4, Sec. 20, T7S, R8E).

terrace deposits exceeding 10 m in thickness along the major Diablo Range drainages (Figure 33). This transition is particularly well exposed in California Aqueduct cuts in the SW 1/4, sec 18 and W 1/2, sec 17, T7S, R8E (Newman 7.5-minute Quadrangle, Plate 2).

The foothill remnants of Los Banos alluvium are best preserved in the Laguna Seca Hills immediately north of Little Panoche Creek (Figure 31 and 10, locality 18). This area is suggested as the type locality because the deposit is well preserved, well exposed and displays most of the geomorphic and pedologic criteria for recognition of the unit. Pediment gravels are extremely well exposed in gully walls in sections 7 and 18, T13S, R11E; stream terrace deposits are well exposed along Ortigalita Creek in sections 7, 20, 29, and 30, T11S, R10E; and alluvial fan deposits are well exposed along Little Panoche Creek in section 16, T13S, R11E.

All three members of Los Banos alluvium are preserved in the Laguna Seca Hills type area. The lower and middle members form the extensive, well-preserved surfaces over the Laguna Seca Hills (Figure 31 and Figure 10 locality 18, Laguna Seca Ranch, Charleston School and Ortigalita Peak NW 7.5-minute Quadrangles, Plates 14, 15, and 20) while the upper member is best displayed as a relatively small, inset terrace along Los Banos Creek in sections 6 and 7, T11S, R10E. The three members are also preserved in the vicinity of Orestimba Creek and south of San Luis Creek, but in most areas only the older two members are recognized.

Where not faulted by the valley margin San Joaquin fault (Herd, 1979b), the foothill pediments descend smoothly to the valley floor and grade imperceptibly with alluvial-fan deposits. Within the valley, these deposits overlie alluvium of the Tulare Formation and are overlain by San Luis Ranch and Patterson alluvium. Superposition, indicated by buried soils or erosional unconformities, thus becomes the primary mapping criterion. For example: an eroded buried soil developed on Tulare deposits and overlain by Los Banos alluvium is exposed in Interstate-5 and California Aqueduct cuts in secs 5, 8 and 18, T7S,R8E (Newman 7.5-minute Quadrangle, Plate 2 Figure 10, locality 40); and an exceptionally well preserved buried soil developed on Los Banos alluvium and overlain by San Luis Ranch alluvium is exposed in a tractor trench and stream bluff in the S 1/2, SW 1/4, sec 11, T13S, R11E (Figure 24 and 34 and Figure 10, locality 16 Hammonds Ranch 7.5-minute Quadrangle, Plate 21).

Fan deposits of Los Banos alluvium are generally exposed at the valley surface only in small discontinuous patches adjacent to the foothills near the mouths of major Diablo Range drainages. Well preserved outcrops of this variety are present near the mouths of Little Panoche Creek, San Luis Creek, Garzas Creek and Orestimba Creek (Figure 25).

A unique exposure of Los Banos alluvium is present, however, several miles from the valley margin on the coalescing alluvial fans of Garzas and Quinto Creeks (Figure 25 and Figure 10, locality 34, Ingomar 7.5-minute Quadrangle, Plate 5). In this area, hills of Los Banos alluvium with 3 to 10 m relief rise above younger fan deposits of Garzas and Quinto Creeks. The hills probably represent a dissected, former coalescing alluvial-fan deposited by Garzas and Quinto Creeks. The hills lie along the trace of a possible broad, northeast-trending Quaternary anticline and may represent the

Figure 33: Upper member of Los Banos alluvium near the mouth of Panoche Creek. The lack of buried soils or weathered horizons suggests that depositon probably occurred rapidly and/or continuously. Alternatively, such horizons may have been removed by erosion. The deposit contains locally derived white, angular clasts of Kreyenhagen diatomite reflecting erosion of the foothill belt, possibly during the bevelling of the broad foothill pediments. (NE 1/4, Sec. 15, T15S, R12E, Chounet Ranch 7.5-minute Quadrangle).

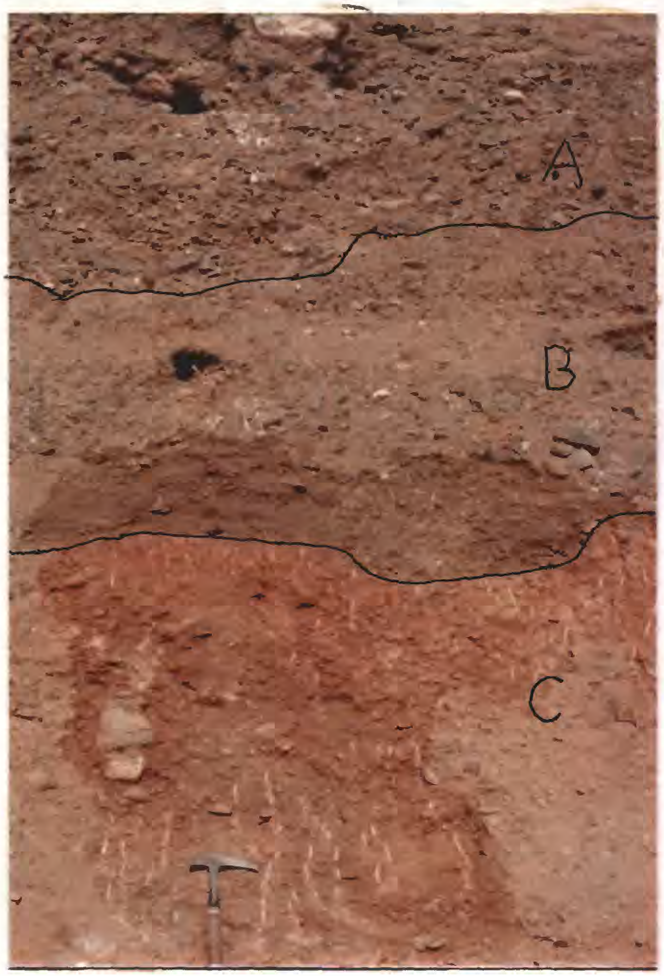

Figure 34: Upper member of Los Banos alluvium overlain by the lower member of San Luis Ranch alluvium. The lower member of San Luis Ranch alluvium consists of poorly-sorted, possibly mudflow deposits containing clasts exceeding 25 cm across (A) underlain by by laminated, moderately sorted, possibly fluvial deposits (B). The fluvial deposits are channeled into a well-developed, red (5YR hue) buried soil formed on poorly-sorted, possibly mudflow deposits in the upper portion of the upper member of Los Banos alluvium (C). The short, vertical, white streaks in the Los Banos alluvium are weathered clasts streaked by hammer blows during escavation of the exposure. Hammer is 30 cm long (Figure 10, locality 16, Hammonds Ranch 7.5-minute Quadrangle, Plate 9).

valleyward extension of this structure. The southeastern limb of the anticline is well exposed in the foothills north of Quinto Creek where beds of Tulare alluvium dip 16 to 20° to the southeast in Interstate-5 roadcuts (Figure 28 and Figure 10, locality 33 Howard Ranch 7.5-minute Quadrangle, Plate 4).

Lithology

Los Banos alluvium consists of unconsolidated, poorly- to well-bedded gravel, sand, silt and clayey silt similar in composition and texture to deposits of the Tulare Formation. Clast lithologies reflect bedrock lithologies of the Diablo Range. Clasts of graywacke, metagraywacke, red and green quartzite-veined chert and, locally, andesite and basalt are common. Less common lithologies include greenstone, serpentinite, diatomite, black chert and gabbro. These lithologies are derived principally from the Franciscan assemblage, Great Valley Sequence and locally, the Quien Sabe Volcanics and Kreyenhagen Formation. The clasts range from subangular to well-rounded, however, suggesting that some may be second or third generation, reworked from the Tulare, Oro Loma and/or Carbona Formations.

Los Banos alluvium ranges from coarse in texture to fine-grained depending on the geographic distribution of depositional environments discussed earlier (Figures 5 and 15, Table 9). Deposits underlying stream terraces and veneering the broad foothill pediments consist mainly of poorly bedded, poorly sorted, coarse sandy gravel and gravelly coarse sand. Clasts are crudely imbricated and range in average size from 2 to 8 cm, with maximum size as much as 25 cm. The coarser beds are commonly channeled into underlying deposits, or in the case of pediment gravels, into underlying bedrock (Figures 18 and 32 for example). Exposures of alluvial-fan deposits commonly show a vertical succession of well-bedded, well-sorted silt and fine sand overlain and channeled by moderately-bedded, poorly sorted coarse sandy gravel. These deposits are particularly well exposed in Interstate-5 and California Aqueduct exposures between San Luis and Los Banos Creeks and north of Orestimba Creek (Volta and Newman 7.5-minute Quadrangles, Plates 2 and 9 Figure 10, between localities 24 and 31 and localities 39 and 40). The beds of silt and fine sand are generally planar, laterally continuous at the outcrop scale and internally laminated. Beds average 0.5 to 1 m thick and laminae average 3 to 8 mm thick. The beds of coarse sandy gravel are generally massive, lenticular and average 2 to 4 m thick.

Surface Modification

Erosional dissection of Los Banos alluvium has produced a typical relief of low, rolling hills between steep-walled canyons. The relief is particularly evident in the Laguna Seca Hills, south of San Luis Creek and north and south of Orestimba Creek. Under similar local conditions of climate, vegetation, availability of water and rate of deformation, the size and density of gulleying increase with age. In the Laguna Seca Hills, for example, an area of late Pleistocene uplift, the upper member of Los Banos alluvium is moderately dissected (sec 7, T11S,R10E Ortigalita Peak NW 7.5-minute Quadrangle, Plate 14), the middle member deeply dissected, locally into underlying bedrock (sec 1, T12S,R10E Charleston School 7.5-minute Quadrangle, Plate 15) and the lower member is generally eroded to bedrock (sec 36, T12S, R10E Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20). North of Ortigalita Creek, on the other hand, an area of less active Pleistocene deformation, the middle and upper members are only moderately eroded, commonly 5 to 10 m thick (sec 30, T11S,R10E Charleston School 7.5-minute Quadrangle, Plate 15) and underlying bedrock is rarely exposed (the lower member is not present in this area).

Relict soils developed on Los Banos alluvium--chiefly the Denverton, Los Banos, Herdlyn, Positas, Linne, Keefers, Ohmer and Ambrose soil series (Cole and others, 1943, 1948, 1952; Harradine, 1950, Harradine and others, 1956; Isgrig, 1969; McLaughlin and Huntington, 1968) typically have very well developed zonal profiles. Each soil series is recognized on every Los Banos Valley member except the Herdlyn and Ambrose series which are only mapped on the upper member. The Kettleman soil series is a residual soil commonly mapped on eroded side slopes (Table 10).

The most representative soils are the Los Banos and Denverton (Mollic Haplargids) series. The characteristic properties of these soils are shown in Table 10 and the Los Banos soil is described below. These soils generally have a thick, reddish and yellowish-brown (5YR and 7.5YR hues), highly calcareous argillic horizon with distinct, discontinuous clay films on ped surfaces.

Los Banos Soil Series

A1 -- 0 to 20 cm -- Reddish brown (5YR 5/4) dry, light clay loam, reddish brown (5YR 4/4) moist; weak coarse angular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; abundant very fine vertical roots; many medium tubular pores; few fine gravels; mildly alkaline (pH 7.4); clear wavy boundary. (10 to 33 centimeters thick.)

B1 -- 20 to 80 cm -- Yellowish red (5YR 4/6) dry, light clay loam, dark yellowish red (5YR 3/6) moist; weak coarse prismatic structure; slightly hard, friable, slightly sticky, slightly plastic; plentiful very fine vertical rootmarks; few moderately thick clay films on ped faces and in pores; disseminated lime, strongly effervescent, lime also occurs as fine irregular shaped filaments or threads; few fine gravels; mildly alkaline (pH 7.8); clear irregular boundary. (23 to 66 centimeters thick.)

B2tca -- 80 to 105 cm -- Yellowish red (5YR 4/8) gravelly heavy clay loam, dark yellowish red (5YR 3/6) moist; massive; hard, firm, non-sticky, slightly plastic; plentiful micro random roots; common very fine discontinuous tubular and common interstitial pores; many thick clay films line pores; disseminated lime slightly effervescent and large irregular soft masses and concretions of lime; moderately alkaline (pH 8.0); clear irregular boundary. (17 to 28 centimeters thick.)

IIC1 -- 105 cm + --Semi-consolidated mixture of calcareous sand, gravel and clay, very dense and compact.

<u>Type location</u>: Approximately 10 miles southwest of Los Banos, Merced County, California. 2.6 miles southwest of oil pumping station at west end of Mervel Avenue in the NE 1/4, SE 1/4, sec 20, T11S,R10E; approximately 100 feet south of paved road.

National Cooperative Soil Survey, Department of Agriculture

Where unmodified by recent agriculture practices, a pronounced and extremely well developed micro relief is common on Los Banos alluvium (NE 1/4, sec 28, T13S,R11E; and NE 1/4, sec 23, T9S,R8E for example). The microrelief consists of regularly spaced, concentric mounds 3 to 6 m in average diameter and about 0.5 to 1 m average height. They are present on the strongly developed Denverton and Los Banos soil series despite their lack of well-defined hard pans. The origin of these mounds has not been investigated in this study. Similar microrelief in other areas however, has variously been attributed to ground squirrel or pocket-gopher activity, wind modification, and the shrinking and swelling of montmorillinite-rich soils (Page and others, 1977; Arkley and Brown, 1954).

<u>Age and Correlation</u>

Based on stratigraphic superposition and meager paleontologic and absolute age data (Table 12), the three members of Los Banos alluvium are interpreted to have accumulated between about 535,000 and 80,000 years ago. The upper member contains bone and teeth fragments of <u>Equus</u> sp. suggesting an Irvingtonian or younger age (less than 1.9 my) and bone fragments of <u>Bison</u> sp. suggesting a late Rancholabrean age (less than 140,000 years, C. A. Repenning, written communication, 1981, refer to Table 12 for localities). Uranium-thorium series dates on these bones and teeth indicate an age of 95,167 + 1632 years for the <u>Bison</u> sp. and 81,661 + 188 years for the Equus sp. (E. L. Begg, oral communication, 1981). The <u>Equus</u> sp. remains were recovered in U.S. Bureau of Reclamation core hole 15/13-16N (Plate 25A) and are associated with a possible buried soil separating the upper member of Los Banos alluvium from the lower member of San Luis Ranch alluvium. The uranium-thorium series age, therefore, may date the intervening non-depositional period between Los Banos and San Luis Ranch alluvium.

Ground water carbonate nodules collected from the middle member of Los Banos alluvium during U.S. Bureau of Reclamation trench studies near O'Neill Forebay (U.S. Bureau of Reclamation, O'Neill Dam fault study, unpublished report, 1980) yield preliminary uranium-thorium disequilibrium series dates of 112,000 + 14,000 and 160,000 + 15,000 years B.P. (T. Ku, oral communication, 1981). Ground water carbonate, however, is subject to repeated dissolution and reprecipitation, and these dates, therefore, can only be considered minimum values.

In the San Joaquin Valley subsurface, Los Banos alluvium overlies a strongly developed buried soil overlying the Corcoran Clay Member of the Tulare Formation (Plate 25A and B, U.S. Bureau of Reclamation core hole 12/10-1B, for example). Minimum age of the Corcoran Clay is about 615,000 years and at least 80,000 to 100,000 years is required for development of the buried soil (D. E. Marchand, 1979, oral communication); thus Los Banos alluvium is interpreted to be younger than about 535,000 years B.P.

Correlation of Los Banos alluvium with other alluvial stratigraphies in California, the marine oxygen isotope record and the glacial stratigraphy of the Sierra Nevada is shown in Figure 27. The alluvium occupies the same approximate age range as the Los Lobos Formation in the San Emigdio Mountains (McGill, 1951), the Riverbank Formation in the eastern San Joaquin Valley (Marchand and Allwardt, 1981), the Riverbank Formation in the Sacramento Valley (Harwood and others, 1981) the Tylerhorse Formation in the Antelope Valley (Ponti, 1981) and older alluvium QOa_2 in the southeastern San Joaquin Valley (J. Alan Bartow, in press). The alluvium spans oxygen isotope stages 5 through 10 (Emiliani, 1978) and thus probably three major glacial to interglacial climatic transitions.

SAN LUIS RANCH ALLUVIUM

Definition and General Description

San Luis Ranch alluvium is an informal name given to the undeformed, generally unweathered, unconsolidated deposits of gravel, sand, silt and clay covering large areas of the present western floor of the San Joaquin Valley, that are demonstrably younger than Los Banos alluvium and demonstrably older than Patterson alluvium based on stratigraphic superposition and pedologic (Table 10) and geomorphic criteria within the valley, they veneer deposits of Los Banos alluvium, commonly bearing a well developed buried soil near the fan-head (Figures 24 and 34) and are, in turn, either overlain by a thin veneer (Figure 35) or constructional ridge (Sec 19 and 30, T8S, R9E, Howard Ranch 7.5-minute Quadrangle, Plate 4, for example) of Patterson alluvium (Figure 35) or occupy topographically high positions between inset channel deposits of Patterson alluvium (Sec 11, 14, 15, T13S, R11E, Hammonds Ranch 7.5-minute Quadrangle, Plate 21, for example). Within the foothills, deposits of San Luis Ranch alluvium were laid down on topography deeply incised into the geomorphic surface of Los Banos alluvium.

San Luis Ranch alluvium is nearly identical in lithology, range of textures, and sedimentary character to Los Banos alluvium. Deposits within the San Joaquin Valley are thus interpreted to have accumulated on a complex of coalescing alluvial-fans deposited by streams draining the Diablo Range.

San Luis Ranch alluvium records at least two cut-and-fill events based on topographic position (Figures 20, 26 and 36) and relative age deduced from the degree of soil-profile development (Table 10). Deposits associated with these events are informally designated as the upper (younger) and lower members of San Luis Ranch alluvium. These members are distinct fill deposits on stream terraces within the foothills of the Diablo Range and alluvial-fans in the San Joaquin Valley.

Locally, one or more poorly preserved, unpaired strath terraces are cut into the lower member (Figure 26). These terraces are common along several of

Figure 35: Veneer of Patterson alluvium overlying a weakly-developed, brown (10YR hue) buried soil formed on the upper member of San Luis Ranch alluvium in Little Panoche Valley. Hammer handle is 30 cm long (Figure 10, locality 11).

Figure 36: Terrace sequence along Little Panoche Creek. The terrace on the upper left skyline forms a broad surface across the foothills and is the middle member of Los Banos alluvium. The lower four terraces are confined to Little Panoche Valley and include members of the San Luis Ranch alluvium and of the Patterson alluvium. The lower (older) (A) and upper (younger) (C) members of the San Luis Ranch alluvium and the Patterson alluvium (D) commonly underlie terraces that are paired at numerous localities along the course of Little Panoche Creek and are one to ten meters thick. The intermediate terrace (B) is an unpaired strath cut down to a gravel horizon cemented during a period of groundwater carbonate accumulation.

the major Diablo Range streams including Little Panoche Creek (secs 20 and 21, T13S, R11E), Los Banos Creek (secs 6 and 7, T11S, R10E (Figure 10, locality 14) and north of the study area, Corral Hollow (sec 19, T3S, R5E; Tracy 7.5-minute Quadrangle). Soils formed on the straths are laterally continuous with soils developed on Los Banos alluvium and buried by the lower member of San Luis Ranch alluvium suggesting that the straths probably were cut during a single period of stream incision shortly after deposition of the lower member. I do not believe they have regional significance.

<u>Distribution</u>

San Luis Ranch alluvium is well preserved within the foothills of the Diablo Range as stream terraces or valley fills. These deposits are present along every major Diablo Range drainage but are not widely distributed in interfluve areas of the foothills. Their presence in valleys deeply incised into the foothill belt suggests that the foothills were elevated prior to deposition of San Luis Ranch alluvium.

In these foothill valleys, the upper (younger) member is typically inset from 1 to 15 m into the lower (older) member. The amount of separation typically increases mountainward from the valley front (Figure 37) suggesting that either streams with gentler gradient deposited the upper member or uplift tilted the lower member eastward prior to deposition of the upper member. The upper member only veneers the lower member in subsiding foothill basins such as Carrisalito Flat (T12S, R9E) and Panoche Valley (sec 30, T15S, R11E). In these areas the upper member occasionally buries a laterally continuous soil developed on the lower member suggesting that an interval of non-deposition and surface stability separated their accumulation.

The foothill stream terrace and valley fill deposits merge downstream with stream terrace and alluvial-fan deposits within the San Joaquin Valley. The general distribution of the San Luis Ranch alluvium is shown in Figure 25. At the fan-heads the deposits commonly lie in broad shallow valleys cut into Los Banos alluvium (for example Little Panoche and Orestimba Creeks). Farthur out on the fans, however, the San Luis Ranch alluvium overlies older alluvium.

Buried soils commonly separate the alluvial units of different age on the upper fan. For example, a buried soil developed on Los Banos alluvium and overlain by the lower member of San Luis Ranch alluvium is well-exposed in a tractor trench and in stream cuts along Little Panoche Creek in the S 1/2, SW 1/4, Sec 11, T13S, R11E (Hammonds Ranch 7.5-minute Quadrangle , Plate 21, Figure 10, locality 16). Locally, erosion has stripped the lower member of San Luis Ranch and exhumed the soil developed on the Los Banos alluvium as a strath terrace along Little Panoche Creek (NW 1/4, Sec 14 and E 1/2, Sec 15, T13S, R11E). On the south wall of San Luis Creek (NW 1/4, Sec 6, T10S, R9E) deposits of the upper member of San Luis Ranch overlie a well preserved, well exposed buried soil developed on the lower member of San Luis Ranch. Examination of cores drilled by the U.S. Bureau of Reclamation near the Dos Amigos Pumping Plant (number 200, 201, 202, 203 and 204, Plate 24, and Appendix 1) also shows a sequence of late Quaternary deposits that are separated by at least 3 poorly to well preserved buried soils. I have interpreted these deposits to be members of the Los Banos and San Luis Ranch alluvium. These buried soils suggest that the alluvial units near the fan-

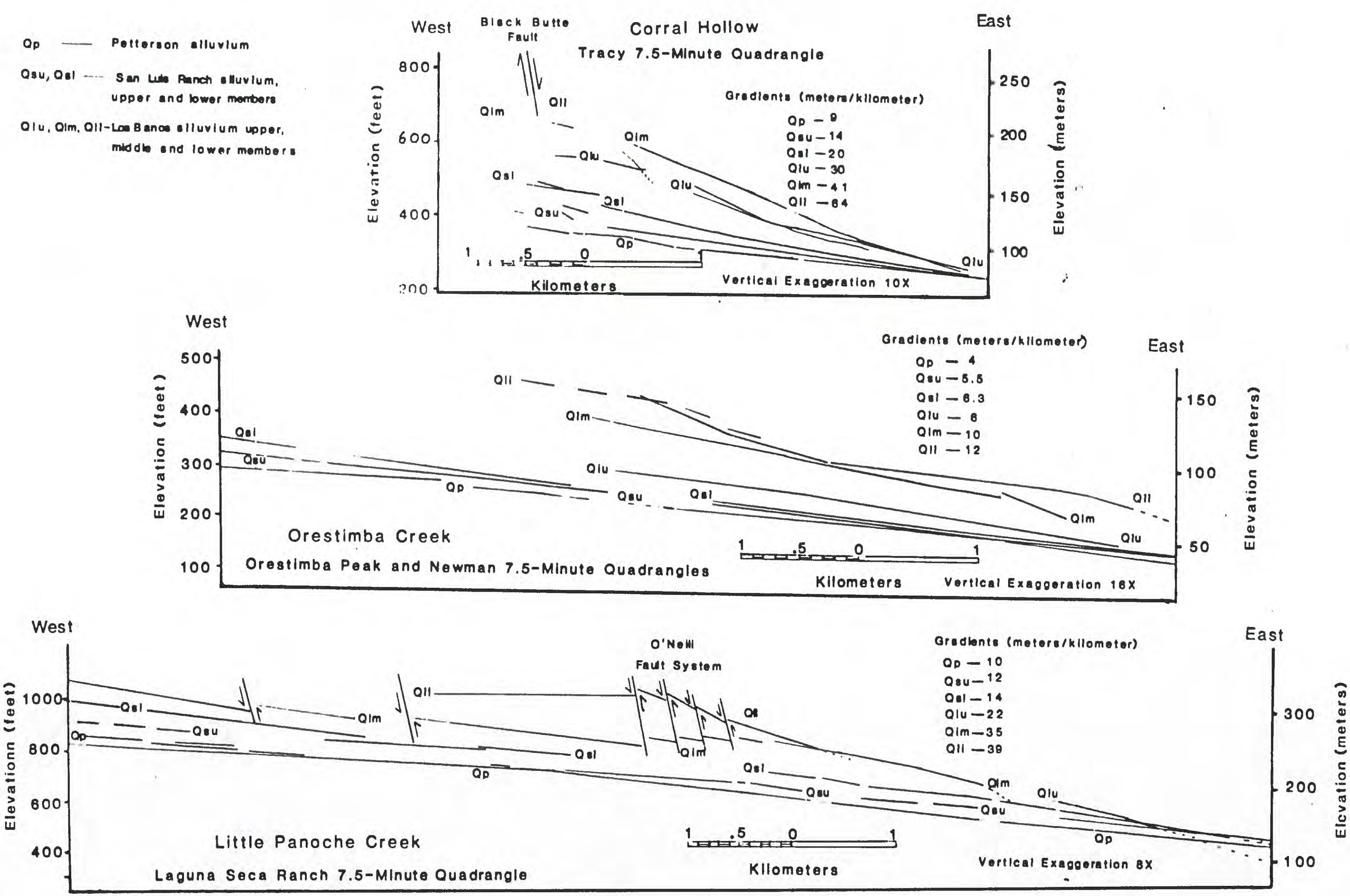

Figure 37: Longitudinal terrace profiles for three drainages in the western San Joaquin Valley.

head are separated by periods of non-deposition, which allowed soils to develop on the fan deposits.

I have not recognized buried soils in bore holes drilled during this study, or U.S. Bureau of Reclamation core holes, on the lower alluvial fan, however, suggesting that the soils decrease in development and/or preservation down-fan (Plates 25A and B, Figure 30). The absence of buried soils may indicate more or less continuous deposition on the middle- and lower-fan.

The lower member of San Luis Ranch alluvium is exposed at the surface of the valley principally in a discontinuous narrow belt along the valley margin, particulary adjacent to the mouths of major Diablo Range streams where the upper member of San Luis Ranch alluvium and Patterson alluvium are incised into the upper-fan. Younger mudflow deposits, however, emanating from small foothill drainages commonly overlie and obscure the lower member near the range front particularly north and south of Little Panoche Creek (for example: secs 26 and 36, T11S, R10E), The lower member is also sparsely exposed on some of the larger fans where the veneer of younger deposits formed an incomplete sheet. (For example: Figure 10, localities 32 and 46).

Two type areas are suggested where San Luis Ranch alluvium is particularly well exposed and displays most of the characteristic pedogenic and geomorphic criteria for recognition of the unit. One area is on the Little Panoche Creek alluvial-fan in secs 11, 14, and 15, T13S, R11E, where extensive quarrying exposes the upper member south of Little Panoche Creek and the lower member and basal contact with Los Banos alluvium north of the creek. The second locality is along San Luis Creek in secs 31 and 32, T9S, R9E and sec 6, T10S, R9E, where deep stream cuts expose both members north of the creek. Other areas where both members are very well preserved but not particularly well exposed are near the fan-heads of Los Banos Creek, Ortigalita Creek, Quinto Creek and Orestimba Creek.

Lithology

San Luis Ranch alluvium consists of unconsolidated, poorly to well-bedded gravel, sand, silt and less clay similar in composition and range of textures to deposits of the Tulare Formation and Los Banos alluvium. Clast lithologies include red and green quartz-veined red chert and metagraywacke derived from the Franciscan assemblage, graywacke from the Great Valley Sequence and, locally along San Luis Creek and Los Banos Creek, nearly 80 percent basalt, andesite and rhyolite derived from the Quien Sabe Volcanics. Less common lithologies include actinolite schist, glaucophane schist, diatomite, gabbro, black chert, conglomerate, and serpentinite.

The clasts range from angular to well-rounded suggesting that more than one cycle of reworking may have occurred. They average 1 to 3 cm diameter, although cobbles up to 15 cm are common and sparse boulders up to 1.5 m in long dimension are present (sec 26, 35 , T13S, R11E, Hammonds Ranch 7.5-minute Quadrange). The boulders are generally Franciscan quartz-veined chert derived from the Franciscan assemblage in the distant central Diablo Range, suggesting at least in part, high density mudflow transport (Blackwelder, 1928) . Alternatively, the boulders may be locally reworked from fluvial deposits of the Tulare Formation or Los Banos alluvium transported by a former, larger ancestral drainage for which no evidence remains.

Texturally, San Luis Ranch alluvium ranges from poorly to well-sorted, poorly to well-bedded and coarse to fine-grained depending on the geographic distribution of depositional environments (Table 9, Figures 5 and 15). Within the foothills, stream terrace and valley fill deposits consist mainly of poorly to moderately sorted, poorly to moderately bedded coarse sandy-gravel and gravelly coarse-sand. Within the San Joaquin Valley, alluvial-fan deposits grade from moderately bedded gravelly coarse sand near the fan-apex to well bedded, well sorted, laminated silt and fine sand on the lower-fan. Such a gradation is typical of alluvial fan deposits in semi-arid and arid regions (Blissenbach, 1954; Hooke, 1968).

Water and/or mudflow reworking, however, has commonly homogenized the fan deposits and carried coarser grained detritus over the finer grained outer fan detritus in distinct lobes or "finger-like" projections (For example: secs 11 and 12, T10S, R10E, Los Banos 7.5-minute Quadrangle, Plate 10.). These projections commonly extend radially down fan and are bordered by constructional levees or form distinct topographic ridges suggesting rapid deposition along former distributary channels (For example: secs 17 and 18, T10S, R10E; Volta 7.5-minute Quadrangle, Plate 9). Similar stream-built ridges of Patterson alluvium on San Luis Ranch alluvium are common (Quinto Creek and Garzas Creek alluvial fans, for example, Howard Ranch 7.5-minute Quadrangle, Plate 4) but are not actively forming today. Present fluvial and mudflow channels are typically incised into older deposits near the fan-head ("fanhead trenches,", Bull 1964a) and alluvial-fan deposits commmonly fill topographic depressions between the former constructional ridges.

Surface Modification

San Luis Ranch alluvium is slightly to moderately dissected, generally with large unmodified surfaces preserved between gullies. The size and density of gulleying is everywhere less than on adjacent Los Banos Valley alluvium (for example sec 16, T13S, R11E, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20) and greater than on adjacent Patterson alluvium (for example: sec 11, T13S, R11E, Hammonds Ranch 7.5-minute Quadrangle, Plate 21).

The degree of erosional dissection on similar age San Luis Ranch alluvium varies regionally due to local changes in the rate of deformation, vegetation cover and availability of running water but appears to be predominantly influenced by the growth of vegetation in response to the amount of precipitation. San Luis Ranch alluvium along Little Panoche Creek, for example, is considerably more dissected than it is along Corral Hollow or Hospital Creek north of the study area on the Solyo and Tracy 7.5-minute Quadrangles. Corral Hollow, located 110 Km north of Little Panoche Creek, receives more precipitation, so the availability of water for erosion as well as growth of vegetation is greater. Late Quaternary terrace and fan surfaces are more steeply inclined along Corral Hollow than along Little Panoche Creek (Figure 37) suggesting that the rate of deformation is also greater. Relatively greater dissection of terrace surfaces along Little Panoche Creek suggests that vegetation cover in response to precipitation has the greatest influence on slope stability and rate of erosional modification of alluvial deposits in the western San Joaquin Valley.

Soils developed on San Luis Ranch alluvium typically have weakly to moderately developed azonal to zonal profiles (Table 10). Soil series mapped on the lower member include the Lost Hills, Pleasanton, Ambrose, Ortigalita, Esparto, Rincon and Lethent, and soil series mapped on the upper member include the Rincon, Sorrento, Panhill, Esparto, Orestimba, Rossi, and Volta (Cole and others, 1943, 1948, 1952; Isgrig, 1969; Harradine, 1950; Harradine and others, 19561 and McLaughlin and Huntington, 1968). The profile description of several of these soil series, in particular the Rincon, Esparto and Pleasanton, varies from region to region depending on the usage and interpretation of each author.

The most representative soils developed on the lower member are the Lost Hills, Pleasanton and Ortigalita series (Mollic Haploxeralfs). The characteristic range of properties of these soils is shown in Table 10 and the Pleasanton soil is described below. These soils generally have reddish brown and brown (10YR and 7.5YR hues), moderately calcareous argillic horizons with thin, discontinuous clay films on ped surfaces. The profiles are generally thinner, less calcareous and not as red as those developed on Los Banos alluvium.

Pleasanton Soil Series

Ap	0 to 24 cm	Grayish brown (10YR 5/2) gravelly fine sandy loam, very dark grayish brown (10YR 3/2) when moist; massive; hard, friable, slightly sticky, slightly plastic; many very fine, common fine and medium roots; common very fine and fine interstitial pores; slightly acid (pH 6.3); abrupt smooth boundary. (12 to 25 centimeters thick)
A1	24 to 52 cm	Similar to Ap horizon except neutral (pH 6.8); clear smooth boundary. (25 to 35 centimeters thick)
B2t	52 to 124 cm	Brown (10YR 4/3) gravelly sandy clay loam, dark brown (10YR 3/3) when moist; moderate medium subangular blocky structure; very hard when dry, friable sticky, plastic; common very fine and fine roots; many very fine and fine, few medium tubular pores; common moderately thick clay films on peds and in pores; neutral (pH 7.3); gradual wavy boundary. (30 to 81 centimeters thick).
B3	124 to 165 cm	Brown (10YR 4/3) gravely loam; dark brown (10YR 3/3) when moist; weak medium subangular blocky structure; very hard, friable, sticky, plastic; few very fine roots; many very fine, common fine pores; few thick and few thin clay films on peds and in pores; neutral (pH 7.3); gradual wavy boundary (20 to 51 centimeters thick)
C1	165 to 195 cm	Yellowish brown (10YR 5/4) gravelly fine sand loam near gravelly loam, dark yellowish brown (10YR 4/4) when moist; weak blocky structure; hard friable, sticky, slightly plastic; many very fine, common fine, few medium pores few thin clay films on peds and in pores; mildly alkaline (pH 7.4)

Location East of Panoche Valley Road; road cut 200 yards southeast of the junction of Panoche Valley Road and Browns Valley Road, San Benito County, California (Isgrig, 1969).

National Cooperative Soil Survey Department of Agriculture.

The most representative soils developed on the upper member are the Sorrento (Calcic Haploxeroll) and Panhill (Mollic Haplargid) series. The characteristic range of properties of these soils are shown in Table 10 and the Panhill soil is described below. These soils are generally pale brown or grayish brown (10YR 6/2 to 4/3) and typically have thick AC profiles or a weakly developed cambic or argillic B horizon overlying slightly oxidized C horizons. Interstitial pore fillings of clay and thin, discontinuous clay coatings on clast and ped surfaces are common. The profiles are generally thinner, less calcareous and not as red or brown as soils developed on the lower member of San Luis Ranch alluvium. Calcium carbonate cemented duripans with overlying argillic horizons (Volta soil series) have developed under impeded drainage in overbank lower fan deposits of the upper member.

Panhill Soil Series

Ap1	0 to 20 cm	Light brownish gray (10YR 6/2) silty clay loam, dark grayish brown (10YR 4/2) when moist; strong moderate to coarse angular blocky structure; hard to very hard friable, slightly sticky and plastic; abundant fine and medium roots, common fine and medium tubular pores; mildly alkaline (pH 7.8); gradual wavy boundary. (15 to 25 centimeters thick).
B2t	20 to 51 cm	Brown (10YR 5/3) silty clay loam, dark grayish brown (10YR 4/2) when moist; weak coarse angular blocky structure, hard to very hard, very firm, sticky and plastic; abundant fine and medium roots; common fine open tubular pores and common fine open interstitial pores; few thin dark clay films on ped faces and in pores; mildly alkaline (pH 7.8); gradual wavy boundary (25 to 35 centimeters thick)

C1 51 to 81 cm Yellowish brown (10YR 5/4) with common medium distinct mottles of yellowish brown (10YR 5/6) silty clay loam, brown (10YR 4/3) when moist; with common medium faint mottles of dark yellowish brown when moist; weak coarse angular blocky structure; hard, firm, slightly sticky, plastic; plentiful very fine and fine roots; many very fine continuous open tubular pores; few thin clay films; moderately alkaline (pH 8.0) violently effervescent, segregated lime in filaments; diffuse wavy boundary (25 to 38 centimeters thick).

IIC2 81 to 143 cm Yellowish brown (10YR 5/4) sandy loam, dark yellowish brown (10YR 4/4) when moist; with many medium faint mottles of dark yellowish brown (10YR 3/4) moist, dark yellowish brown (10YR 4/4) rubbed; massive; slightly hard, friable, non-sticky, nonplastic; abundant very fine, fine and medium roots; many very fine and fine continuous open tubular pores; no clay films; moderately alkaline (pH 8.2), strongly effervescent, disseminated and large, generally rounded soft masses of lime; abrupt smooth boundary. (58 to 63 centimeters thick).

IIIC3 143 to 165 cm Light yellowish brown (2.5Y 6/4) silt loam, olive brown (2.5Y 4/4) when moist; weak fine platy structure; hard, friable, nonsticky, nonplastic; abundant very fine, fine and medium roots; many very fine and fine continuous open tubular pores; moderately alkaline (pH 8.4), strongly effervescent with disseminated lime. Lime also occurs as large, irregular soft masses.

Type Location: Merced County, California. About 7 miles southwest of Dos Palos, at a point 2,500 feet south of Bagle Field Road and 300 feet west of the east boundary of sec. 15, SE 1/4, NE 1/4 sec. 15, T 12S, R11E (Harradine and others, 1956).

National Cooperative Soil Survey, Department of Agriculture.

Where unmodified by recent agricultural practices, a distinct but poorly developed micro relief of regularly spaced mounds is occasionally developed on both the lower and upper members of alluvium of San Luis Ranch (Secs. 13, 14 and 23 T13S, R11E). Although not nearly as well developed as those on alluvium of Los Banos Valley, the mounds clearly indicate that pedogenic hardpans are not required for their development as suggested by Arkley and Brown (1954) and Page and others (1979) for the development of "mina-mound" or "hogwallow" relief.

Age and Correlation

The age of San Luis Ranch alluvium is poorly constrained but appears to range from late Pleistocene into early Holocene based on paleontologic, pedologic and absolute age data (Table 12). In core hole 15/13-/16N (Plate 25A), the lower member of San Luis Ranch alluvium overlies a weak buried soil developed on Los Banos Ranch alluvium containing tooth fragments of Equus sp. The fragments have been dated by the uranium-thorium method as 81,661± 188 years B. P. (E. L. Begg, personal communication, 1981). Along Crow Creek (Figure 10, locality 43; Table), the upper member of San Luis Ranch alluvium contains Equus sp.(?) bone fragments dated by the uranium-thorium method as 16,600 ± 100 years B. P. (E. L. Begg, personal communication, 1981).

At a depth of 17m in bore hole 14/15-7P (Plate 25A), San Luis Ranch alluvium overlies an oxidized horizon (possibly a "Cox" soil-horizon) developed on San Joaquin River alluvium containing detrital wood 43,800 + 1700 - 1400 ^{14}C years old, and roots 31,300±650 ^{14}C years old (Stephen W. Robinson, personal communication, 1981; Lab. number USGS-1199 and 1200). Each sample may have been contaminated by the other and thus these dates indicate that the contact represents a hiatus of at least 10,000 years between deposits of the San Joaquin River and the prograding fan deposits of Coast Range provenance. The underlying Sierran alluvium is interpreted to be a floodplain facies of the lower member of the Modesto Formation (Marchand and Allwardt, 1981) and the overlying Coast Range deposits are here assigned to the lower member of San Luis Ranch alluvium.

Near the valley margin, upper fan deposits of the lower member occasionally overlie a buried soil developed on Los Banos alluvium (Figures 24, 34 and 10, locality 16 for example). The buried soil has a well developed argillic B horizon which I believe probably required a minimum of 30,000 to 40,000 years to form. Because the upper member of Los Banos alluvium contains bone fragments dated by the Uranium-Thorium method at 80 to 100,000 years old (Table 12), the buried soil suggests a probable age of 40,000 to 60,000 years for the lower member of San Luis Ranch alluvium.

The upper member of San Luis Ranch alluvium is overlain by or is inset into Patterson alluvium. Soils developed on the upper member and buried by Patterson alluvium generally have thin A-C profiles (Figure 35, for example), which I believe probably required less than 5,000 to 10,000 years to develop. Absolute age control on the Patterson alluvium (Table 12) indicates that it is largely late Holocene which, in turn, suggests that the upper member of San Luis Ranch alluvium may be as young as early Holocene.

Thus absolute and relative age control indicates that the San Luis Ranch alluvium is late Pleistocene and possibly early Holocene. The lower member probably accumulated between 30,000 to 60,000 years ago, and the younger member probably accumulated between 7,000 and 20,000 years ago.

Correlation of San Luis Ranch alluvium with the marine oxygen isotope record, the glacial stratigraphy of the Sierra Nevada and other alluvial stratigraphies in California is shown in Figure 27. The alluvium is approximately coeval with the Palmdale Formation in the Antelope Valley (Ponti, 1981), younger alluvium QOa_3 east of Bakersfield (J. Alan Bartow, in press), older fanglomerate in the San Emigdio Mountains (McGill, 1951), the Modesto Formation in the Sacramento Valley (Harwood and others, 1981) and the Modesto Formation and possibly post-Modesto I deposits of the eastern San Joaquin Valley (Marchand and Allwardt, 1981). The age range of the alluvium spans oxygen isotope stages 4, 3 and 2 and early stage 1 and thus probably two major glacial to interglacial climatic transitions.

PATTERSON ALLUVIUM

Definition and General Description

Patterson alluvium is an informal name given to the unconsolidated deposits of gravel, sand, silt and silty clay that underlie modern stream channels, levees, low terraces and alluvial fans. The deposits are demonstrably younger than San Luis Ranch alluvium based on pedologic and geomorphic criteria, and stratigraphic superposition. They are undeformed and essentially unweathered. Their surfaces exhibit little or no soil profile development (Table 10). Within the foothills, deposits of Patterson alluvium underlie the present stream channels and low terraces incised into San Luis Ranch alluvium (Figure 26). Within the San Joaquin Valley, the Patterson alluvium forms a thin veneer over parts of alluvial fans consisting mainly of San Luis Ranch alluvium.

Patterson alluvium is nearly identical in composition, range of textures and sedimentary character to San Luis Ranch and Los Banos alluvium. The alluvium thus provides a modern analogue for the range of depositional environments in which the earlier alluvium accumulated. The deposits differ from the older alluvial units, however, in scale. They are generally confined to distributary channels or form thin alluvial veneers on the piedmont alluvial-plain of the western San Joaquin Valley. Their formation is not entirely analogous, therefore, to the large aggradational events of Coast Range alluvium on the alluvial-plain represented by the earlier alluvial units. The upper member of San Luis Ranch alluvium, in fact, probably combines with Patterson alluvium to form a single alluvial unit similar to those recorded by the older alluvial units.

Distribution

Patterson alluvium is common within the foothills along all the major Diablo Range drainages as well as along many of the minor gullies and streams tributary to the major drainages or leading directly to the San Joaquin Valley. Along the major drainages, the alluvium typically occupies the modern channel and underlies low terraces bordering the channel. These terraces are generally inset 1 to 30 m into San Luis Ranch alluvium. The amount of vertical separation typically increases mountainward from the valley front (Figure 37).

Within the smaller drainages and several of the large foothill valleys, the Patterson alluvium forms a valley fill. In the smaller drainages the fill commonly chokes the channel and backfills into tributary gullies or arroyos suggesting that the sediment shed from the hillslopes is not being completely flushed downstream to the valley. Many of these valley fills are mapped as Patterson alluvium or Patterson-San Luis Ranch alluvium undifferentiated, in the absence of conclusive data indicative of age. In several of the large foothill valleys, including Panoche Valley, Little Panoche Valley and Carrisalito Flat, Patterson alluvium forms extensive valley fills exceeding 7 m thick (Figure 38 and Figure 10 localities 1, 2, and 3) as well as veneers less than 1 m thick (Figure 35 and Figure 10, locality 11). As shown by Figures 35 and 38, these valley fills commonly overlie laterally continuous soils developed on underlying alluvium suggesting that a period of surface

Figure 38: Valley fill of Patterson alluvium in Panoche Valley overlying a calcic, reddish-brown (7.5YR hue), buried soil formed on the lower member of San luis Ranch alluvium about 5 m below the ground surface. A weak, oxidized horizon is present within the Patterson alluvium about 2 m below the ground surface and may represent a former valley surface during the late Holocene. No evidence of pedogenesis is present, however. Late Holocene incision by Griswald Creek has exposed the valley fill. Dissected terraces of the upper member of Los Banos alluvium are visible in the background (Figure 10, locality 1).

stability and soil development preceeded their deposition. Subsequent erosion of the foothills and local aggradation produced the Patterson valley fills.

These foothill stream channel, terrace and valley fill deposits merge downstream with stream channel, terrace and alluvial fan deposits within the San Joaquin Valley. Near the fan-heads, they commonly occupy small, steep-walled valleys incised into San Luis Ranch and Los Banos alluvium (For example: Little Panoche, San Luis and Orestimba Creeks). Farther down fan, however, the channels eventually merge with the fan surface and the deposits spread out as a veneer over San Luis Ranch alluvium.

The alluvial-fan veneers commonly have a branching lobate pattern which, in some cases, continue to widen downfan until merging to form a continuous veneer. These fan deposits thus occupy a discontinuous, northwest-trending belt from 0 to 12 km wide, between the older San Luis Ranch alluvial-fan deposits on the west and the basin floor deposits to the east (Figure 25). The lateral extent of this veneer increases to the south. The Panoche Creek alluvial fan south of the study area, for example,is nearly completely veneered by a sheet of Patterson alluvium.

Besides the fluviatile alluvial-fan setting, Patterson alluvium occupies a second distinct topographic and depositional setting in the San Joaquin Valley. Fringing the margin of the foothills and locally veneering older San Luis Ranch and Los Banos alluvium are small, steep conical fans constructed by the many small streams and gullies draining the front of the foothills. These fans commonly have surface gradients exceeding 15 to 20 m/km (sec 30, T13S, R12E; sec 36, T13S, R11E Hammonds Ranch 7.5-minute Quadrangle, Plate 21) as compared to 6 to 8 m/km for the larger alluvial-fans associated with the major drainages (For example: secs 5, 6, 7 and 8, T13S, R12E Hammonds Ranch 7.5-minute Quadrangle, Plate 21). They are built principally by streams with relatively small drainage basins, generally 2 to 12 Km^2, of which Laguna Seca and Wildcat Creeks are excellent examples (Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20).

The fans occupy a discontinuous belt along the range front between the major Diablo Range drainages (Figure 25). The belt generally ranges in width from 2 to 5 km, diminishing in extent adjacent to the majo drainages. An excellent example of these fans prograding over and veneering older deposits of San Luis Ranch alluvium is south of Little Panoche Creek in secs 22, 23, 24, 25, 26 and 27, T13S, R11E.

Lithology

Patterson alluvium consists of unconsolidated, poorly to well sorted gravel, sand, silt and silty clay. It is similar in lithology and range of textures to deposits of San Luis Ranch and Los Banos alluvium and the Tulare Formation and thus probably represents a modern analogue of the earlier depositional units. Alluvium deposited on the piedmont alluvial-plain and within stream valleys of the Diablo Range consist entirely of detritus shed from the Diablo Range. Red and green chert, graywacke, and locally andesite and basalt are the principal clast lithologies and reflect erosion of the Franciscan assemblage. Great Valley Sequence and Quien Sabe volcanics.

Patterson alluvium ranges greatly in texture depending on its principal mode of deposition. Within the foothills, it consists mainly of poor to moderately sorted, poorly bedded coarse sand and coarse sandy-gravel. The gravel clasts are generally subangular to subrounded and average 3 to 6 cm diameter, up to 50 cm maximum diameter. Many of the larger clasts exhibit a preferred orientation downstream.

On the alluvial fans, the Patterson alluvium generally grades from moderately to well sorted coarse sand on the upper fan to well sorted fine sand and silt on the lower fan. The sand and silt are moderately to well bedded and commonly laminated, suggesting, at least in part, fluvial deposition or reworking. Lateral continuity of bedding and laminae, however, were not clearly observed due to generally poor exposure on the lower fan. Anomalous, isolated, subangular to well rounded pebbles averaging 0.5 to 1 cm diameter are sparsely interbedded in the silt and fine sand suggesting that deposition by infrequent mud slurries may be an important process on the lower fan. The deposits are typically unweathered, weakly oxidized to a yellowish brown (2.5Y, 5Y, and 10 YR hues) and moderately to well-drained.

The belt of small, steep fans fringing the foothill front consists principaly of unsorted, unstratified coarse sandy gravel, gravel and coarse sand. The surfaces are commonly strewn with large, isolated boulders up to 1.5 m in long dimension, tens of meters from the range front (for example: Sec 26, T13S, R11E). Blackwelder (1928) has shown that boulders of this size on small fans are unlikely to have been transported by water even during flood stage. These boulders and the unstratified and unsorted nature of the deposit are evidence of transport by mudflows.

Surface Modification

Patterson alluvium has not been effectively modified. Terrace and fan surfaces have not been dissected, and original sheetflow morphology is commonly observed on pre-agricultural aerial photography (for example, secs 8, 9, 10, 14, and 15, T12S, R12E; Hammonds Ranch 7.5-minute Quadrangle, Plate 21; Department of Agriculture Photos ABF 19:14 through 1936). The microrelief of regularly spaced mounds, common to San Luis Ranch and Los Banos alluvium, is conspicuously absent on adjacent Patterson alluvium (for example: secs 22 and 23, T12S, R11E; Hammonds Ranch 7.5-minute Quadrangle, Plate 21).

The mudflow fans, however, are commonly entrenched by fanhead gullies (Bull, 1964a; Verhoogen and others, 1970 p.416). Most trenches are small and have been artificially filled for cultivation, irrigation and erosion prevention purposes. A few of the larger trenches remain, however, and are well-preserved between Laguna Seca and Ortigalita Creeks (secs 7, 8, 17, T12S, R11E).

The trenches are sharply incised into underlying unconsolidated fan deposits, and the resulting steep banks calve and slough into the trench. During periodic cloudbursts, discharge from the catchment basin is locally impeded by the debris, until saturated when it flows as mud down the confining channel of the trench. Upon debouching at the trench mouth, the mudflow rapidly loses velocity and depth as it spreads laterally and is deposited. Resultant gradual steepening of the fan gradient in this area eventually surpasses the gradient of the trench channel producing progressive backfilling of the trench. Much of the mudflow debris, therefore, is probably reworked older fan materials. Confinement by the fanhead trench permits the mudflows to travel large distances, frequently over the fluvial fan deposits associated with the larger drainages.

The trenches exhibit various stages of incision and back-filling. The various stages of trench development and lack of trenches on some mudflow fans indicate that trenching is not a response to regional, long term climatic fluctuation. Rather, new trenches probably form in response to local external stimuli in the catchment basin of the ephemeral stream; such as natural or domestic overgrazing, localized rainfall of high intensity; large landslides etc. Bull (1964a), for example has shown that two episodes of fanhead trenching occurred in response to abnormally high annual rainfall from 1875 to 1895 and from 1932 to 1945. Fanhead trenching would therefore, may be synchronous from fan to fan in short term pulses (about 50 to 100 years), requiring a triggering stimuli such as Bull (1964a) noted (e.g. abnormally wet years). In the interval of a glaciation or inter-glacial, however, (10,000 or more years), a sufficient number of trenching episodes will occur to obscure any long-term climatic significance.

Soils developed on Patterson alluvium typically have weak, thin A-C and A-Cox-C profiles or lack profile development entirely (Table 10). They include the Panoche, Mocho, Orestimba, Willows, Oxalis, Clear Lake and Levis Series (Cole and others, 1943, 1948, 1952; Isgrig, 1969; Harradine, 1950; Harradine and others, 1956; and McLaughlin and Huntington, 1968). The most representative soil is the Panoche Series (Typic Torriorthent), a pale brown or light yellowish brown (10YR hues) slightly calcareous soil with a weakly developed A-C profile. Fresh, loose stratified parent material is normally found within a 1 m of the surface.

Panoche Soil Series

Ap	0 to 20 cm	pale-brown (10YR 6/3) loam, brown (10YR 4/3) when moist; moderate, fine, granular structure; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; few very fine and fine roots; common, very fine, tubular pores, common, fine interstitial pores; mildly alkaline, slightly effervescent; clear, smooth boundary.
A1	20 to 30 cm	pale-brown (10YR 6/3) loam, brown (10YR 4/3) when moist; weak, medium, subangular blocky structure; slighltly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; few very fine and fine roots; common very fine, tubular pores and common, fine, interstitial pores; moderately alkaline, strongly effervescent, clear, smooth boundary.
C1	30 to 74 cm	pale-brown (10YR 6/3) loam, brown (10YR 4/3) when moist; weak medium subangular blocky structure; slightly hard when dry, very friable when moist, slightly sticky and slightly plastic when wet; plentiful very fine and fine roots; many very fine, fine, and medium tubular pores;

common, small, soft masses of lime; moderately alkaline, violently effervescent; clear, smooth boundary.

C2	74 to 100 cm	light yellowish-brown (10YR 6/4) loam dark yellowish brown (10YR 4/4) when moist; weak, fine, subangular blocky structure; soft when dry, very friable when moist, slightly sticky and slightly plastic when wet; few very fine and fine roots; many, very fine and fine, tubular pores; common, small soft masses of lime; moderately alkaline violently effervescent; clear, smooth boundary
C3	100 to 190 cm	brown (10YR 5/3) loam, dark brown (10YR 4/3) when moist; weak, fine, subangular blocky structure; soft when dry, very friable when moist, slightly sticky and slightly plastic when wet; few very fine and fine roots; few very fine, and fine tubular pores; common, small soft masses of lime stratified; moderately alkaline, violently effervescent; clear, smooth boundary.

Location Recalde Ranch in Panoche Valley; 500 yards southeast of house, NE 1/4, SW 1/4 Sec 30, T15@, R11E (Isgrig, 1956)

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Age

Patterson alluvium is younger than the upper member of San Luis Ranch alluvium based on superposition, relative soil profile development and degree of surface modification and is thus interpreted to be Holocene in age. Radiocarbon dates from various localities (Table 12) suggest that much or all of the Patterson alluvium is late Holocene. Gastropods from a low terrace inset into San Luis Ranch alluvium along San Luis Creek (Figure 10, locality 30) are 2415 ± 190 ^{14}C years old. Detrital charcoal from 4.0 m below the surface in Panoche Valley (Figure 10, locality 2 is 2850 ± 100^{14} C years old; and detrital charcoal 3 m below the surface near the mouth of Panoche Valley (Figure 10, locality 3; is 200 ± 70^{14} C years old. North of the study area, Patterson alluvium on the Del Puerto Creek alluvial fan progrades over arkosic basin floor deposits containing detrital wood near the contact dated as 8230 ± 80^{14} C years old (B. F. Atwater and W. R. Lettis, unpublished data). This latter date provides a maxiumum limiting age for the Patterson alluvium in this area.

Many of the terrace, alluvial-fan and basin floor deposits were frequently overtopped by historic floods prior to construction of detention reservoirs at many Interstate-5 and California Aqueduct crossings and impoundment dams across the mouths of many of the large streams draining the Diablo Range (for example: San Luis Dam, Little Panoche Dam and Los Banos Dam). The age of the Patterson alluvium, therefore, ranges up to the present century.

DOS PALOS ALLUVIUM

Definition and Distribution

Dos Palos alluvium is an informal name given to the undeformed, generally unweathered, unconsolidated deposits of arkosic gravel, sand, silt and clay covering the floodbasin of the lower San Joaquin River. The deposits are demonstrably younger than the bordering alluvial-fan deposits of the late Pleistocene Modesto Formation (Marchand and Allwardt, 1981) and deposits of the San Luis Ranch alluvium based on stratigraphic superposition and pedologic, geomorphic, and absolute age criteria. The Dos Palos alluvium is generally coeval with the Patterson alluvium but is lithologically distinct because of its predominantly Sierran provenance and arkosic composition.

The Dos Palos alluvium underlies a continuous northwest-trending belt from 1 to 25 km wide in the San Joaquin Valley axis between the Coast Range and Sierra Nevada alluvial fans (Figures 5 and 25). In several areas, shallow drilling (Figure 30, Plates 25 A and B), and the map distribution of soils indicate that the Coast Range alluvial fans of Patterson alluvium prograde over the basin floor deposits (For example: alluvial fans of Little Panoche Creek, Panoche Creek, Orestimba Creek and, north of the study area, Del Puerto Creek). The progradation is schematically illustrated in Figure 17.

The floodbasin narrows from as much as 15 km wide south of the town of Newman to less than 5 wide km north of Newman (Figure 5). Cause for the constriction of the floodbasin north of Newman or expansion of the floodbasin south of Newman is not known. Greater deposition on the bordering Coast Range Orestimba Creek and Sierra Nevada Merced River alluvial fans north of Newman relative to deposition on the basin floor may have resulted in progradation of the fans over the basin floor. The Merced River alluvial fan is the first major glacial outwash fan north of the San Joaquin River alluvial fan. The expansion of the basin floor south of Newman may thus simply reflect the inter-fan depression between these two giant glacial outwash fans.

Alternatively, the change in the size of the floodbasin may be structurally controlled. As previously mentioned, a broad, northeast-trending Quaternary anticline is exposed in Interstate-5 roadcuts north of Quinto Creek where Tulare beds dip 16 to 20 ° southeast on its southeastern limb (Figure 28 and Figure 10, locality 33). The constriction of the floodbasin north of Newman lies just north of the trace of this anticline. The valleyward projection of this anticline is indicated by a northeast-trending warp in the Corcoran Clay centered near the town of Ingomar (Figure 29) and also coincides with the exposure of hills of Los Banos alluvium above the surrounding valley floor (Figure 10, locality 34). Similarly the expansion of the floodbasin may reflect projection of the adjoining northeast-trending San Luis Valley syncline (Refer to "Late Cenozoic Structure) section of this report).

Lithology

The Dos Palos alluvium consists primarily of moderately to well sorted, moderately to well bedded unconsolidated sand and silt with lesser amounts of gravel, clayey silt, and clay. The arkosic composition of the detritus indicates derivation largely from the plutonic rocks of the Sierra Nevada.

The deposits probably accumulated by overflow and channel migration of the San Joaquin River and associated sloughs on the basin floor of the San Joaquin Valley. The beds of fine sand, silt, and clayey silt are typically laminated, laterally continuous and are interpreted as overbank deposits on the basin floor. Beds of medium and coarse sand and gravelly coarse sand are generally lenticular, difficult to trace laterally, cross stratified and have channeled lower contacts. They are interpreted as channel, point bar and levee facies of the river and sloughs. Beds of clay and silty clay, occasionally containing pelecypod remains, are laminated, lenticular, and are interpreted to have accumulated in ephemeral or perennial oxbow lakes, ponds or swamps on the basin floor. These facies are well exposed along the banks of the San Joaquin River and are schematically illustrated in Figure 17.

Gravel clasts are primarily granitic and a wide variety of multicolored metamorphic litholgies. The clasts are typically well to very well rounded, average 0.5 to 1 cm in diameter, and are rarely larger than 3 cm in diameter. Near the confluence of the San Joaquin River and major Diablo Range drainages, an appreciable admixture of Diablo Range bedrock lithologies are present, including red and green chert, graywacke and serpentinite. Many of the aforementioned metamorphic clasts in fact may be trunk stream reworking of Diablo Range detritus.

The Dos Palos alluvium is generally unweathered, poorly drained and ranges in color from green to bluish green to yellowish green (5G, 5BG and 5 GY hues are common). The gleyed colors reflect the poor drainage and high water table on the basin floor and provide an approximate criterion for separation of basin floor deposits from the better drained, typically oxidized Coast Range alluvial-fan deposits. (Meade, 1967)

<u>Surface Modification</u>

Dos Palos alluvium has not been greatly modified. Incision and migration of the San Joaquin River and associated sloughs have produced sequences of low terraces bordering the main channels which are inset into the broad, expansive floodbasin, as well as numerous abandoned channels, oxbow lakes and ponds on the floodbasin. Local relief ranges from one to three meters on the floodbasin increasing up to eight meters where natural levees border the main channels.

Soils formed on the poorly drained basin floor deposits commonly have a week cambic-B horizon or lack profile development entirely (Table 10). They include the Merced, Temple, Columbia and Sacramento Series (Cole and others, 1943, 1948, 1952; Isgrig, 1969; Harradine, 1950, Harradine and others, 1956; and McLaughlin and Huntington, 1968).

The most representative soils developed on the Dos Palos alluvium derived from the Sierra Nevada are the Merced and Temple Series (Pachic Haploxerolls). The characteristic range in properties is shown in Table 10 and the Temple Soil is described below. These soils are generally dark gray, moderately alkaline, and moderately to highly calcareous.

Temple Soil Series

A_1	0 to 20 cm	Dark gray (10YR 4.5/1) loam, black (10YR 2/1) when moist; essentially massive dry, weak fine and medium granular structure moist; hard when dry, friable, slightly plastic and slightly sticky; moderately high in organic matter; numerous fine roots and fine pores; slightly acid (pH 6.5); gradual smooth boundary. 17 to 25 centimeters thick.
B_1	20 to 30 cm	Gray (10YR 5/1) clay loam, dark gray (10YR 4/1) when moist; weak medium blocky structure; hard when dry, firm, plastic and sticky; thin patchy clay films of very dark gray (10YR 3/1) moist; low organic matter content; few roots and fine pores; neutral; clear smooth boundary. 10 to 25 centimeters thick.
B_{2g}	30 to 64 cm	Light olive gray (2.5Y 6/2) clay loam, dark grayish brown (2.5Y 4/2) when moist with distinct medium and fine mottles of strong brown (7.5YR 5/6 and 5/8) when moist; weak medium blocky structure; hard when dry, firm, plastic and sticky; thin patchy clay films of very dark gray (10YR 3/1) when moist; moderately alkaline (pH 8.2); slightly calcareous, lime content increasing with depth with some soft light colored masses segregated in the lower part; clear smooth boundary. 25 to 38 centimeters thick.
B_{3gca}	64 to 125 cm	Light olive gray (2.5Y 6/2) clay loam, grayish brown (2.5Y 5/2) when moist with common fine and medium strong brown (2.5Y 5/6 and 5/8) mottles, weak medium blocky structure; hard when dry, firm, plastic and sticky; moderately alkaline (pH 8.2); strongly calcareous with much segregated lime in soft light colored masses and small hard nodules; clear smooth boundary. 25 to 63 centimeters thick.
Cg	125 cm +	Pale Olive (5Y 6/3) stratified alluvium mainly of fine sandy loam and sandy clay loam, olive (5Y 5/3) when moist; massive; hard when dry, mainly firm but with friable layers; moderately alkaline (pH 8.2); slightly to moderately calcareous with segregated soft masses of lime and small hard nodules in the upper part decreasing with depth but still calcareous for several feet. Over one meter thick.

Location: Merced county, California; Turner Island, 2 1/1 miles west and 1/2 mile north of McNamara Ranch Headquarters T9S, R12E (no section lines).

National Cooperative Soil Survey, Department of Agriculture.

Age

The age of the Dos Palos alluvium is partly Holocene, but probably extends into the late and middle Pleistocene as well. Geomorphic and absolute age data indicate that the Dos Palos immediately underlying the surface is younger than the bordering alluvian-fan deposits of the late Pleistocene and early Holocene San Luis Ranch alluvium and the late Pleistocene Modesto Formation (Marchand and Allwardt, 1981), and is approximately coeval with the Holocene Patterson alluvium and post-Modesto alluvium of Marchand and Allwardt (1981). The basin floor deposits are typically inset into and topographically lower than the bordering late Pleistocene glacial outwash deposits of the Modesto Formation (Gustine, Poso Farm and Santa Rita Bridge 7.5-minute Quadrangles, Plates 3, 12 and 18). The basin floor deposits north of the study area near Del Puerto Creek yield dates on detrital wood of 1110 $\pm$ 50 and 3330 $\pm$ 60 ^{14}C years (Table 12). Furthermore, most of the basin floor was subject to frequent historic flooding by the San Joaquin River and associated sloughs prior to the construction of artificial levees and impoundment reservoirs across the mouths of rivers draining the western slopes of the Sierra Nevada.

Buried soils, however, are generally absent on the basinfloor and distinct chronologic separation of surface basin floor deposits from underlying deposits based on stratigraphic superposition is not available. Consequently, the Dos Palos alluvium probably includes, with depth, deposits which are coeval with San Luis Ranch and Los Banos alluvium, and the Modesto and Riverbank Formations (Marchand and Allwardt, 1981). Buried soils on the Tulare and Turlock Lake Formations, however, may extend under the basin floor, thus the Dos Palos alluvium is probably middle Pleistocene or younger.

SUBSURFACE STRATIGRAPHY

INTRODUCTION

The late Cenozoic alluvial, lacustrine, paludal and floodbasin deposits beneath the San Joaquin Valley contain a long and rich record of climatic and tectonic events affecting central California. These deposits thicken toward the valley axis where the presence of lacustrine and alluvial sediment hundreds of meters below sea level suggests deposition in a continually subsiding topographic basin. Lack of marine sediment in the late Cenozoic section requires that subsidence of the basin was at least roughly matched by sedimentation fróm the surrounding mountains, so that the valley floor was always at or above sea level (Janda, 1966). The approximate equality in the rates of subsidence and sedimentation, in turn, suggests that sediment load may have been a major factor in causing the subsidence. This section describes the late Cenozoic deposits in the subsurface of the north-central San Joaquin Valley and provides information on the late Cenozoic tectonic, climatic and depositional history of the central San Joaquin Valley.

Overview of Geologic Structure and History

The San Joaquin Valley is essentially a long deep asymmetric trough trending approximately N30 to 40^{o} W whose axis lies near its western margin. The regional structure of the basin is reasonably well defined by published geophysical and lithologic data (Harding, 1976). The eastern flank dips gently with dips rarely exceeding 4^{o} to 6^{o} in the Tertiary section (Mitten and others, 1970). The western flank dips more steeply with dips of 10^{o} to 30^{o} in Tertiary section.

During much of the early and middle Tertiary, marine waters invaded the southern and central San Joaquin Valley (Harding, 1976). In the late Tertiary, alluviation, largely from the Sierra Nevada and partially from the Coast Ranges, progressively filled the basin from north to south so that in Pliocene time the sea was confined to the area south of Coalinga, connected to the ocean via a strait toward Hollister. This sea persisted until the beginning of Pleistocene time when the strait was closed by uplift of the Diablo Range and offset along the San Andreas Fault. The marine deposits of the earlier Tertiary were covered by deposits of fresh-water and brackish-water lakes and by deltaic and alluvial-fan deposits from the flanking mountain ranges, and drainage to the sea was redirected via Susuin Bay, Carquinez Strait and the Golden Gate.

The late Tertiary and Pleistocene continental deposits record many volcanic, tectonic and climatic events in the valley and adjacent mountains. For example, the Oligocene to early Miocene Valley Springs and Miocene and Pliocene Mehrten Formations record volcanism in the Sierra Nevada (Dalrymple, 1964), the Miocene and early Pliocene(?) Oro Loma and Carbona Formations record uplift and erosion of the Franciscan core of the central Diablo Range (Briggs, 1953; Pelletier, 1951), the Pleistocene alluvium from the Sierra Nevada records glaciation of the high Sierra (Marchand and Allwardt, 1981), and the Pleistocene alluvium from the Diablo Range records climatic changes and possibly tectonic events in the unglaciated Coast Ranges.

A large, freshwater lake occupied the Valley floor between 725,000 and 615,000 years ago and is represented by the Corcoran Clay Member of the Tulare and Turlock Lake Formations. The present valley floor is underlain by alluvial-fan and floodbasin deposits of late Quaternary age.

PREVIOUS LITERATURE

Late Cenozoic deposits in the San Joaquin Valley subsurface have been investigated chiefly for (1) groundwater supply and storage (see Bertoldi, 1979, and Olmstead and Davis, 1961) for complete discussion), (2) the effects of groundwater withdrawal and wetting on land subsidence (U. S. Geological Survey professional paper series 437A-G by Bull, Miller, Green, and Davis, 1964; and 497A-E by Bull, Green, Johnson, Meade, Lofgren, Miller, and Moston, 1967); and (3) engineering properties for construction of major aqueducts and canals through the Valley (U. S. Bureau of Reclamation, unpublished studies, 1951-4 and 1962-4). Of particular relevance to this report are the studies of the alluvial-fans and near-surface subsidence in western Fresno County by Bull (1964a,b) and detailed investigations of the compaction and petrology of the water-bearing sediments underlying areas of subsidence in the western San Joaquin Valley by Meade (1967, 1968). Meade (1967) also presented valuable criteria for distinguishing alluvial-fan, floodplain and lacustrine deposits in the subsurface of the San Joaquin Valley.

Other relevant literature of the subsurface geology include: descriptions of subsurface lacustrine and alluvial deposits of Pliocene and Quaternary age by Barbat and Galloway (1934), Frink and Kues (1954), Klausing and Lohman (1964) and Croft (1967, 1968, 1972); cross-sections through the San Joaquin and Chowchilla River alluvial fans by Janda (1966) and Helley (1967) respectively; an east-west cross-section through the central San Joaquin Valley and accompanying discussion of the Valley's late Cenozoic history by Croft and Wahrhaftig (1965) and studies of subsurface geology near proposed nuclear reactor sites by private consulting firms (unpublished Woodward-Clyde Consultants and Fugro Incorporated reports on the Wasco, Stanislaus, San Joaquin, and Madera sites; Davis and others, 1977).

METHODS

With minor modification, the techniques and mapping criteria used for defining and delineating subsurface units are similar to those used in conventional surface geologic mapping. The deposits are separated into informal units based on lateral and vertical changes in lithology, mineralogy, texture, state of oxidation and degree of weathering. These include units, usually separated by buried soils, that are the result of distinct aggradational events, and also units that are bodies of sediment with distinctive compositional or textural characteristics.

Mappable units were identified in each core and correlated with adjacent cores and more distant cores on the basis of: (1) stratigraphic position in a vertical sequence; (2) projection of available pedologic horizons and (3) stratigraphic position with respect to available marker horizons, in particular the Corocoran Clay, the Friant Ash and the Brunhes-Matuyama geomagnetic boundary.

Initial correlation of surficial deposits with buried soils is accomplished by projecting the upper surfaces of fan units into the subsurface. Extrapolation or projections of surface gradients as a horizon into the subsurface assumes relatively constant slopes with little or no relief. The assumption is justified because: (1) The present valley floor has a surface of low relief suggesting that former valley surfaces probably had similar low relief; (2) the Corcoran Clay and Friant ash have consistent projection from or near the surface into the subsurface; (3) buried soils having less than 5 m of relief can be traced at least 25 km beneath the fan of the Tuolumne River (B. F. Atwater and W. R. Lettis, 1981 unpublished data); and (4) Tertiary Formations have consistent subsurface projections.

Plates 25A and 25B illustrate the vertical succession of late Cenozoic sediments in the central San Joaquin Valley and their probable stratigraphic relations. The sections cross the north-central San Joaquin Valley from southwest to northeast approximately perpendicular to the Valley's topographic and structural axes. They were located to: (1) best utilize the most accurate and detailed core descriptions; (2) utilize cores with available paleomagnetic and absolute age information; (4) utilize cores with identifiable pedogenic and lithologic horizons; and (5) identify areas where the late Cenozoic surface stratigraphy is well understood.

The stratigraphic correlations are preliminary, intended only to provide a stratigraphic framework from which to study the late Cenozoic geologic history of the San Joaquin Valley. Many of the correlations across the valley axis are based on the assumption that little erosion has occurred and that therefore the deposits record only periods of deposition and periods of landscape stability. As will be shown, however, frequent migration and incision by the Valley's axial stream commonly disrupts the stratigraphic succession. Consequently, many correlations across the valley axis, especially of pre-Corcoran units are extremely uncertain and are queried on the cross sections. Correlation of the units across the valley axis is accomplished principally by the superposition of buried soils preserved on the alluvial fans with the Corcoran Clay marker horizon in the Tulare and Turlock Lake Formation. Factors limiting the accuracy of these correlations, however, include the lack of observed buried soils beneath the valley axis, a paucity of deep core information in the valley axis, and limited absolute age control.

SUBSURFACE INFORMATION AVAILABLE

Core Holes

Information on the subsurface deposits was assembled and interpreted principally from the examination of core and well records supplemented by shallow augering and field mapping performed during this study. Plate 24 is a compilation of available core holes in the San Joaquin Valley and shows the location of the cross sections Plate 25 and Figure 30. The cores were drilled primarily by the U. S. Bureau of Reclamation, California Department of Water Resources, and U. S. Geological Survey in the 1950's and 1960's. A description of the precise location depth, driller, owner, date and literature reference for each hole is provided in Appendix 1. Core holes shown on Plate 24 are also coded indicating the availability of radiometric, paleontologic, paleomagnetic or pedologic information at each site.

Most of the cores have been destroyed for a variety of reasons; consequently most of the information is available only from written records. Along with routine geophysical and descriptive logs, detailed mineralogical analyses are also available for selected cores. Ira E. Klein of the U. S. Bureau of Reclamation supervised much of the mineralogic work in the 1950's and 1960's and identified many of the stratigraphic horizons such as the Corcoran Clay, buried soils, Friant Pumice, and alluvial deposits of Coast Range and Sierran provenance. I am grateful to the Bureau of Reclamation and to Ira Klein for providing much of this unpublished data. D. E. Marchand and I examined numerous other cores in storage during 1978 and 1979 for pedologic and lithologic data prior to their destruction in 1979.

Water Wells

Thousands of water wells have been drilled in the San Joaquin Valley. Regulations require the driller to log each well on prescribed forms and to submit these logs to the California Department of Water Resources in Sacramento. These logs give the location, total depth, owner, and driller, and a brief description of the deposits penetrated.

Water-well logs are generally the only subsurface data available between cores. Their geologic information, however, is limited because: driller's descriptions of the sediments penetrated are commonly ambiguous and inconsistent and generally provide insufficient description for confident geologic interpretation. The descriptions are often adequate however, for interpolating principal stratigraphic horizons between cores-holes.

Only those water wells within three kilometers of the transect were projected onto the profiles (plates 25A and 25B). Although water well logs are available for inspection by the public in Sacramento, their complete descriptions and location may not be released legally to the public. Consequently these wells are not located on from the profiles.

Supplemental Augering

In several areas lacking sufficient core-hole or water-well data to interpret the stratigraphy, supplemental augering was performed with a 13-cm-diameter truck-mounted auger. Auger holes did not exceed 32 meters (115 feet) in depth and information is obtained from cuttings retrieved from the auger stem. The uncertainty in establishing sample depth ranges from $\pm$ 0.5 m to $\pm$ 5 m depending on depth of sampling and ease of penetration

Two transects were drilled during the course of this investigation on the Little Panoche Creek and Panoche Creek alluvial fans. Figure 30 presents the results from the Little Panoche drilling program. Results from the Panoche drilling are incorporated on plate 25A.

The lower Panoche Creek alluvial fan was drilled to obtain additional stratigraphic and absolute age information on the stratigraphically complex interfingering of the lower fan deposits with the floodbasin deposits of the basin floor. The drilling also provided data on the extent of cut and fill by the axial stream of the San Joaquin Valley; lateral continuity, age, origin and environment of deposition of clay and silt horizons in the valley axis; and contact relationship of Coast Range and Sierran deposits. Little Panoche Creek alluvial fan was drilled to test our ability to recognize and trace a

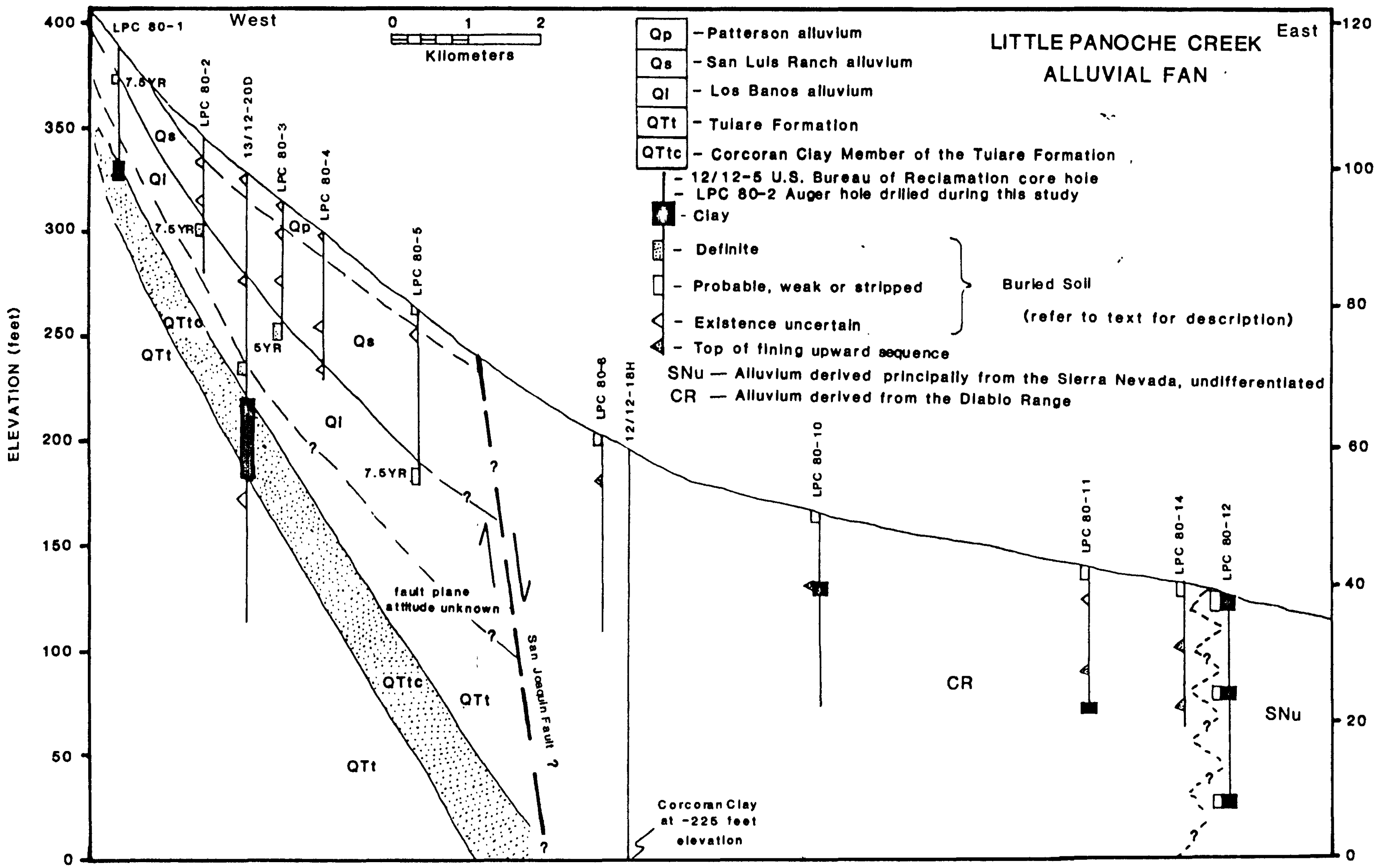


Figure 30: Subsurface stratigraphy of late Cenozoic deposits on the Little Panoche Creek alluvial fan.

well preserved surface stratigraphy into the subsurface and because very little subsurface data on the fan is available.

Buried Soils

Buried soils are common, widespread features in the subsurface of the San Joaquin Valley. Laterally persistent, planar, well developed buried soils have been recognized on the Tuolumne River alluvial-fan (B. F. Atwater and W. R. Lettis, unpublished data, 1981), San Joaquin River alluvial-fan (Janda, 1966), Chowchilla alluvial-fan (Helley, 1967) and over wide areas of the southern and central San Joaquin Valley (I. E. Klein, unpublished U. S. Bureau of Reclamation report, 1954).

In addition to being identifiable subsurface horizons in the valley subsurface, the buried soils have important climatic and depositional implications. They represent past intervals of landscape stability during which both erosion and deposition of the alluvial fan were nil. If deposition were continuous, even with shifting loci of deposition, laterally persistent buried soils would not be expected. Their presence, therefore, would indicate that episodic pulses of deposition are separated by long intervals of neither deposition or erosion.

Although a single laterally continuous buried soil may be time transgressive over several tens of thousands of years (Fullerton, 1981), a buried soil probably represents intervals of 100,000 years or less (Gile and others, 1981). The regionally episodic cycle of deposition alternating with surface stability indicated by a buried soil, therefore, would support a climatic control governing deposition of the alluvium as argued by Janda (1966) and Marchand (1977), among others, for the glacial outwash alluvial-fan deposits in the eastern San Joaquin Valley.

Fullerton (1981) defined a buried soil as a soil or remnant of a soil that formed at the earth's surface, was buried through natural processes subsequent to pedogenesis, and has been preserved to the extent that one or more pedogenic characteristics--e.g. color, texture, ped development, character of carbonate and horizonation--persist. Based largely on these criteria, buried soils in the San Joaquin Valley subsurface have been recognized with three degrees of certainty: (1) definite, (2) probable, (3) doubtful. These levels of confidence are illustrated on Plates 25A and B and Figure 27.

(1) Definite soils are those with well developed, well preserved, thick argillic or calcic B horizons exhibiting ped development, clay coatings around grains and peds, and iron-oxidation. Most of these soils were recognized by I. E. Klein (unpublished U. S. Bureau of Reclamation reports, 1954, 1964) and D. E. Marchand (unpublished data, 1978-1980) during field and laboratory study of core samples.

(2) Probable soils are those with thin profiles or those from which the A and upper B Horizons were possibly eroded before deposition of overlying sediment. They have well-preserved clay coatings around grains and are moderately to strongly oxidized, and less diagnostic features such as unoxidized rootlets, root casts, "granular" texture suggesting dessication, poor sorting in an otherwise well sorted matrix suggesting clay illuviation

and/or bioturbation, abrupt increase in bulk density decreasing gradually downward into less dense material, and the rare presence of a possible organic rich A horizon. These soils have been recognized in core samples by D. E. Marchand (unpublished data, 1970) and auger cuttings during this study.

(3) Doubtful soils are those with very thin profiles. The possible presence of a B horizon is indicated by ferric oxide, carbonate, and manganese accumulation, and by pedogenic granular texture. These soils have been recognized in auger cuttings during this study and from core and well log descriptions punctuated by vague comments such as unusual degrees of sediment "rottenness". Many of these features, however, can also be caused by reaction with ground-water.

The buried soils are best developed, thickest, and most completely preserved high on the fans near the valley perimeter and diminish in degree of development, thickness and preservation toward the valley axis where they become indistinct or are not present (Plates 25A and B). Several possible factors contributing to this trend are (1) that episodes of deposition are more frequent on the lower alluvial-plain basin floor and than close to the heads of the alluvial fans and thus provide less time for soils to develop; (2) the trunk stream of the valley has migrated laterally through time periodically removing soils; and (3) well-drained alluvial-fan soils on the upper piedmont alluvial-plain have distinct, conspicuous pedogenic features but basin soils have typically developed in fine-grained, reduced sediment and their pedogenic features are far more subtle and more easily overlooked; hence if present, they may have escaped detection.

SUBSURFACE STRATIGRAPHIC UNITS

General

Late Cenozoic deposits are divided into two kinds of units, each of which contributes important information on the climatic and tectonic evolution of the San Joaquin Valley: (1) Lithologic units, which reflect source terrain and environment of deposition; and (2) Depositional units, which represent distinct periods of aggradation separated by intervals of non-deposition.

Lithologic units

Two kinds of lithologic units are present: (1) alluvial-fan deposits of the piedmont aluvial-plain; and (2) lacustrine, floodbasin and paludal deposits of the basin floor. Alluvial-fan deposits range from fine to coarse grained and are further subdivided based on source terrain. These deposits comprise the vast majority of the San Joaquin Valley fill. The lacustrine, palustrine and floodbasin deposits interfinger with the coarser-grained alluvial-fan deposits in the valley axis and are characterized principally by their fine-grained texture and gleyed color (Meade, 1967).

Alluvial-fan deposits of the Piedmont Alluvial Plain

Mineralogy of the alluvial-fan deposits allows subdivision by provenance. Mineralogic analyses, principally by I. E. Klein (unpublished Bureau of Reclamation report, 1954), permits division of the alluvium into

(1) undifferentiated Coast Range alluvium; (2) Undifferentiated Sierra Nevada alluvium; (3) alluvium derived principally from the higher part of the Sierra Nevada underlain principally by granitic rocks, and (4) mixed Sierra Nevada alluvium derived from metamorphic and volcanic rocks of the foothills as well as from the higher granitic parts of the range.

Coast Range Alluvium

Coast Range alluvium typically contains more than 30 percent dark grains and lithic fragments (Meade 1967). The lithic fragments are characteristically green and red chert, graywacke, altered andesite and less abundant green serpentinite and actinolite and glaucophane schist - a common Franciscan assortment consistent with a Coast Range source. Clasts of diatomite from the Kreyenhagen and Moreno Formations are commonly a minor but conspicuous constituent. Glaucophane and hornblende are common auxillary minerals in the heavy mineral fraction with hornblende particularly abundant (20 to 25%) in the southwestern San Joaquin Valley where andesitic detritus of the Etchegoin Formation underlies part of the source terrane. Micaeceous minerals, primarily biotite, are present only as sparse (less than 1%) weathered flakes (Meade, 1967, I. E. Klein, unpublished data, 1954).

In general, the Coast Range deposits consist of poorly to moderately sorted, subangular to subrounded, yellowish-brown sand, silt and gravel (2.5Y-5Y hues). Clay content ranges from 0 to 30 percent depending on mode of transport. Bull (1964) reported that mudflow deposits contain 15 to 30 percent clay and stream deposits less than 15 percent clay.

Size analyses of U.S Bureau of Reclamation core samples (Meade, 1967, Bull, 1964b) and my subsurface auger investigations suggest a possible cyclic pattern of fluvial deposits overlain by mudflow deposits. The fluvial(?) deposits generally exhibit better sorting, higher degree of clast roundness and little clay matrix. Mudflow (?) deposits are more poorly sorted, clasts are more angular to subrounded and their matrix contains abundant clay. However, contamination of auger samples from gravelly sections generally prevents positive discrimination of mudflow from fluvial deposits.

Sierra Nevada Alluvium

Alluvium derived from the Sierra Nevada is typically light colored and arkosic, with 25 to 50 percent feldspar, 20 to 30 percent quartz, 2 to 5 percent biotite, commonly in large unweathered flakes, and 1 to 2 percent green hornblende commonly in prismatic, euhedral grains (Meade 1967). The alluvium can be further divided on the basis of mineralogy and clast lithology into what I believe represent (1) glacial-outwash alluvium derived principally from the glaciated part of the Sierra Nevada, and (2) non-glacial alluvium, a mixture of detritus derived from the foothills and high part of the Sierra Nevada.

Glacial-Outwash Alluvium

Alluvium derived from the glaciated high Sierra Nevada has a composition reflecting a plutonic source terrain. Most rock fragments are granitic (65 to 75%), with fewer metavolcanic (10 to 15%) and less common amphibolite and quartzite (0 to 5%). Alkali feldspar commonly exceeds 25 percent of the fine-grained mineralogic fraction. Sparse hypersthene and clinopyroxene (less than 2% of heavy mineral fraction) may reflect erosion of sparse silica-poor plutons (dioritic composition) in the high Sierra or minor local erosion of volcanic rocks in the foothills. The pyroxenes generally have uncorroded margins suggesting little physical or chemical weathering during transport.

Non-Glacial Alluvium

Alluvium derived from both the foothills and high Sierra Nevada has been derived from both the plutonic rocks of the high Sierra as well as the volcanic and metamorphic rocks of the foothills. Rock fragments include plutonic (30-40%) and metamorphic (30-40%) lithologies as well as abundant andesitic and basaltic clasts (20-30%). The San Joaquin River foothill assemblage also includes 0.5 to 5 percent rhyolitic ash, probably reworked from the Friant pumice, which today is exposed only in the foothills of the Sierra Nevada.

Alkali feldspar comprises only 5-15 percent of the fine-sand mineral fraction. The heavy mineral fraction includes both volcanic and plutonic pyroxenes. Sixty to 70 percent of all pyroxene grains have corroded margins as opposed to less than 30 percent of the pyroxene grains in alluvium derived from the high part of the range (unpublished analyses by I. E. Klein, 1951-54).

Recognition of these two kinds of Sierran alluvium requires quantitative mineralogic data which are available only for selected U. S. Bureau of Reclamation cores examined by I. E. Klein (U. S. Bureau of Reclamation, unpublished mineralogic investigations, 1951 to 1954). The mineralogic separation is possible only for the San Joaquin River alluvial-fan deposits overlying the Corcoran Clay (Plate 25A). The deposits below the Corocoran Clay on Plate 25A, and deposits from the Sierra Nevada on Plate 25B are grouped as "undifferentiated alluvium from the Sierra Nevada" in the absence of quantitative data.

The mineralogic distinction was initially recognized by I. E. Klein who thought it represented deposits from different drainages of the Sierra Nevada. The common presence of both types on a single alluvial fan, however, suggests that the deposits may have accumulated from a single drainage with changing source areas.

The general subsurface distribution of these two kinds of deposits indicate that glacial-outwash alluvium comprises most of the San Joaquin River alluvial fan while non-glacial alluvium underlies the basin floor of the valley (Plate 25A). Such a distribution implies that the principal periods of deposition on the alluvial fan occur during glacial or waning glacial periods when the overloaded Sierran Rivers aggrade their channels with glacial outwash (Marchand, 1977; Janda, 1966; Helley, 1966). The principal periods of deposition on the basin floor occur during interglacial periods when the underloaded Sierran Rivers entrench their channels across their alluvial fans and transport non-glacial and reworked glacial-outwash alluvium directly to the valley axis. Intercalation of the deposits on the lower-fan may reflect the relative expansion and contraction of the basin floor and/or alluvial fan in response to the fluctuating rates of sedimentation.

Friant Pumice

The Friant Pumice is a deposit of locally nearly pure rhyolitic ash and pumice underlying more than 2500 Km^2 of the eastern San Joaquin Valley (I. E. Klein, 1954, unpublished U. S. Bureau of Reclamation Report). The pumice is well-exposed in outcrops near the town of Friant, California (Janda, 1965) and is an important Pleistocene marker horizon in the eastern San Joaquin Valley. It is interpreted by Janda (1965, 1966) and Frink and Kues (1954) to be largely a fluvial deposit derived from the drainage basin of the San Joaquin River. According to Janda (1965): "...The pumiceous alluvium...lies near the base of the alluvium deposited during the youngest aggradational cycle of the Turlock Lake Formation...The basal 10 to 30 feet of the rhyolitic material consists of flat-lying, remarkably even beds of fine ash 1 to 30 mm thick. The rhyolitic alluvium is progressively coarser, more impure, and thicker-bedded uwpard in the section. Large scale fluviatile cross-bedding is present." Marchand and Allwardt (1981) formally designated the Friant Pumice a Member of the upper unit of the Pleistocene Turlock Lake Formation. Core holes in Madera County show that the pumice thickens, coarsens, and increases in purity eastward (Plate 25A).

Based on trace and minor element chemistry, Sarna-Wojcicki and others (1980) suggest that the Friant Pumice is correlative with the Bishop ash erupted from the Long Valley Caldera in the southeastern Sierra Nevada and that these two deposits may be considered members of a single eruptive episode of short duration. Bailey and others (1976) suggest that the Friant Pumice may represent a resurgent eruption of the Long Valley Caldera subsequent to eruption of the Bishop Tuff. Potassium-argon dates of 615,000 ± 22,000 years on the Friant Pumice (discussed earlier in section titled "Age of Corcoran Clay") and 725,000 ± 15,000 years on the Bishop Tuff (Dalrymple, 1980) indicate possibly two events at least 60,000 years apart.

The Friant Pumice is chemically identical with the thin 10 ± 10 cm ash horizons in the Corcoran Clay of the San Joaquin Valley Subsurface (refer to "Tulare Formation" Section of this report; Sarna-Wojcicki and others, 1980). These thin ash horizons may represent the air-fall equivalent of the fluvially reworked Friant Pumice and thus may indicate that the pumice was erupted when a large lake depositing the Corcoran Clay occupied the San Joaquin Valley. Core holes in the eastern San Joaquin Valley (Plates 24, 25A and B) show that, although the main body of the pumice overlies the Corcoran Clay, ash-laden fluvial deposits from the San Joaquin River also accumulated in the upper Corcoran Clay, indicating that the Friant Pumice during erupted late in the period of deposition of the Corcoran Clay.

Floodbasin, Lacustrine and Palustrine deposits

Floodbasin, lacustrine and paludal deposits underlie the present valley trough. These deposits consist of lenses of greenish-gray, gray and blue (5G, 5GY, 10G, 5B, 5BG Hues) silt, clayey silt and subordinant silty clay. Their petrology is described by Meade (1967) and was found to reflect both Coast Range and Sierra Nevada bedrock lithologies. The lenses are occasionally interbedded with alluvial-fan deposits of Coast Range or Sierran provenance at the margin but become more continuous near the present and ancestral valley trough and therefore help delineate the former positions of the valley's topographic axis.

In the Tulare Lake Basin, south of the study area, where subsidence has produced a continuous lake basin (Davis and Green, 1962), these deposits range in age from late Pliocene to Holocene and are over 1000 meters thick. Northward, however, these deposits branch into clayey and clayey-silt tongues called the "A","B","C","D","E" and "F" clays, in descending order, by Croft (1968) who believed them to be distinct lacustrine units. Croft (1972) traced their subsurface extent principally by geophysical electric log methods, and made extensive correlations, particularly for the "A","C", and "E" clays, with the central and northern San Joaquin Valley.

Recent data support his correlation of the "E" clay, which forms a laterally continuous horizon underlying most of the San Joaquin Valley and is considered equivalent with the Corcoran Clay. The "A" and "C" clays, were also extended discontinuously into the northern San Joaquin Valley (Croft, 1972); however, detailed augering during this study has shown that Crofts "A" and "C" clays were based on several sandy silt horizons of different age in different wells, rather than on two distinct lacustrine clay deposits. Plate 25A contrasts the interpretation favored by Croft's correlations (main body of plate) and the interpretation required by closely spaced auger holes (expanded inset above main plate). Croft's correlation of the "A" Clay shown on plate 25A also seems unlikely because it requires greater deformation of the "A" clay than of the underlying clay and because radiometric dates of 2 8,200 ± 330 years, 29,970 ± 250 years, 43,800 + 1700-1400 years, 22, 670 ± 200 years and 31,300 ± 650 years (Stephen Robinson, written communication, 1981; USGS # 1197,1198, 1199, 1200 and 1201) from wood in and above the clay (Plate 25A) are older than the 9,640 ± 1300 year old "A" clay in the Tulare and Buena Vista Lake basins.

The predominance of silt and fine sand relative to clay, common presence of oxidized rootlets and a common granular texture suggesting dessication, indicates that the deposits probably accumulated on the basin floor under subaerial rather than lacustrine conditions. As the insert on Plate 25A illustrates, repeated channel migration and incision by the trunk stream has removed and fragmented the once continuous floodbasin deposits (Figure 39). A laterally continuous stratigraphy is thus not presesnt; incision by the trunk stream precludes physical tracing of the alluvial-fan stratigraphy across the Valley's axis in the vicinity of Dos Palos. The vertical and lateral extent of the cut-and-fill deposits is little known. The lateral continuity of the Corcoran Clay, however, indicates that it has not been interrupted by cut-and-fill.

The multiple floodbasin deposit ion and the repeated channeling by the San Joaquin River are natural geomorphic and fluvial processes which have several other important implications:

(1) Ground water aquifers. The A and C clays do not exist as continuous aquicludes in the north-central San Joaquin Valley as shown by Croft (1968, 1972), and further study may prove this to be the case elsewhere in the San Joaquin Valley.

(2) Geologic structure. Contours of the top of the"C" clay by Croft (1968) and Croft and Gordon (1968) that suggest considerable late Pleistocene deformation 20 to 30 km east of the principle structural axis of the valley are probably on a time-transgressive surface and hence cannot be used to infer tectonic deformations.

(3) Sedimentation rates. Janda (1966) suggested that interbedding of 1-to 3m-thick clays with thicker sections of fine to coarse sand in the valley trough

indicated alternating periods of relatively slow sedimentation with periods of relatively rapid sedimentation. It appears, however, that slow and rapid net accumulation can occur concurrently on different parts of the basin floor as the trunk stream migrates laterally.

(4) Age of contiguous alluvial-fan deposits. Dates on material recovered from floodplain deposits in the valley trough do not necessarily date alluvial-fan deposits at the same depth nearby, because the trunk stream could have eroded the toe of the fan and rapidly deposited much younger floodplain alluvium in its place (Figure 40). Time lines therefore, rarely project across the Valley axis because of cut-and-fill (Figure 39 and Plate 25A).

IMPLICATIONS OF THE DISTRIBUTION OF COAST RANGE AND SIERRA NEVADA ALLUVIUM

The Sierran and Coast Range alluvial-fan deposits interfinger valleyward with the fine-grained floodbasin, lacustrine and palustrine deposits. Past position of the Valley's topographic axis approximates the location of these fine-grained deposits and the interface of Coast Range and Sierran sediment (Plates 25A and 25B).

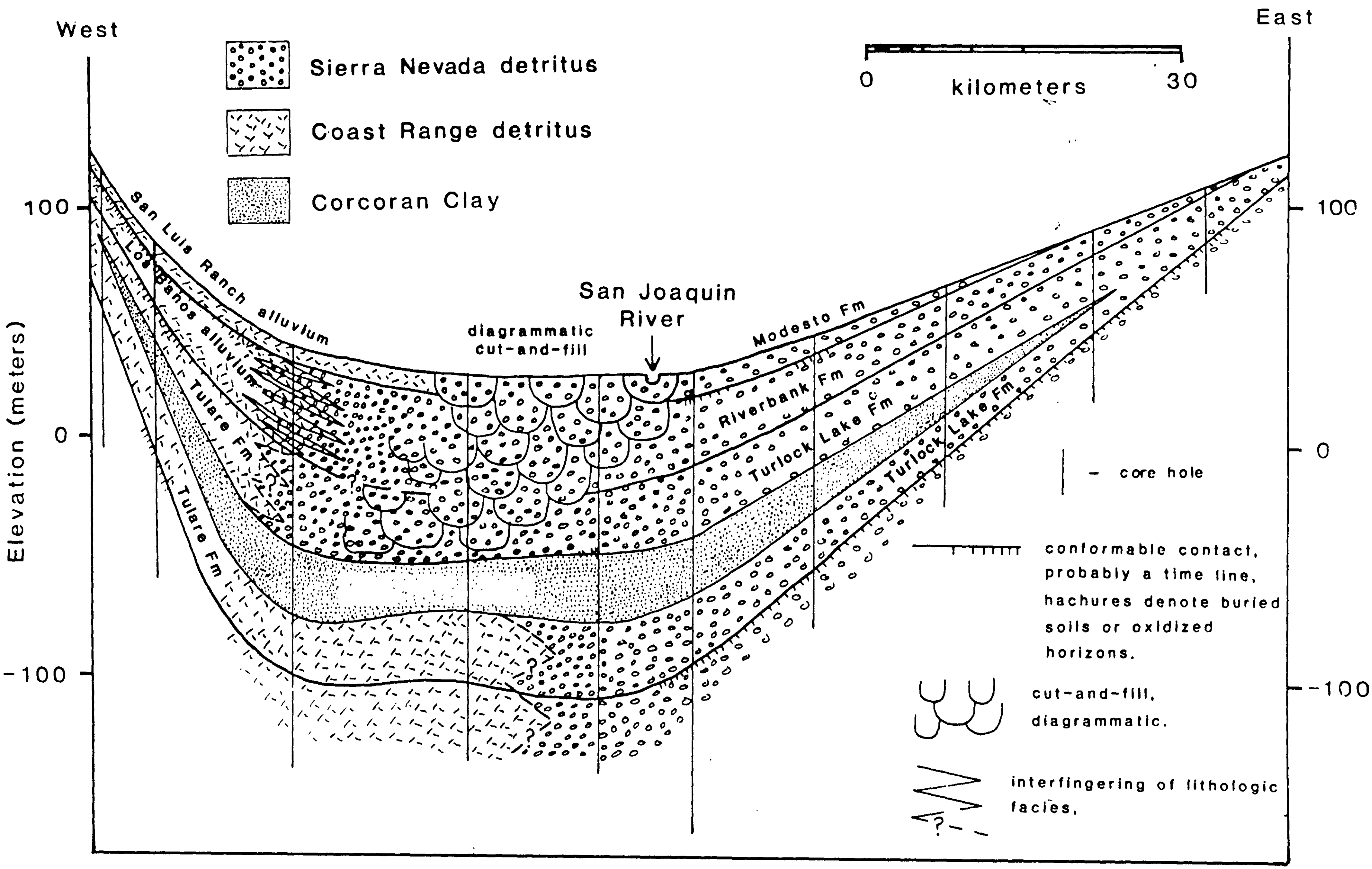
The position of the topographic axis is in dynamic equilibrium with depositional rates on the floodbasin and flanking alluvial fans. If the valley floodbasin remains in a fixed position with constant areas, the rate of deposition on the floodbasin must equal that on the alluvial-fans (Hooke, 1969). Migration of the valley trough, therefore, probably reflects changes in depositional rates on the valley floodbasin versus the bordering alluvial fans. Increasing rates of deposition on the fan system would cause the fan to increase its thickness faster than the floodbasin and thus, ultimately encroach on the floodbasin.

Several possibilities arise: (1) The rate of deposition increases on both flanking alluvial-fan systems relative to the basin floor; in which case the alluvial fans will prograde valleyward at the expense of the basin floor; (2) The rate of deposition increases on the basin floor relative to the flanking alluvial fans; in which case the basin floor will expand over the lower piedmont alluvial-plain; (3) The rate of deposition increases on one flanking fan-system while the rate on the floodbasin and opposing fan-system remains unchanged. The fans with greater rates of deposition will prograde over the floodbasin, but because the basin floor and opposing fan-system maintain a constant rate of deposition, the floodbasin may also migrate over the opposing fan-system to maintain a steady state of areas. Incision by the trunk stream into the opposing fans is possible. (4) The rate of deposition increases on one flanking fan-system and the basin floor relative to the opposing fan system; in which case the growing fan-system and basin floor will expand and migrate over the opposing fan-system largely by aggradation with little or no trunk stream incision; and (5) the rates of deposition decrease throughout the valley until the rate of subsidence exceeds the rate of deposition; in which casea the position of the topographic axis of the valley will be governed by the position of the structural axis of the valley.

Changes in the location of the Coast Range-Sierran alluvial interface indicate two major eastward shifts of the topographic (depositional) axis of

Figure 39: Diagrammatic cross-section of the San Joaquin Valley illustrating general stratigraphic and lithologic relations in the valley subsurface. Refer to Plates 25A and B for detailed geology.

(Next page)



West
East
Sierra Nevada detritus
Coast Range detritus
Corcoran Clay
0
kilometers
30
100
0
-100
Elevation (meters)
San Luis Ranch alluvium
Los Banos alluvium
Tulare Fm
Tulare Fm
diagrammatic
cut-and-fill
San Joaquin
River
Modesto Fm
Riverbank Fm
Turlock Lake Fm
Turlock Lake Fm
- core hole
conformable contact, probably a time line, hachures denote buried soils or oxidized horizons.
cut-and-fill, diagrammatic.
interfingering of lithologic facies.
?

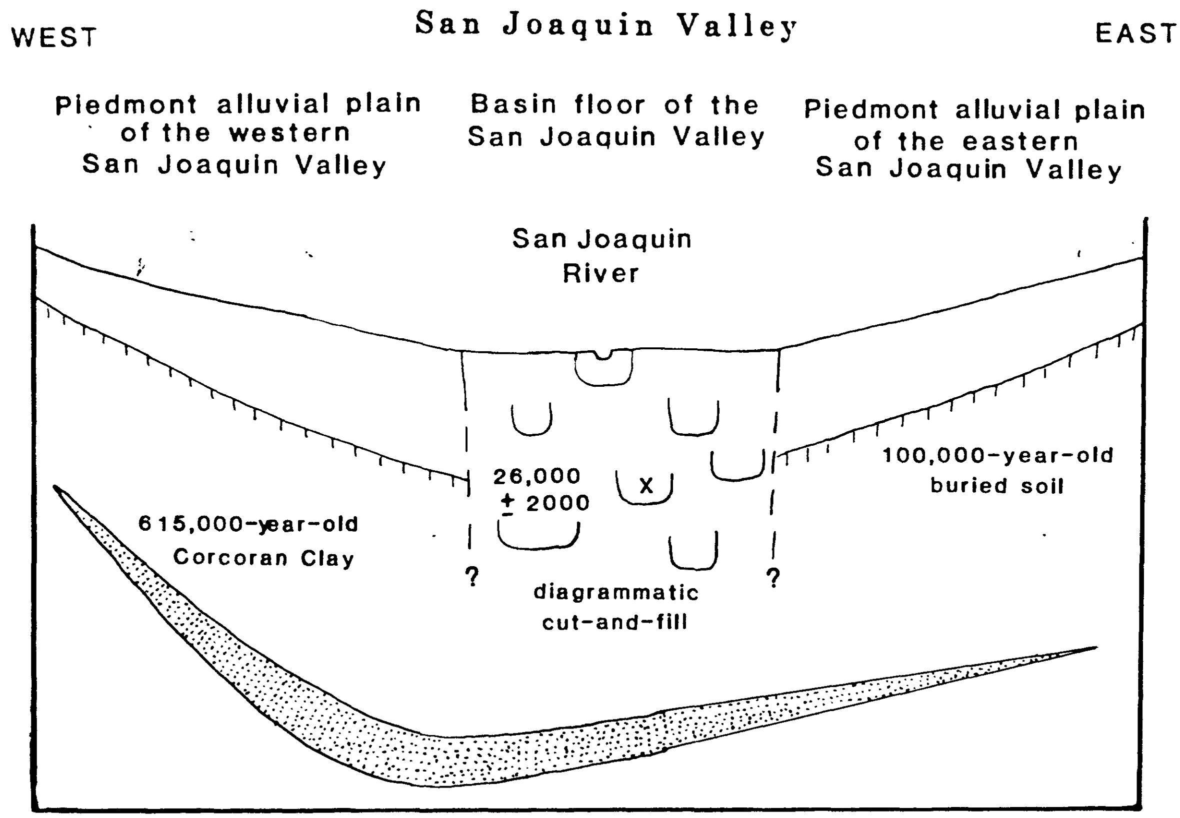


Figure 40: Diagrammatic cross-section of the San Joaquin Valley illustrating effect of basin floor cut-and-fill on the distribution of late Quaternary deposits. Basin floor deposits are commonly incised into older alluvial-fan deposits during migration and channel incision of the San Joaquin River. Sedimentation rates calculated from the basin floor, therefore, cannot always be applied to the rate of sedimentation on the piedmont alluvial-plain.

the north-central San Joaquin Valley (Plates 25): (1) An abrupt shift that predates the Corcoran Clay; and (2) A gradual shift that post-dates the Corcoran Clay.

The first migration is recorded by a tongue of Coast Range alluvium greater than 30 meters thick that extends as much as 30 km east of the present topographic axis and 50 km east of the structural axis of the San Joaquin Valley (Plate 25A). The tongue was informally named the Buena Vista Bed by I. E. Klein (unpublished U. S. Bureau of Recalmation Report, 1954). A commensurate shift of the structural axis to produce this migration is not evident at the scale shown on Plate 25A. There is also no indication of Sierran alluvium admixture or interstratification suggesting that the bed probably formed by rapid eastward progradation of Coast Range alluvium with little interference from Sierra Nevada alluviation. Well developed buried soils are present in core holes 13/16-2D (locality 165, Plate 24, Appendix 1) both on the Buena Vista Bed and on the underlying Sierra Nevada detritus suggesting a period of non-deposition on Sierran fans during this time.

There is not sufficient data from cores north and south of plate 25A, however, to evaluate the regional extent of this bed or lateral continuity of the buried soils. Development of the bed may simply reflect entrenchment of the San Joaquin River or southwestward flow of the River into the Tulare lake basin. However, a similar approximately coeval bed of Coast Range detritus near Bakersfield (core hole 31/25-27F, locality 12 on Plate 24, I. E. Klein, unpublished data, 1954) implies regional progradation of Coast Range alluvial-fans in the southern San Joaquin Valley as well.

Correlation of buried soils in the valley (Plate 25A) indicates that the Buena Vista Bed is roughly coeval with the Pliocene or early Pleistocene North Merced Gravel, whose extensive pediment in the foothills of the Sierra Nevada suggests a period of tectonic quiescence (Marchand, 1977). Soils developed on the North Merced Gravel indicate a semi-arid climate (Marchand and Allwardt, 1981, p. 20) and hence probably formed during an interglacial period.

The Buena Vista Bed, therefore, represents a major eastward shift of the valley's topographic axis, independent of structural subsidence in the valley during a period of diminished erosion in the Sierra Nevada. Out-of-phase deposition of Coast Range and Sierran alluvium is thus indicated. The progradation may have occurred during a glacial-interglacial transition or during an interglacial period when Sierran alluviation was minimal and allowed eastward growth and migration of Coast Range fans. Insufficient age data on the North Merced Gravel and Buena Vista bed, however, precludes a more precise correlation of the sequence with climatic change.

Alternatively, a major Pliocene or early Pleistocene Coast Range tectonic event may have caused deposition of the Buena Vista bed. Significant deformation and homoclinal tilting the foothill belt to attitudes of 35 to 40° followed deposition of the late Miocene Oro Loma Formation and may have stimulated Coast Range alluvial activity. As described earlier, however, the minimum age of this deformation is constrained by the overlying, undeformed 9.35 my old Basalt Hill outlier of the Quien Sabe volcanics. If my correlation of the Buena Vista Bed with the North Merced Gravel is correct, deposition of the Buena Vista Bed post-dates this deformation by at least 5 my. Furthermore, the Basalt Hill outlier is at the same elevation in the foothills as are the Quien Sabe volcanics in the central Diablo Range, indicating that the central Diablo Range was not significantly elevated at the time of deposition of the Buena Vista in the Pliocene, or early Pleistocene (described in "Late Cenozoic Structure" Section of this report).

A second interval of deformation warped and faulted the Tulare Formation and elevated the Basalt Hill outlier over 300 meters in the foothills of the Diablo Range (described in the following "Late Cenozoic structure" section of this report). The onset of this deformation may have triggered a period of increased alluvial activity in the western San Joaquin Valley. Following the eastern migration of the Buena Vista alluvium, however, the topographic axis of the valley attained equilibrium over 3 km west of the valley's structural axis near the mouth of Panoche Creek (Plate 25A) and 10 to 15 km east of the structural axis near Dos Palos (Plate 25B). The presence of Sierran alluvium west of the Valley's structural axis near Panoche Creek prior to deposition of the Corcoran clay suggests that the anticlinal deformation of the Tulare Formation in the Panoche Hills post-dates deposition of the Buena Vista Bed and even possibly the Corcoran Clay. If so, the second interval of Coast Range deformation probably is not responsible for progradation of the Buena Vista alluvium. Either climatic fluctuation induced greater erosion in the Coast Range causing progradation of the Buena Vista alluvium or southward flow of the San Joaquin River and its alluvium into the Tulare Lake basin enabled the Coast Range fans of Buena Vista aluvium to migrate eastward.

The second eastward progradation of Coast Range alluvium began after deposition of the Corcoran Clay and has continued intermittently to the present, such that today the trunk stream of the valley flows 20 to 30 km east of its course just after deposition of the Corcoran Clay. In general, the Coast Range alluvium is thickest in the structural trough and forms a wedge the base of which rises eastward to reach the surface at the present topographic axis of the valley.

The cause for this second progradation is poorly understood. Although there is no commensurate shift in the position of greatest subsidence to produce the eastward shift of the topographic axis, the eastward migration of Coast Range alluvium spans many climatic fluctuations and therefore cannot be attributed entirely to climatic change. The migration probably reflects, therefore, either (1) an adjustment of the valley to reestablish a topographic axis dependent on the rates of sedimentation after a period when relatively rapid subsidence governed the position of the axis during deposition of the Corcoran Clay, or (2) the aforementioned late Quaternary uplift of the Diablo Range.

During deposition of the Corcoran Clay, the rate of subsidence probably exceeded the rate of sedimentation in the valley to produce a closed basin (refer to "Corcoran Clay" section of this report). Is so, the lake basin axis probably would have coincided with the structural axis along the western margin of the valley. The Corcoran Clay is thickest at the axis of the structural trough supporting coincidence of the two axes (Plate 25A and B). Under more common conditions, however, deposition in the valley generally equalled the rate of subsidence, in which case the position of the topographic axis would have depended on relative depositional rates on the Coast Range and Sierra Nevada alluvial fans. Consequently, the location of the valley's topographic axis has rarely coincided with the more stationary structural axis (Plates 25A and B).

Thus, when rates of deposition again equalled subsidence after deposition of the Corcoran Clay, the topographic axis was shifted eastward. The late Quaternary uplift of the foothills of the Diablo Range may have made available progressively more detritus encouraging further eastward shift of the axis.

Many temporary reversals of this eastward shift occurred after deposition of the Corcoran Clay, however, when Sierra Nevada alluvium prograded westward. Plate 25A shows three major interfingering events but the complexity is best illustrated on Plate 25B in core hole 11/11-22Q where, between 100 and 200 feet below the land surface, ten alternations between Sierran and Diablo Range alluvium were recognized by I. E. Klein, (unpublished data, 1954).

Two buried soils, bracketing a tongue of Sierra Nevada alluvium in Core Hole 14/14-13E (Plate 25A Number161, Plate 24 and Appendix 1) indicate that alluviation from the Diablo Range was diminished before, during and after deposition of the Sierran alluvium. The lower soil also indicates that the floodplain probably expanded westward by rapid trunk stream aggradation rather than trunk stream migration and channel incision.

Plate 25B shows a latest Pleistocene or Holocene eastward progradation of Coast Range alluvium over Sierran alluvium producing a 1 to 10 m thick veneer. This progradation, perhaps typical of interglacials, contrasts with westward migration of the San Joaquin River during periods of glacial-outwash deposition. Incision by the river during westward migration may have removed similar, former interglacial veneers of Coast Range alluvium destroying the record of their development as a consequence. If the veneer is unique, however, it may reflect very recent deformation of the Laguna Seca Hills.

The available subsurface evidence suggests that there are three major causes for the interfingering: (1) Information obtained from augering near the confluence of the Fresno Slough and the San Joaquin River (Plate 25A, inset at top) indicates that trunk stream channel incision and migration are normal fluvial processes unrelated to long-term (10^5 yr) climatic fluctuation. During migration, the trunk stream commonly swing westward, scalloping the toe of the Coast Range Panoche Creek alluvial fan and producing a nearly vertical contact between Sierran and Coast Range alluvium. Subsequent growth of the Coast Range fan overlaps the older channel margin, producing what would appear as distinct interfingering at a smaller map scale; (2) The multiple interfingering noted in core 11/11-22Q probably represents minor expansion and contraction of the trunk stream floodplain unrelated to trunk-steam incision or longterm climatic fluctuation. The interfingering occurs between two buried soils that are interpreted to bracket, at the most, only two significant episodes of alluviation; (3) The larger tongues of Sierran alluvium (best illustrated in core hole 14/14-13 Plate 25A), however, probably reflect glacial-outwash events, when Sierran rivers carried sufficient sediment to prograde over the floodbasin and driving the axial stream westward. The reduced nature of these coarse-grained deposits indicates deposition on the floodplain of the San Joaquin River. The scarcity of Coast Range detritus implies that the volume of detritus shed from the

Sierra Nevada far exceeded that from the Coast Range, and/or that the water flowing down the axial stream came mainly from the Sierra Nevada. These changes are consistent with increased glacial erosion and transport in the Sierra Nevada and greater slope stability in the unglaciated Coast Range during glacial periods.

SEDIMENTATION RATES

The thick section of continental alluvium overlying the Corcoran Clay probably accumulated on average at a rate equal to the rate of subsidence after deposition of the Clay because the valley has neither been inundated by the sea through Carquinez Strait nor has it contained a large lake since deposition of the Corcoran Clay. The rate of sedimentation probably will not exceed the rate of subsidence over the long term because continuing aggradation of the valley floor will cause a progressively steeper gradient to the Sacramento-San Joaquin Delta, increasing the stream velocity and hence the ability of the axial river to transport sediment through the system.

Plate 25A indicates that 250 meters of alluvium has accumulated above the Corcoran Clay in the synclinal axis suggesting an average rate of sedimentation of about 40cm per millenium over the past 600,000 years. The majority of this alluvium is derived from the Coast Ranges suggesting that Coast Range drainages have a greater rate of sedimentaion than do Sierran drainages in the study area. This probably reflects either: (1) more active late Cenozoic tectonism in the Coast Ranges relative to the Sierra Nevada; (2) continuously flowing Sierran rivers may flush their sediment load to the axial stream of the Valley, and ultimately out to sea, whereas Coast Range streams, with far less discharge, more commonly deposit their load as their discharge seeps into underlying deposits; and/or (3) the principal axis of subsidence is closer to the Diablo Range than to the Sierra Nevada.

The average rate of sedimentation above the Corcoran Clay decreased toward the Valley margins to less than five cm per millenium in the eastern San Joaquin Valley (core hole 11/18-8Q, number 170, Plate 24 and Appendix 1) and less than ten cm per millenium in the western San Joaquin Valley (core hole 15/12-23Q, number 208, Plate 24 and Appendix 1). East of about Highway 199, the Sierran Rivers are entrenched into earlier late Cenozoic alluvial deposits and the San Joaquin Valley in these areas is no longer a basin of sedimentation. These rates, like rates for the center of the Valley, indicate more rapid deposition of Coast Range alluvium.

The average degree of soil profile development and/or preservation varies inversely with these rates of sedimentation. More continuous deposition and shorter periods of surface stability occur in the basin than higher on the alluvial fans. The greater rate of Coast Range sedimentation may also explain the scarcity of well-developed and preserved buried soils observed in the western San Joaquin Valley subsurface. Alternatively Coast Range streams may migrate laterally across their alluvial fans more frequently than Sierran rivers which have more deeply incised, stable channels during interglacial and early glacial periods, or aggradational events on Coast Range alluvial fans may be more numerous and frequent than the chronologically distinct glacial-outwash events on the Sierran alluvial fans.

AGGRADATIONAL EVENTS

Alluvial-fan deposits in the eastern and western San Joaquin Valley are divided into stratigraphic units based on the presence of distinct aggradational events. On the east side of the valley, these deposits consist mainly of arkosic material derived from the Sierra Nevada and are divided into the Laguna Formation (including the China Hat gravel of Arkley, 1962), the North Merced gravels, and the Turlock Lake, Riverbank and Modesto Formations and post-Modesto deposits (Marchand and Allwardt, 1981). On the west side of the valley, these deposits consist of alluvium derived from the Coast Ranges and are divided into the Tulare Formation and the informally named Los Banos alluvium, San Luis Ranch alluvium and Patterson alluvium (This study). Each of these units can be further subdivided into deposits of shorter aggradational events separated by periods of surface weathering and soil-profile development.

Attempts to correlate the eastern and western alluvial units across the valley axis through the projection of and correlation of buried soils and the use of the Corcoran Clay marker, have not been successful. Trunk stream cut-and-fill on the floodbasin has significantly disturbed the stratigraphic sequence and well developed buried soils have not been recognized for the reasons described earlier in this section.

A speculative correlation of the alluvial units is querried on Plates 25A and B, however, based on the available age control and superposition of buried soils with the Corcoran Clay in the eastern and western San Joaquin Valley. I suggest the following correlations: the Modesto Formation with the San Luis Ranch alluvium, the Riverbank Formation with the Los Banos alluvium, and the Turlock Lake Formation, North Merced gravel and possibly the upper part of the Laguna Formation with the Tulare Formation. The Corcoran Clay is a formal member of both the Turlock Lake and Tulare Formations indicating their correlation.

PRE-LATE CENOZOIC DEPOSITS

Pre-Late Cenozoic alluvial deposits encountered in the subsurface are shown on the eastern part of Plate 25B. Valleyward, the deposits attain too great a depth to be shown at the profile scale. Deposits of Sierran source terrain include the late Miocene Mehrten and early to middle Miocene Valley Springs Formations. The Mehrten Formation consists principally of pyroxene-rich crystal, lithic andesitic sands and the Valley Springs of rhyolitic tuffaceous sandstone. Valleyward the Mehrhten and Valley Springs interfinger with and underlie unnamed marine sand, silt and clay containing unidentified mollusc fragments and marine diatoms of middle to late(?) Miocene age (Lohman, 1954, written communication to I. E. Klein). The presence of glaucophane and arkosic detritus suggests a mixed Coast Range and Sierra Nevada source. The deposit may be equivalent in part to the informally named "Zilch" Formation in the southern San Joaquin Valley subsurface and the continental Oro Loma Formation of the western San Joaquin Valley.

These Formations are truncated in the subsurface by the North Merced pediment and do not extend to the surface in this area. Gravels in the North

Merced, for example, contain abundant reworked andesitic detritus reflecting this truncation. The Laguna and older alluvial deposits probably thin and onlap the Mehrten Formation in the subsurface or are also truncated by the North Merced pediment and do not extend to the surface.

SUMMARY

The principle results of this subsurface investigation include the following:
(1) The Valley is structurally an asymmetric syncline whose axis lies near the western margin and trends North 30-40° west.
(2) Averaged over the last 615,000 years, sediment has accumulated in parts of the valley trough at a minimum rate of 0.4 m per millenium.
(3) The topographic axis of the north-central San Joaquin Valley has rarely coincided with the structural axis during late Cenozoic time. Position of the topographic axis has typicaly migrated laterally in response to fluctuating rates of alluvial fan and floodbasin deposition from the Sierra Nevada and Coast Ranges. The axes coincided only when the rate of subsidence exceeded the rate of deposition from either mountain range.
(4) The lake in which the Corcoran Clay was deposited probably formed when the rate of subsidence exceeded the rate of deposition (due either to increased subsidence or decreased sedimentation, or both) producing a closed basin. The Corcoran Clay is thickest along the structural axis suggesting that it accumulated when the structural and topographic axes coincided.
(5) The subsurface sediment can be divided by provenance into alluvium from the Coast Ranges, glacial-outwash alluvium from the highest parts of the Sierra Nevada, and non-glacial alluvium derived from the foothills of the Sierra Nevada. Two major episodes of eastward progradation of Coast Range alluvium have occurred, one in the early Pleistocene coeval with development of the North Merced pediment and the other commencing after deposition of the Corcoran Clay and continuing today. Causes for the two migrations are different, however. The early Pleistocene migration occurred rapidly, during a time of very little alluviation from the Sierra Nevada. Diminished alluviation is consistent with development of the North Merced Pediment and inferred semiarid climatic and tectonic quiesense (Marchand, 1977). The later Pleistocene migration has progressed slowly and reflects depositional reestablishment of the topographic axis of the valley following deposition of the Corcoran Clay, a time when subsidence probably controlled the position of the topographic axis. Minor reversals of later this migration occurred during glacial fluctuations when major pulses of Sierran glacial outwash and floodbasin alluvium temporarily pushed the axis westward.
(6) Many of the deposits in the north-central San Joaquin Valley designated by Croft (1968, 1972) as extensive lacustrine clays are in fact floodbasin deposits. Later migration of the lower San Joaquin River commonly has removed parts of the floodbasin and lower alluvial-fan deposits and any soils developed on them, producing complex cut-and-fill relationships and making impossible direct physical correlation of the alluvial formations on the east side of the valley with those on the west side.
(7)Lateral incision by the San Joaquin River followed by rapid deposition, produced high apparent rates of late Pleistocene deposition on the valley floodplain. These rates cannot be extrapolated to the alluvial-fans or be considered a standard for rates of sedimentation in the valley throughout the Pleistocene.
(8) Additional criteria for the proper location of valley cross-sections not

considered during this study but which might be important considerations in future investigations include: (1) selection of areas where San Joaquin Valley trunk stream channeling can be minimized - for example where the Valley flood plain is most constricted or the axial river is absent. This will help alleviate problems arising from trunk stream cut-and-fill and admixture of various lithologies; (2) selection of areas off the principal axes of alluvial fans which will help alleviate similar problems of foothill stream cut-and-fill encountered during our drilling on the Little Panoche Creek alluvial fan (Figure 30). Marginal or inter-fan areas provide a more consistent record of major alluvial events because overbank alluvium reaches these sites during major alluviations but trunk streams will not have disrupted the sedimentary record.

LATE CENOZOIC STRUCTURE

Introduction

Quaternary deformation in the San Joaquin Valley and the foothills of the Diablo Range consists of broad gentle folds and three northwest-trending fault systems. This deformation is manifest principally by tilted, warped and offset Pliocene and Pleistocene terraces, pediments, and deposits. The total deformation is reflected in structure-contours on deformed pediments in the foothills, veneered by deposits of Los Banos alluvium, and by structure contours on the surface of the Corcoran Clay beneath the San Joaquin Valley. An apparently linear relationship between the gradients of stream terraces in the foothills and their age (Figure 41) suggests that the deformation has been relatively constant in the last 600,000 years.

Folds

The Quaternary folds include: (1) the large asymmetric syncline trending north 30 to 40° west that underlies the San Joaquin Valley; and (2) many smaller, northeast trending anticlines and synclines evident in the foothills and which may project into and slightly deform sediments in the San Joaquin Valley.

San Joaquin Valley

The San Joaquin Valley syncline governs the general location and orientation of the valley, although as described in the previous section, rarely do the structural and topographic axes of the valley coincide. The structure exists primarily because of westward tilting of the Sierran block and uplift of the Coast Ranges. It has persisted from at least Miocene time when the Coast Ranges were elevated, eroded, and overlain by the late Miocene Quien Sabe Volcanics. Prior to the Miocene, the valley was principally a region of subsidence on the continental shelf where the thick sequence of marine sediment comprising the Cretaceous and early Tertiary Great Valley Sequence accumulated.

Synclinal nature of the valley is best expressed by structure contours on the surface of the 615,000-year-old Corcoran Clay (Figure 29, see also Croft, 1972 and Miller and others, 1971, for contour maps of the southern San Joaquin Valley). The clay defines an asymmetric trough whose west limb dips 1 to 3° northeast and east limb dips less than 1° southwest (Plates 25A and B). The line of maximum subsidence lies near the western margin of the northern and central San Joaquin Valley, generally from 20 to 30 km west of the present courses of the San Joaquin River and Fresno Slough.

The contour map of the Corcoran Clay (Figure 29) shows several basins and arches superimposed on the major syncline. These basins and arches have amplitudes of 5 to 40 m (about 15 to 130 ft). The basins underlie areas immediately southeast of Panoche Creek and east of Little Panoche Valley. Contour maps by Croft (1972) also show major basins below the Buena Vista and Tulare lake beds in the southern San Joaquin Valley. The basins and intervening arches may be the northeastward extension of the small northeast trending basins and arches exposed in the foothills.

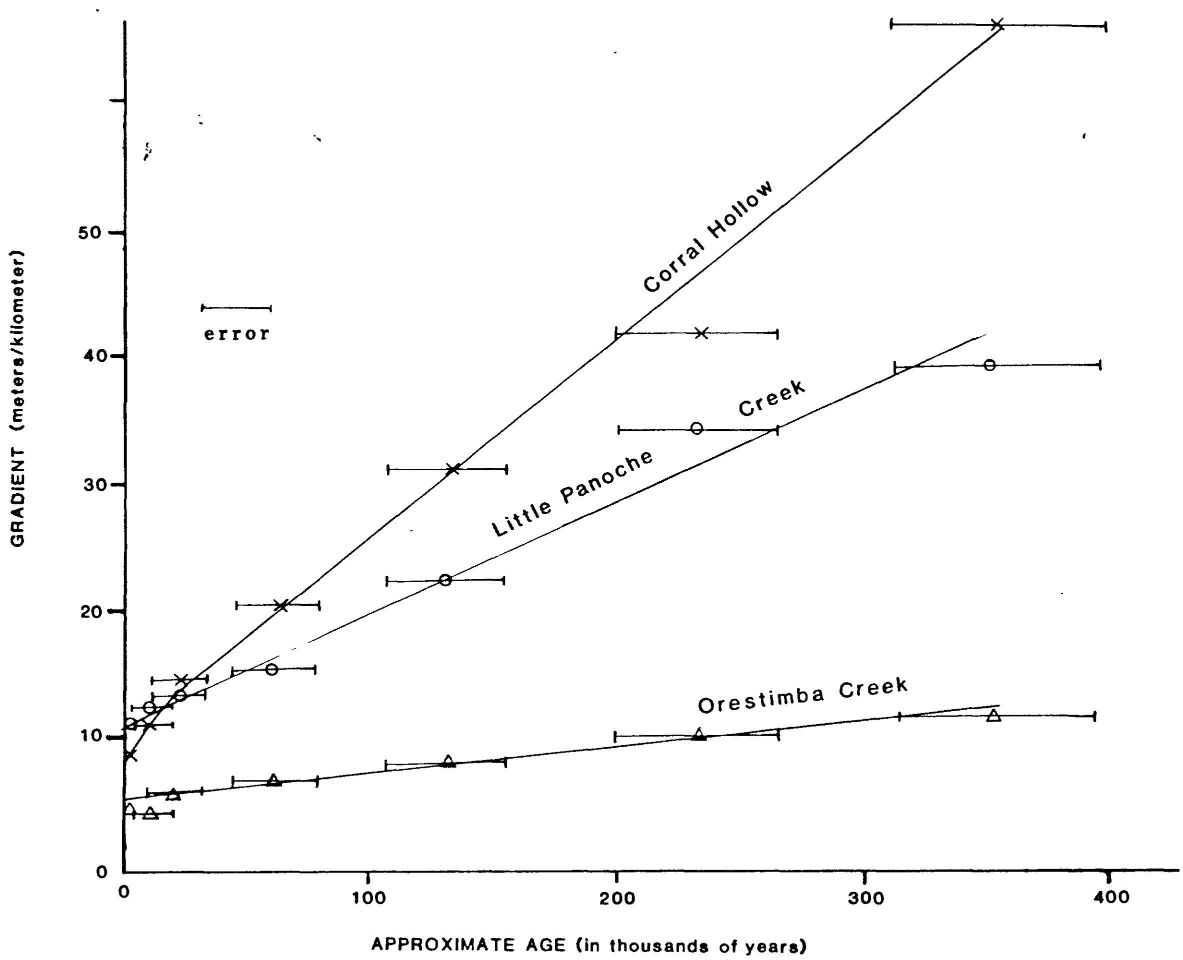


Figure 41: Terrace gradients for three major drainages in the western San Joaquin Valley. Average gradients are calculated from longitudinal profiles shown in Figure 37 and are plotted versus their approximate age determined from pedologic, radiometric, paleomagnetic, paleontologic and stratigraphic data.

Average rates of subsidence in the valley can be estimated from the deformation of the Corcoran Clay and from the average rates of deposition in the valley. Calculation of the rate of subsidence from the contours of the Corcoran Clay, however, depends on several imperfect assumptions: (1) The Corcoran Clay was deposited at or above sea level. This assumption is probably valid because marine waters did not invade the valley at any time during the Quaternary, although connecting waterways did exist. An exception is possible, however, if a structural sill or topographic bench separated the valley from the ocean across Carquinez Strait. For example, the bottom of Lake Superior is about 160 meters (500 feet) below sea level and marine tidal action does not extend beyong the St. Lawrence River near Montreal, Canada. (2) The Corcoran Clay is essentially a time stratigraphic unit. This assumption is not strictly valid because the lake must have expanded from a center and dried out to a center and is thus partially time transgressive. The lower age of 725,000 years B.P. is used, therefore, to insure calculation of a minimum rate of subsidence. (3) The surface on which the Corcoran Clay accumulated had a relief similar to that of today's valley floor which must be removed from the relief of the clay to estimate the relief of the clay due to deformation. (Figure 42). The drowned surface did not, however, mirror the configuration and relief of the present valley for two reasons - (a) the topographic axis at that time probably coincided with the structural trough 20 to 30 Km west of the present valley axis (Figure 42); and (b) the western and eastern former margins of the valley floor probably extended further into their respective foothills then today's valley margin. Extension of the valley floor into the foothills suggests that the former valley floor had a gentler surface gradient than todays. This agrees well with the evidence suggesting that the lake in which the clay was deposited was extensive but shallow (refer to section on the Corcoran Clay). Inundation of the valley today to deposit a clay as extensive as the Corcoran Clay would require a lake whose bottom has relief exceeding 600 feet.

Based on these assumptions, the estimated rates of subsidence will be minimum average values. If the assumptions are invalid, for example, if the clay accumulated on a lake bed below sea level similar to Lake Superior, the calculated rates may be too large. If the valley subsided intermittently rather than continuously or if the rate of sedimentation varied, the actual rate of subsidence at any time may be much greater than or less than the calculated rate.

Calculated Rates of Subsidence from Plate 25A

Section A-A' (Plate 25A) crosses the maximum area of subsidence in the northern San Joaquin Valley immediately southeast of the Panoche Hills (Plate 24, Figure 29). In the synclinal trough (Point "A"), the surface of the Corcoran Clay is 625 feet below sea level suggesting an average minimum rate of subsidence of 625 feet/0.725 million years or about 0.2 to 0.3 meters per millenium. If the valley floor had an elevation of 200 feet similar to todays' minimum elevation at the latitude of the cross section, and the younger age of the Corocoran Clay is considered, a conceivable maximum average rate of subsidence is 825 feet/0.615 million years or about 0.4 meters per millenium.

The magnitude of subsidence decreases to about zero in the western and eastern San Joaquin Valley near the margins of the Corcoran Clay. The

Figure 42: Diagrammatic sketch of the present San Joaquin Valley floor and the approximate valley floor during depositon of the Corcoran Clay. The former valley floor is reconstructed by assuming that it had a relief from trough to margin similar to today's, that the topographic axis coincided with the structural axis during accumulation of the clay, that the former valley margin is approximated by the westernmost extent of the Tulare and Turlock Lake Formations. The diagram illustrates both the eastward shift in the topographic axis of the valley and the calculation of the present and former valley relief between two arbitrary points.

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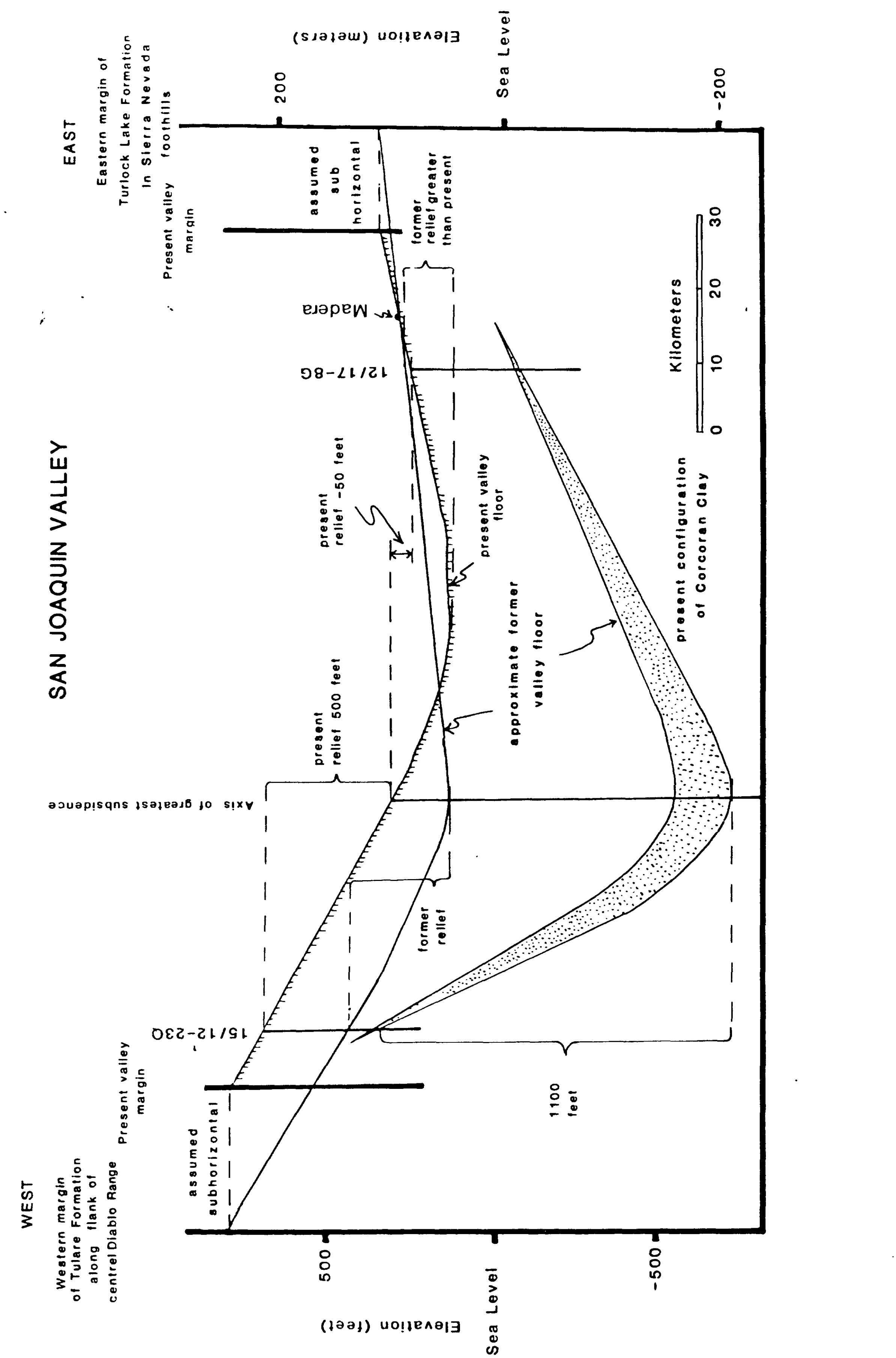
SAN JOAQUIN VALLEY
EAST
Eastern margin of Turlock Lake Formation in Sierra Nevada foothills
WEST
Western margin of Tulare Formation along flank of centrel Diablo Range
Present valley margin
Present valley margin
assumed sub horizontal
assumed subhorizontal
former relief greater than present
Madera
12/17-8G
15/12-23Q
present relief -50 feet
present relief 500 feet
present valley floor
approximate former valley floor
present configuration of Corcoran Clay
Axis of greatest subsidence
former relief
1100 feet
Kilometers
0
10
20
30
Elevation (meters)
200
Sea Level
-200
Elevation (feet)
500
Sea Level
-500

subsidence is estimated both directly by removing the former valley relief from the present relief of the Corcoran Clay (Figure 42), and indirectly from geomorphic evidence. Figure 42 illustrates the relief of the San Joaquin Valley today and the estimated relief of the valley during deposition of the Corcoran Clay. The former valley relief is approximated by the present valley relief in the western San Joaquin Valley but exceeds the present valley relief in the eastern San Joaquin Valley by some unknown amount. Consequently the rate of deformation can only be calculated for the western limb of the Corcoran Clay.

The present surface relief of the valley floor from the synclinal axis to core hole 15/12-23Q (core containing the last well-defined westward occurrance of the Corcoran Clay number 208, Plate 24 and Appendix 1) is 500 feet. The present relief on the base of the Corcoran Clay over the same interval is 1100 feet suggesting a differential rate of subsidence between the trough and limb of approximately 600 feet/0.725 m.y. or 25.1 cm per millenium. Allowing for the rate of subsidence in the trough produces a minimum rate of 26.5-25.1 = 1.4 cm or about 0.1 meters per millenium for subsidence of the western limb at core hole 15/12-23Q.

Calculation of a rate of subsidence in the eastern San Joaquin Valley is not possible. Eastward migration of the topographic axis make it impossible to reconstruct the approximate surface relief of the valley during deposition of the Corcoran Clay (Figure 42). Indirect geomorphic evidence, however, suggests that part of the eastern San Joaquin Valley has subsided and part has been elevated. The Corcoran Clay in core hole 12/17-8G (core containing the last well defined eastward occurrence of the Corcoran Clay number 166, Plate 24, Appendix 1) is about 20 feet below sea level suggesting that the eastern limb of the syncline to this longitude has probably subsided in late Quaternary time. Core 12/17-8G is approximately 8 km west of Madera. The stratigraphic projection of the Corcoran Clay horizon in the subsurface east of Madera is above sea level and it is not possible to document whether net subsidence or net elevation of the valley resulted in this area. The glacial-outwash fans from the San Joaquin River east of Madera form a sequence of nested surfaces (Marchand and Allwardt, 1981) however, suggesting that net elevation and westward tilting of the valley may have occurrred in the Valley east of Madera.

<u>Calculated Rates from Plate 25B</u>

Similar calculations for profile 25B indicate a minimum rate of subsidence of 310 feet/0.725 my or 13 cm per millenium in the synclinal trough and a potential maximum rate of 410 feet/0.615 million years or 20.3 cm per millenium. The western limb of the valley in the vicinity of core hole 12/10-1K (number 204, Plate 24 Appendix 1) has undergone differential deformation of 250 feet/0.725 million years or 10.4 cm per millenium which, allowing for subsidence of the synclinal trough, suggests a rate of subsidence of 13-10.4 cm = 2.6 cm per millenium.

These rates of deformation from Plates 25A and B suggest that the valley may be actively undergoing subsidence as far west as the foothill margin and to some point east of the San Joaquin River and Fresno Slough. Although the western limb of the syncline is relatively sharply flexed upward, reflecting uplift of the Diablo Range, it has actually subsided as far west as the valley margin (Hall, 1965) and in some cases, net subsidence persists in some of the local foothill basins (for example, San Luis Valley).

The inception of synclinal deformation clearly predates origin of the Corcoran Clay because the clay is deformed less than the underlying early Quaternary Buena Vista Bed (Plate 25A). Although wells are not sufficiently deep in the structural trough to penetrate the Buena Vista Bed, thus precluding accurate assessment of the rate of deformation, the Buena Vista Bed is 200 feet below the Corcoran Clay in core hole 13/16-2D (number 165, Plate 24, Appendix 1) and more than 235 feet below in core hole 13/15-35 (Plate 25A number 163, Plate 24 Appendix 1) suggesting that it has been deformed more than the overlying Corcoran Clay. The onset of deformation and existence of a topographic valley can be identified as early as the Miocene when uplift of the Coast Ranges tilted the Great Valley Sequence along the western margin of the Valley. Subsequent erosion of the range shed alluvium of the Oro Loma and Carbona Formations eastward into the valley as prograding alluvial fans, prior to eruption of the late Miocene Quien Sabe Volcanics. The persistence of broad, gentle folding in the San Joaquin Valley during most of the late Tertiary suggests that the syncline may be due to a necking of the crust under extension rather than buckling under compression.

Foothills

In the foothills, Quaternary pediments and alluvium are deformed into several broad arches and basins. These arches and basins are shown on Figures 3 and 9 and include arches over the Panoche, Wisenor, Los Banos and Laguna Seca Hills and an unnamed arch north of Quinto Creek. Structural basins include the Little Panoche, San Luis, Carrisalito Flat, Salt and, south of the study area, Panoche Valleys. Figure 43 is a contour map of the restored pediment surfaces that are veneered by gravelly coarse sand of Los Banos alluvium. the Laguna Seca Ranch, Ortigalita Peak, Ortigalita Peak Northwest and Charleston School 7.5-minute Quadrangles (Plates 14, 15, 19 and 20) are covered in the map. which shows the shape of many of these warps. Figure 44 is a map of drainages in the same area and illustrates the effect of Quaternary folding on the evolution of drainage in the foothills of the Diablo Range.

If the structures have any significant direction of elongation, it is approximately N40^{o} to 90^{o}E, although the Panoche Hills arch seems to be a simple quaquaversal dome. The structures range from 5 to 20 km across, have a structural relief ranging from 10 to 150 m, and their flanks dip gently to moderately from less than 5^{o} to 20^{o} (Figures 28 and 45). The underlying Cretaceous and Tertiary bedrock, which strikes N 35 to 50^{o} W and dips 30^{o} northeast to vertically, rarely reflects the Quaternary warping. The structural attitude of these rocks typically persists with little change across the Quaternary structures. The lone exception is the Los Banos arch which has produced a 25 to 35^{o} change in strike of the underlying Great Valley Sequence bedding (Briggs, 1953), and which indicates that deformation in this area probably began prior to Quaternary time. The general lack of bedrock deformation, suggests that the structures have been produced by bedding plane slippage in the bedrock in response to continued flextural uplift and tilting of the foothill belt. Warping due to extension along en echelon faults (i.e., "pull-a-part" basins) would produce basins but would not produce the broad uplifted arches that are so prevalent in the foothills south of San Luis Dam.

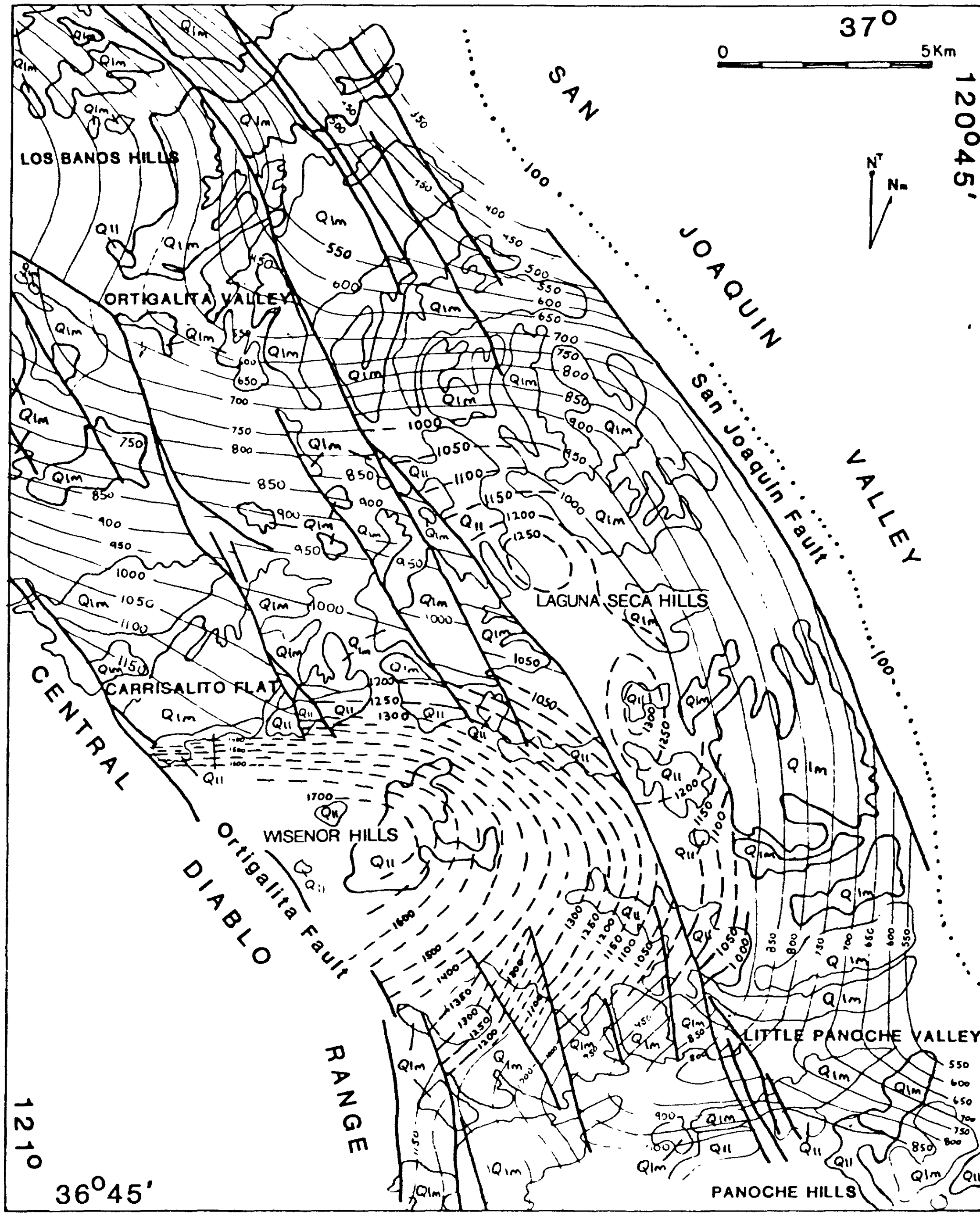

Figure 43: Structure contour map of reconstructed pediment surfaces in the foothills of the Diablo Range. Solid lines are contours drawn on the middle member of Los Banos alluvium, dashed lines are contours drawn on the lower member of Los Banos alluvium. Dotted lined are contours drawn on the surface of the Corcoran Clay. Contour interval is 50 feet. Faults are indicated by heavy solid lines. Generalized outcrop of pediments are shown. The pediments are typically veneered by gravelly coarse sand of Los Banos Alluvium. Area of map includes Plates 14, 15, 19, and 20. Unlabeled faults are members of the O'Neill Fault system.

Briggs (1953) recognized the Wisenor Hills and Los Banos Hills anticlines and suggested that the latter may reflect a local intrusion related to the Quien Sabe volcanic period not exposed by subsequent erosion. However, the Quien Sabe volcanics were erupted from 7.5 my to more than 10 my ago (Snyder and Dickenson, 1979) and continued deformation of the Quaternary Los Banos alluvium requires an alternative origin.

Longitudinal terrace profiles converge downstream (Figure 37) suggesting that tilting of the foothills has continued into the Quaternary. A plot of the terrace gradients at any one place against the best determination of the age of the terrace, based on radiometric, paleontologic and pedologic criteria, is approximately linear (Figure 41), which suggests that either the tilting and warping has been continuous over the past 500,000 years, or that streams with progressively gentler gradients carved the terraces.

The average minimum rate of deformation for several of the foothill folds is given in Table 14. The rates of deformation were calculated by two methods: (1) half the fold amplitude, determined from the crest of an arch to the trough of an adjacent basin, divided by the maximum probable age of the pediment or deposit; and (2) deviation in the elevation of an arch or basin from the projection of the former San Joaquin Valley floor over the foothills divided by the age of the surface or deposit. Method 2 assumes that the foothill pediments and the surface of the Tulare Formation were at one time graded to the San Joaquin Valley floor. The former valley floor was projected over the foothills using the present surface gradient of the valley and by removing subsequent displacement on Quaternary faults in the area. Method 1 will yield a minimum average rate of deformation while Method 2 will yield a rate probably between the minimum and maximum.

Figure 44 illustrates the drainage patterns in a portion of the foothills and provides information on the ages of the Wisenor and Laguna Seca Hills structures. In general, three principal drainage patterns are exhibited: (1) a well-developed dendritic pattern southwest of the Wisenor Hills on terrain underlain entirely by the Franciscan assemblage; (2) a moderately well-developed dendritic pattern with minor trellis tributaries in the Wisenor Hills and (3) a well-developed trellis pattern in the Laguna Seca Hills.

The dendritic drainage in area 1 probably reflects the gross lithologic and erosional homogeneity of the Franciscan assemblage, and the existence of trellis drainage in areas 2 and 3 probably reflects the lithologic heterogeneity and erosional contrasts in the underlying Great Valley Sequence.

The prevalence of trellis-drainage in the Laguna Seca Hills and a dendritic drainage in the Wisenor Hills on the same bedrock suggests that the combination of valleyward slope and thickness of overburden was great enough in the Wisenor Hills that dendritic drainage became established, but was not great enough in the Laguna Seca Hills to establish a dendritic drainage that would persist through the erosion of the well bedded, northeast-striking Great Valley Sequence. In the Wisenor Hills, deep channel incision into the overburden of consequent streams probably created divides between the stream that were too high to be breached, and thus prevented capture to form a trellised drainage when these streams encountered bedrock. In the Laguna Seca Hills, the streams flowed on an initially gentle slope, and incision by the main

Rate of Deformation

	Method 1		Method 2	
	1/2 fold amplitude	rate (Cm/1000 yrs)	Elevation above projected valley floor	rate
Wisenor Hills	80 m on lower member Los Banos alluvium	20 to 25	--	--
Laguna Seca Hills	55 m on lower member 45 m on middle member Los Banos alluvium	15 to 20	170 m on lower member 82 m on middle member Los Banos alluvium	35 to 50
Panoche Hills	225 m on base of Tulare Formation	25 to 30	360 to 365 m on surface of Tulare Formation	45 to 50

Table 14: Quaternary rates of uplift for three folds in the foothills of the Diablo Range. Methods 1 and 2 are described in the text. Data are drawn principally from Figure 43 and from field relations in the Panoche Hills. Ages used are 220,000 yrs B.P. and 350,000 yrs B. P. for the middle and lower members of Los Banos alluvium and 740,000 yrs B. P. for the Tulare Formation.

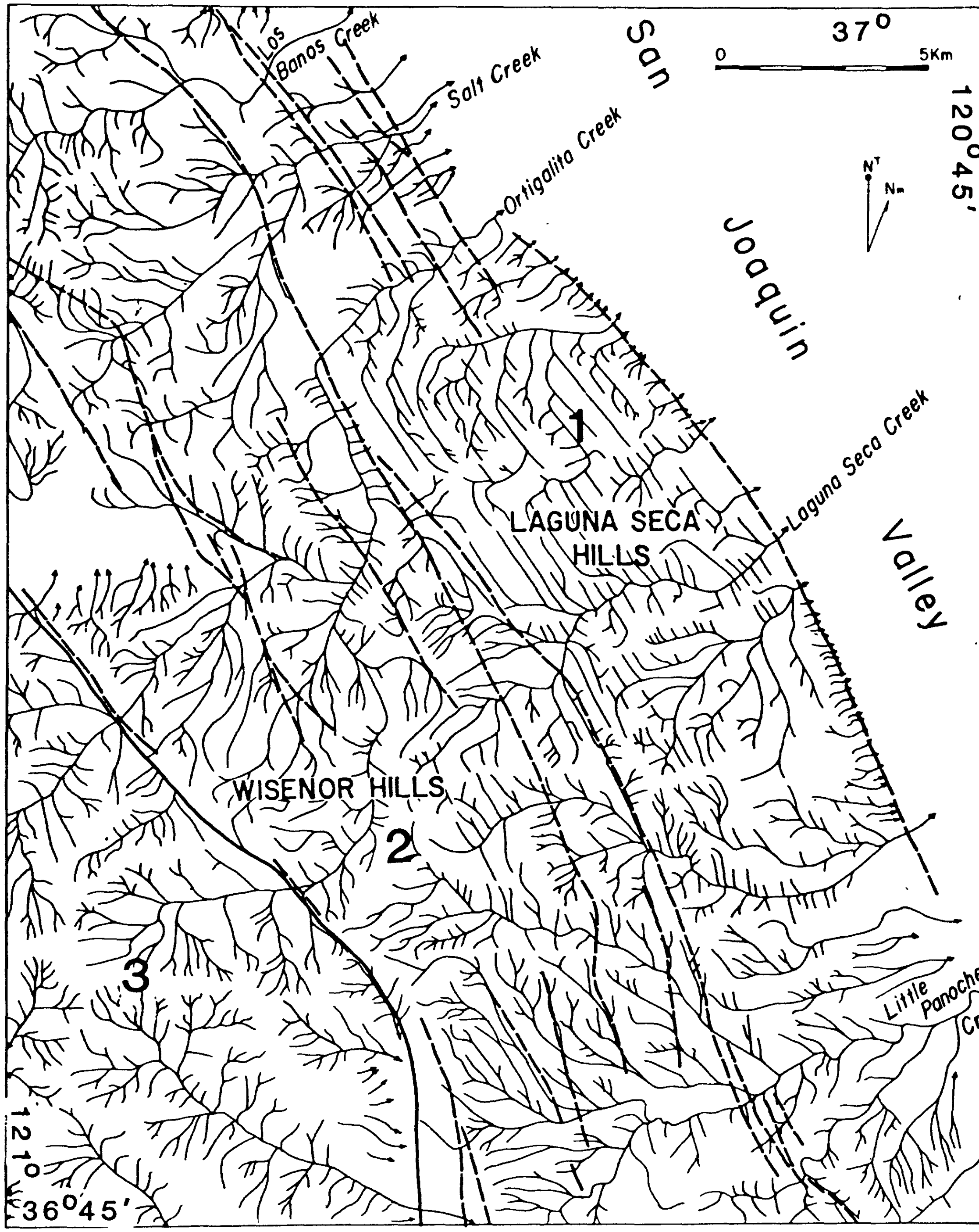

Figure 44: Drainage patterns in area of Figure 43. Three general patterns are recognized and described in the text: (1) Trellis drainage, (2) Dendritic drainage with trelis distributary, (3) Dendritic drainage.

northeast-trending consequent streams encountered bedrock at a shallow depth prior to creating high divides. Slow incision on the gentle slope would permit the streams to capture enough subsequent streams to develop a strong trellis drainage.

Many of the foothill structures are also manifest by bedding attitudes in the Tulare Formation. The Tulare Formation rises from all sides of the dome-shaped Panoche Hills and is locally preserved capping the Hills on Marl Ridge (Figure 10, locality 4). The Tulare deposits dip as much as 6° from the Panoche Hills into Little Panoche Valley (Figure 45 and Figure 10, localities 6, 7, and 8, Laguna Seca Ranch 7.5-minute Quadrangle, Plate 20; 16 to 18° from the Wisenor Hills' into Carrisalito Flat (Figure 10, locality 19, Ortigalita Peak 7.5-minute Quadrangle, Plate 19, and 16 to 20° southeast on the northern limb of the San Luis Valley basin (Figure 28 and Figure 10, locality 33, Howard Ranch 7.5-minute Quadrangle, Plate 4).

The deformed Tulare deposits on the northern limb of the San Luis Valley basin suggests that a corresponding Quaternary arch may exist immediately north of Quinto Creek. The north limb of this arch has not been identified. The valleyward projection of its presumed axis to the northeast coincides with the isolated hills of Los Banos alluvium, surrounded by San Luis Ranch and Patterson alluvium. This is the only area where Los Banos alluvium occurs as erosional remnants in the San Joaquin Valley isolated from the foothills and thus these remnant hills may be the topographic expression of this fold in the valley (Figure 10, locality 34, Ingomar 7.5 minute Quadrangle, Plate 5). Farther northeast along the projection of the inferred arch is a northward constriction of the San Joaquin Valley floodbasin near the town of Newman, from more than 25 km less than 5 km (Figure 5). The northeast projection of the San Luis Valley basin into the San Joaquin Valley coincides with the greatest expansion of the basin floor. Local downwarping of the Corcoran Clay (Figure 29) also coincides with the projection of the San Luis Valley basin (shown in greater detail on a contour map by Hotchkiss, 1972).

Faulting

Three northwest trending fault systems, active during the Quaternary, are present in the Los Banos area. These faults include the Ortigalita Fault System, forming the principle contact between the Franciscan Complex and Great Valley Sequence in the southwestern portion of the study area; the San Joaquin Fault system (Herd, 1979b) between the foothills and the Valley floor through most of the study area; and the O'Neill Fault System, originally named by Herd (1979a) for the small fault near O'Neill Forebay, but which is extended here to include all geologically similar bedding plane faults between the San Joaquin and Ortigalita Fault Systems (Figures 9, 14, and 43).

Many of the faults are manifest by linear escarpments between offset segments of pediments that are veneered by Los Banos alluvium. These linear escarpments extend across drainage divides and therefore cannot have a fluvial origin. Some of the faults have blocked and reversed drainages and are responsible for some of the valleys within the foothills. A few of the faults are also marked by sag ponds and lines of springs.

Figure 45: Deformed Tulare Formation in Little Panoche Valley. Beds dip 3 to 6° NE into a syncline under Little Panoche Valley. To the right, the beds rise over and are preserved on the crest of the Panoche Hills anticline. The tilted upper surface is in part the lower member of Los Banos alluvium and, in part, the preserved, strongly dissected depositional surface of the Tulare Formation. Refer to Figure 20C for detailed geologic section across Little Panoche Valley from this perspective.

Ortigalita Fault

The Ortigalita Fault was first shown by Anderson and Pack (1915) forming the approximate contact between the Franciscan assemblage and Great Valley Sequence rocks. It was mapped in greater detail by Briggs (1953) in the Ortigalita Peak area (Plates 14 and 19) who described it as a major southwest dipping thrust fault whose activity began in the late Jurassic and culminated during the late Pliocene. Briggs (1953) and Taliaferro (1943) describe abrupt changes in the dip of the fault surface both along strike and down dips. The dip ranges from 20° to 30° southwestward to nearly vertical.

Several authors, including Taliaferro (1943), Leith (1949), Briggs (1953) and Page (1981), have suggested that displacement along the Ortigalita and related faults may have elevated the central Diablo Range to its present height during the Pliocene and possibly the Pleistocene. However, the topographic position of the basalt-hill outlier south of San Luis Dam suggests that the central range has not been significantly elevated since Miocene time. The basalt overlies flat-lying stream gravels which suggests that it may have flowed from a source in the central Diablo Range, where athe Quien Sabe Volcanics rest on a broadly warped erosional surface, down a former stream channel probably graded to a former valley floor. The presence of the Quien Sabe volcanics at nearly the same altitude on both sides of the fault near San Luis Reservoir precludes any significant vertical displacement on the Ortigalita Fault in the last 9 my. Vertically undisplaced embayments of the Tulare Formation and Los Banos alluvium into the main Diablo Range also indicate that little, if any, uplift of the central Diablo Range relative to the foothill belt occurred in the Quaternary.

Quaternary strike-slip activity and minor elevation of the foothills relative to the central Diablo Range is indicated however, by the prominent morphologic expression of the fault trace. Springs, sag ponds and conspicuous, weakly dissected escarpments delineate the fault trace. These features are common in Tulare, Los Banos and San Luis Ranch alluvium suggesting late Pleistocene activity. San Luis ranch alluvium is clearly offset along Piedra Azul and Molina Creeks (Figure 10, locality 47, Ortigalita Peak 7.5-minute Quadrangle, Plate 19) and San Luis Ranch and probably Patterson alluvium are offset in the headwater region of Little Panoche Creek (Figure 10, locality 44), Ortigalita Peak 7.5-minute Quadrangle, Plate 19, an area first brought to my attention by Larry Anderson of the U. S. Bureau of Reclamation.

The sense of late Cenozoic displacements is not well understood but is clearly different from the Miocene and earlier vertical displacement which may have elevated the central Diablo Range. Escarpments along the fault trace typically face west-southwest suggesting that the foothill belt has risen relative to the central Diablo Range. The escarpments are prominent in Los Banos Valley (Figure 10, localities 26 and 27 Los Banos Valley 7.5-minute Quadrangle, Plate 13) where Los Banos alluvium on the west is commonly juxtaposed against the Great Valley Sequence on the east, indicating minor uplift of the foothill belt. In the northern portion of Los Banos Valley (Figure 10, locality 27 Los Banos Valley 7.5-minute Quadrangle, Plate 13), relative uplift of the foothill belt is also indicated by the stripped veneers of Los Banos alluvium and exposure of bedrock on the upthrown eastern block. The map distribution of soils on the upthrown surface show discontinuous patches of preserved Los Banos alluvium and intervening exposures of underlying bedrock (Cole and others, 1952).

Fault plane solutions of recent earthquakes (Willie Lee, personal communication, 1981) and the linear en echelon character of the fault trace suggest a prominent component of lateral displacement. The magnitude of lateral displacement, however, is not known. Los Banos Creek makes an abrupt right-lateral change in course in Los Banos Valley of approximately 4.5 km since incision of the creek into the pediments of Los Banos alluvium. However, the absence of other conspicuous, consistent morphological offsets of ridges or creeks along the fault trace suggests that the change in stream course probably occurred in response to erosional contrasts in the underlying bedrock or along a fault zone rather than in response to right-lateral displacement along the Ortigalita fault. Outliers of the Quien Sabe volcanic field east of the fault are located at a latitude north of the main volcanic field in the central Diablo Range indicating that significant late Cenozoic right-lateral displacement of tens of kilometers is not realistic.

San Joaquin Fault System

The San Joaquin Fault System (Herd, 1979b) is situated along the foothill-valley margin and in many areas produces a large, linear, east-facing, faceted escarpment as much as 140 meters high. The escarpment is particularly prominent along the front of the Laguna Seca Hills north of Little Panoche Creek (Figure 10, vicinity northwest and southeast of localities 17 and 22, Laguna Seca Ranch and Charleston School 7.5-minute Quadrangle, Plates 15 and 20). The fault trace trends N35 to 45^{o}W and is a single strand south of San Luis Reservoir, along the foothill margin. To the north, however, the fault is a series of en echelon strands that trend obliquely to the valley margin, which here is approximately N10^{o} - 20^{o}W.

The en echelon pattern and linearity of the fault trace and probable suggests a probable strike-slip component and vertical fault plane as illustrated on Figure 14. Orientation of the fault plane, however, has not been observed during this study, although Herd (1979b) has reported an east dipping fault plane north of the study area near Ingram Creek.

The magnitude of lateral displacement is not known. The ability to tentatively project fold structures from the foothills into the valley near San Luis Creek precludes more than 5 to 10 km of lateral motion. Furthermore, because the fault breaks into en echelon segments to the north, separated by unfaulted ground, it probably doesn't have lateral displacement of more than 0.5 to 1 Km.

Vertical displacement of the pediments associated with Los Banos alluvium across the fault ranges from 0 to 140 m. Figure 43 illustrates the truncation of the reconstructed pediment surfaces by the San Joaquin Fault at the margin of the Laguna Seca Hills. The middle member of Los Banos alluvium veneers a pediment, at one time graded to the valley floor, which now projects approximately 140 m (450 ft) above the present valley floor. The displacement provides an average rate of offset of approximately 47 to 65 cm/1000 years using the minimum and maximum probable age of the pediment. Core holes drilled by the U. S. Bureau of Reclamation (numbers 200, 201, 202, 203 and 204, Plate 24, Appendix 1) encounter the Corcoran Clay Member of the Tulare

Formation about 60 m (185 to 201 ft.) below the ground surface along the valley margin. Deposits of Los Banos alluvium overlie the Corcoran Clay indicating a maximum total displacement of 200 m in the last 250,000 years.

Post-Miocene uplift of the foothill belt by the San Joaquin fault and/or folding is also suggested by the position of the basalt Hill outlier of the Quien Sabe Volcanics described earlier (pages 39-41). The basalt overlies flat-lying stream gravels and probably flowed down a former stream channel graded to a former valley floor. The base of the basalt now lies over 300 m above the projection of the present San Joaquin Valley floor suggesting that the foothill belt has risen at least 300 m relative to the valley since eruption of the basalt 9.35 my ago.

The fault system is typically overlain by unfaulted alluvium of San Luis Ranch and Holocene age, however, near the mouths of major drainages such as Little Panoche Creek, Los Banos Creek and San Luis Creek suggesting that little, if any, activity has occurred in the last 40,000 to 60,000 years. The lack of seismicity along the fault zone supports this interpretation (W. Lee, personal communication, 1981).

O'Neill Fault System

The O'Neill Fault system (Herd, 1979a) includes the zone of numerous small northwest-trending faults between to the Ortigalita and San Joaquin Faults. The faults of this system trend approximately N35 to 50^{o}W parallel to the strike of bedding in the Great Valley Sequence. They are evident principally between Little Panoche Creek and San Luis Dam. The faults differ from the larger, aforementioned faults appearing to be predominantly bedding-plane slips in response to continued uplift and eastward tilting of the foothill belt during the Quaternary.

Fault displacement is manifest principally by offset of the broad foothill pediments veneered by Los Banos alluvium. Contour reconstruction of these surfaces suggests that vertical displacement ranges from 100 m (Figure 10, localities 23 and 45) to less than 5 m (For example: Secs. 19 and 20, T11S, R10E and Sec. 23, T13S, R10E).

Right lateral displacement is not evident. The broad Quaternary folds indicated on Figure 43 are not right-laterally displaced nor is there morphologic evidence of offset ridges or stream valleys which might suggest lateral displacement.

The magnitude of vertical displacement not only changes between individual strands but also changes laterally along each strand. Maximum vertical offset typically coincides with maximum anticlinal flexure, with decreasing displacmenet down the flanks, diminishing to less than 3 m within synclinal structures (Sec. 30, T14S, R11E; Laguna Seca Ranch 7.5-minute Quandrangle, Plate 21). For example: the maximum displacement of approximately 100 m discussed above coincides with the Los Banos Hills anticline and large displacements are evident separating the Laguna Seca Hills and Wisenor Hills anticlines.

The available field data suggests principally reverse displacement along the O'Neill faults. Where the faults can be traced into the homoclinally tilted Tertiary and Cretaceous bedrock (Secs. 1, T10S, R8E; San Luis Dam 7.5 minute Quadrangle, Plate 8), they appear only as sheared shale units between more resistant sandstone beds. Bedding is not displaced. Fault escarpments have a consistent west-facing aspect suggesting reverse displacement along the northeast dipping bedding planes (Figure 14).

The apparent reverse displacement on the faults and lack of bedding offset in underlying bedrock suggests a bedding plane slip origin in response to Quaternary folding of the foothill region and/or fault activity along the larger Ortigalita or San Joaquin Faults. These faults, however, do not displace San Luis Ranch or Patterson alluvium indicating that principal acitivity probably occurred before 40,000 to 60,000 years ago. A similar system of small subparallel flextural-slip faults have been observed in the Ventura basin area (Keller and others, 1981). In this latter area, fault activity is interpreted to be the result of compression associated with folding of the bedrock or sympathetically triggered by earthquakes along major faults.

Fault activity is also an attractive explanation for many geomorphic and stratigraphic features in the foothills of the Diablo Range. Many of the restricted foothill valleys formed, in part, due to vertical displacement across the O'Neill faults. Vertical displacement has blocked and partially impeded eastward drainage of several streams producing narrow, steep-walled canyons through the upthrown block and broad, alluviated valleys on the downthrown block. Carrisalito flat, Los Banos Valley, Wisenor Valley, Salt Valley, Panoche Valley and perhaps San Luis Valley are all partially the result of this fault activity.

In most cases the foothill streams ultimately breached the fault scarp and reestablished their former course. In several instances however, the streams were unable to breach the fault scarp. These streams were captured and/or established new courses through topographically lower outlets to the north and south. For example, Carrisalito Flat and Salt Valley (Ortigalita Peak NW 7.5-minute Quadrangle, Plate 14) at one time drained eastward down Ortigalita and Salt Creeks respectively. Today, these valleys drain northwest into Carrisalito Creek and eventually into Los Banos Creek. Poorly drained basin soils and fine-grained deposits occur in both valleys reflecting the earlier impeded drainage.

The U. S. Bureau of Reclamation recently completed a trenching and seismic study of the San Joaquin, O'Neill, and the Ortigalita fault systems. A detailed report of their findings is under preparation and will provide considerable information on the acvitity and sense of displacement along these faults.

Quaternary activity of the Ortigalita, San Joaquin and O'Neill faults is probably related to the regional strike-slip tectonics of the San Andreas Fault. Harding (1976) and Page (1981) have recently suggested that the effects of strike-slip motion, most of which is concentrated along the San Andreas, may be distributed over a broad zone that encompasses the entire Diablo Range and part of the western San Joaquin Valley. The eastern border of the zone may relate to the poorly known, enigmatic contact between the Franciscan Complex and Sierran granitic lock.

The relative lateral motion between the North American and Pacific Plates is believed to be 5.6 ± 0.3 cm/yr (Minister and Jordan, 1978) of which approximately 3.2 to 3.7 cm/yr is accommodated by the San Andreas and adjacent faults (Hall and Seih, 1977). The balance of the motion, 1.9 to 2.4 cm/yr, is spread out in a broad zone and may involve faults such as the Ortigalita and San Joaquin systems.

DEPOSITIONAL MODEL

Introduction

The landscape of the western San Joaquin Valley and bordering foothills of the Diablo Range was shaped principally by tectonism and climate, which together control much of the weathering, erosion, and transport of sediment in this area. The five major aggradational alluvial units that post-date the Tulare Formation probably represent at least five distinct periods of weathering and erosion in the Diablo Range and fluvial deposition in the western San Joaquin Valley. A hypothesis of climatic control on the deposition of alluvium in the west-central San Joaquin Valley was briefly outlined in the beginning of this paper. Bull (1964a), on the other hand, has argued for a tectonic control for the deposition of alluvial fans in the western San Joaquin Valley immediately south of Little Panoche Creek. This section compares various models for deposition of the alluvium in the west central San Joaquin Valley, argues that climate is the principal independent variable and greatly expands on the climatic model presented earlier.

Hypothetical Models

Hypothetically, the alluvial units in the west-central San Joaquin Valley may have resulted from (1) rise in base level along the San Joaquin River, particularly in response to rise in sea level; (2) episodic uplift of the foothills and/or central part of the Diablo Range relative to the San Joaquin Valley; (3) climatic fluctuations from more humid to more arid conditions; or (4) some combination of the above. I believe that the available field data support model (4) with climatic fluctuations playing a principal role, and tectonic uplift of the Diablo Range a vital secondary role.

Eustatic fluctuations in sea level. Eustatic fluctuations in sea level hypothetically can cause alternating periods of aggradation and incision along the major Diablo Range streams by either directly inundating the San Joaquin Valley with marine water, or, more likely, by causing entrenchment or aggradation of the San Joaquin River, thereby indirectly changing local base level for the Diablo Range streams. Such fluctuations, however, probably did not generate the observed alluvial deposits. One reason is that Pleistocene marine clays indicative of a marine transgression are not present beneath the central San Joaquin Valley (Plates 25 A and B). Another is that stream flow from all of the Diablo Range drainages in the study area is absorbed into their alluvial fans and rarely reaches the San Joaquin River. Therefore, each alluvial fan commonly serves as the local base level for its parent stream and is not influenced by possible sea level induced changes on the channel gradient of the axial river.

It is conceivable that the Corcoran pluvial period produced higher local base level during the mid-Pleistocene and therefore induced alluvial fan or deltaic aggradation of part of the Tulare Formation. Post-Tulare deposits, however, cannot be attributed to such base-level changes because as argued by Frink and Kues (1954), the lake depositing the Corcoran Clay appears to be unique in the Quaternary history of the San Joaquin Valley.

Tectonism versus Climate as a cause for alluviation

The landscape of the Diablo Range and San Joaquin Valley is in dynamic equilibrium with the independent variables of climate and tectonism, and thus, because the effects of base level change are negligible, the periods of deposition recorded by the alluvial units probably reflect changes in one or the other, or both. In the San Joaquin Valley and adjacent Diablo Range the contribution of climate to landscape development is largely direct because water is the principal agent performing the work of weathering, erosion and transportation, but also indirect because temperature and precipitation govern the general distribution and character of slope-stabilizing vegetation. The contribution of tectonism to landscape development is largely indirect because tectonic elevation of the range and subsidence in the valley increases the potential energy gradients along which the work of erosion and transportation is done.

Direct field evidence and absolute age control which might favor a climatic or tectonic origin for the alluvium is not available in the western San Joaquin Valley. Further, as described earlier, cut-and-fill by the lower San Joaquin River prevents rock-stratigraphic correlation of the western San Joaquin Valley alluvial units with the climatically controlled alluvial units of the eastern San Joaquin Valley.

Justification for a climatic or a tectonic origin for the alluvium, therefore, most rely on less direct evidence. Table 15 summarizes this evidence.

The evidence suggests that the alluvial deposits in the western San Joaquin Valley accumulate primarily in response to fluctuations in climate. Tectonic uplift of the foothills and pre-Pliocene uplift of the central Diablo Range contributed to deposition of the alluvium by providing a sufficient energy gradient for streams to tranport detritus from the Diablo Range to the San Joaquin Valley.

The periods of alluviation, however, cannot be attributed to tectonism alone. The major Diablo Range drainages drain the central Diablo Range underlain by rocks of Franciscan assemblage, and detritus shed from the Franciscan typically comprises a large portion of the alluvium in the San Joaquin Valley. Whatever model is invoked, therefore, most involve the tectonic or climatic history of the central Diablo Range. However, as described in the "Structural Section" of this report and shown in Table 15, the central Diablo Range has not been significantly elevated relative to the foothills along the Ortigalita Fault since the late Miocene.

Episodic Quaternary uplift of the foothills also cannot cause the periods of alluviation. A plot of terrace gradients versus their approximate age based on paleontologic, radiometric and pedologic data (Figure 41) is linear suggesting that the foothills have been tilted relatively continuously or that episodes of tilting were less than about 10,000 years apart. Vertical uplift of the foothills along the San Joaquin Fault of as much as 140 meters has also occurred. The fault does not displace San Luis Ranch alluvium, however, and

Table 15: Summary of predicted and observed field observations concerning a climatic versus tectonic origin for the periods of alluviation in the west-central San Joaquin Valley.

Phenomena	Predictions Climatic Model	Tectonic Model	Observation	Model favored by observation
Climatic Fluctuations	Sufficient fluctuation in precipitation and temperature is required to significantly alter vegetation cover, stability of hill slopes, and ability of streams to transport detritus	Not required	Repeated fluctuations in the Quaternary from more humid to more arid conditions	Climatic or Tectonic
Uplift	Sufficient uplift is required to provide energy gradient for water to transport detritus.	Episodic uplift of the Diablo Range in the Quaternary is required. Uplift of sufficient magnitude to significantly alter stability of hillslopes and increase channel gradients enabling streams to transport greater sediment load.	Little or no uplift of the central Diablo Range along the Ortigalita fault to the foothills since the Miocene. Continuous (10^4 yrs) uplift and eastward tilting of the foothills in the Quaternary.	Climatic
Faulting	Not required	Episodic faulting with vertical displacement most likely cause for episodic alluviation.	Quaternary vertical displacement along the San Joaquin and O'Neill Faults is probable, but the faults do not displace San Luis Ranch or Patterson alluvium. Principally lateral displacement along the Ortigalita Fault in the Quaternary.	Climatic
Character of stream channel at foothill-valley margin	Incised into pre-existing alluvium or, less likely, into bedrock if uplift of foothills is sufficiently rapid.	Incised into bedrock in response to uplift of foothills (in absence of climatic change).	Major Diablo Range drainage are typically incised into pre-existing alluvium, rarely into bedrock.	Climatic
Regional alluvial units	Required	May exist in response to May not exist if deformation is local and sporadic	Alluvial units are correlated Valley.[1] Similar terrace sequences are present along consequent streams eroding synclines, such as Little Panoche Valley and San Luis Valley and along antecedent streams eroding anticlinal arches, such as Ortigalita Creek in Laguna Seca Hills and Los Banos Creek in Los Banos Hills. Similar terrace sequences are present in widespread areas of California in different tectonic environments (Figure 27)	Climatic or Tectonic
Character of longitudinal stream-terrace and alluvial-fan profiles	Profiles generally converge downstream (Davis, 1938; Cotton 1940; Blissenbech, 1954; Marchand, 1977; Marchand and Allwardt, 1981). Segmented profiles (Bull, 1964a) may result from climatic fluctuations superimposed on continously uplifted range front.	Profiles generally diverge, but may also be convergent downstream depending on the rate of stream incision (Davis 1938; Cotton, 1940; Bliasenbach, (1954). Segmented profiles are possible if stream-channel gradient is significantly increased in responsed to uplift (Bull, 1964a).	Profiles typically converge downstream to some hinge line near margin of valley where younger deposits overlie older deposits. Distinct segmentation as reported by Bull (1964a) for alluvial fans immediately south of study area, not observed in this study.	Climatic or Tectonic
Relation to glacial-outwash stratigraphy in eastern San Joaquin Valley	Alluvial deposits coeval to or slightly post-date glacial-outwash deposits from Sierra Nevada	No correlation required	Wind-reworked glacial-outwash deposits commonly incorporated in toes of western San Joaquin Valley alluvial deposits suggesting approximate contemporaneity.	Climatic

[1]The correlation of a regional alluvial stratigraphy in the west-central San Joaquin Valley has been somewhat influenced by my working hypothesis that one should exist. However, I believe that the criteria of relative soil development, topographic position, relative degree of surface modification, and superposition of buried soils, if used with discretion, supports the correlations I heve made.

the amount of displacement decreases along strike and no vertical displacement across the fault is evident between Orestimba and Los Banos Creeks. Episodic uplift along the fault, therefore, can not have caused the regional periods of alluviation in the valley.

Climatic Model

Landforms evolve essentially by the erosion of material from one part of the landscape and its deposition on another part. Three important elements of the sculpturing process are: (1) the chemical and mechanical weathering and breaking up of rocks, if not already in a state suitable for erosion, to form a regolith; (2) movement of the regolith by mass wasting and other hillslope processes from the site of weathering to sites where it can be moved by flowing water; and (3) transport of the detritus by flowing water or mudflows to locations of deposition. Each of these processes will be accelerated or be inhibited by fluctuations in moisture.

I believe that the major elements of the late Cenozoic stratigraphy in the west-central San Joaquin Valley (i.e., the alluvial units and soils) probably owe their origin to long term Quaternary fluctuations in climate--in particular shifts from more humid to more arid conditions. The Diablo Range has not been glaciated, however, and the relation of these fluctuations in humidity to the glaciations and interglacials of the Quaternary is difficult to determine. I assume that mean temperature generally increased and precipitation decreased in the San Joaquin Valley during a transition from glacial to interglacial conditions and that vegetation zones responded by moving to higher altitudes, an assumption supported by the pollen record at Clear Lake, California (approximately 250 Km north of the study area in the Coast Range) which indicates that a high frequencey of oak relative to pine and fir pollen corresponds to warm, interglacial conditions (Adam and others, 1981). The magnitude and range of temperature and precipation during these transitions and their precise effect on the geographic distribution and character of vegetation, however, is poorly known.

The following discussion will frequently refer periods of "landscape stability" and periods of "landscape instability." During periods of landscape instability, the foothills and central Diablo Range underwent erosion, producing sediment that caused aggradation in the San Joaquin Valley and isolated foothill valleys. During periods of stability, reduced erosion in the Diablo Range reduced stream sediment yields and caused the underloaded streams to incise their beds. Soils developed on the stable surfaces of the alluvial fans and some of the more stable hill slopes.

Hypothetically, intervals of maximum erosion and resulting deposition coincided with transitions from the more humid conditions of a glaciation to the more arid conditions of an interglacial period, when vegetation cover deteriorates and slope material weathered during the preceeding humid period is exposed. During maximum aridity of an interglacial period, fluvial deposition in the valley is hindered because of insufficient runoff, and mudflows are common. During transitions from arid to humid and within humid periods, erosion and resulting deposition are hindered because of increased vegetation cover. The principal elements of this model are presented in Table 16 and are described in greater detail below.

TIME	CLIMATIC STAGE	APPROX. DURATION (Ka)	TEMP.	PRECIP.	LOCATION: Foothills of unglaciated Diablo Range	LOCATION: Alluvial-fans from unglaciated basins	LOCATION: Alluvial-fans from glaciated basins	LOCATION: Glaciated high Sierra Nevada
↑	late inter-glacial	5 to 10	warm	dry		Soil formation; decreasing fluvial and mudflow activity.		Glaciers absent or confined to highest cirques; soil formation.
	inter-glacial	30 to 50	warmest	driest	Insufficient runoff to transport sediment to streams; gullies drain moisture from slope mantle inhibiting creep and landsliding; soil formation.	Underloaded streams incise channels and deposit fine-grained alluvium in depressions between ridges during floods; mudflows accumulate on smaller fans during periodic, high intensity storms; soil formation.	Soil formation.	Glaciers absent.
	early inter-glacial	2 to 10			Loss of dense vegetation cover destabalizes slopes; gulley, sheetwash, and landslide erosion are common. Pediments carved by laterally migrating, overloaded, aggrading streams.	Deposition of coarse alluvium in coalescing constructional ridges and mudflows on upper-fan; sheet floods deposit fine-grained alluvium on middle and lower-fan; eolian sand interfingers with lower-fan deposits.	Underloaded rivers incise channels; eolian activity; soil formation.	Glaciers retreat; soil formation.
	Transition							
	late glacial	2 to 10	warmer	drier	Soil formation and weathering continue; vegetation communities stressed by climatic change to drier and warmer conditions.	Streams incised; minor eolian activity; soil formation.	Deposition of coarse outwash (sand and gravel) on fans during floods; winds locally rework sand into dunes.	Glaciers retreat; moraines partially or entirely washed out.
	glacial	5 to 15	coldest	wettest	Vegetation cover, weathering, and soil formation at maximum; sediment delivered to streams by creep and landslide slope processes is transported to the lower-fan and basin floor by incised streams.	Soil formation; no deposition on fans; Streams remain in incised channels.	Deposition of fine outwash.	Glaciers and weathering at maximum.
	early glacial	20 to 40	colder	wetter	Dense vegetation cover stabilizes slope; underloaded streams incise channel; soil formation.	Incision of underloaded streams; deposition of fine sand and silt on lower-fan during sheet floods; soil formation.	coarse outwash transported in incised channnels; soil formation.	Glaciers expand; increased weathering.

Table 16: Summary of landscape processes in glaciated and unglaciated areas during Quaternary climatic fluctuations. Processes in glaciated areas are summarized from Marchand (1977), Marchand and Allwardt (1981) and D. E. Marchand (unpublished data).

Previous Literature

The hypothesis that climatic change induces episodes of alluviation and terrace cutting is not new (Cotton, 1945). It has long been observed and reported that climatically induced changes in surface runoff and the type and density of vegetation strongly influence the weathering, erosion, transport and deposition of sediment (Gilbert, 1877; Huntington, 1907, 1914, p. 25; Ekis, 1928, p. 237; Cotton, 1945, 1958; Blissenbach, 1954; Schumm, 1965, 1977; Bull and Schick, 1979; Euler and others, 1979; Gile and others, 1981). Huntington (1914, p. 25), for example, eloquently expressed the principle that vegetation has a profound influence on fluvial processes in non-glaciated terrains:

> "It is suggested that an increase of precipitation will so encourage the growth of vegetation on catchment slopes in the headwater reaches of a stream valley as to reduce their output of waste, with such a reduction in the load to be carried, higher precipitation will so increase the ratio of water to waste in the stream coming from the headwaters as to cause degradation down the valley; a lessening of the ratio of water to waste in the stream, due to decreased precipitation aided by weakening of the vegetational cover on slopes in the catchment basin to increase the absolute rate of supply of eroded debris, will cause overloading and result in aggradation of the valley."

G. K. Gilbert, however, in his "Geology of the Henry Mountains" (1877, p. 105) was one of the first American geologists to recognize the effects of fluctuating precipitation on landscape development:

> "Hence in regions of small rainfall, surface degradation is usually limited by the slow rate of disintegration; while in regions of great rainfall it is limited by the rate of transportation. There is probably an intermediate condition with moderate rainfall, in which a rate of disintegration greater than that of an arid climate is balanced by a more rapid transportion than consists with a very moist climate, and in which the rate of degradation attains its maximum

Schumm (1965, 1977, Figure 3-1; reproduced in Figure 46) later quantified the approximate range of intermediate precipitation of which Gilbert spoke. For example, his model indicates that in the western San Joaquin Valley and adjacent Diablo Range, a predicted maximum "sediment yield" (that portion of sediment removed from the drainage basin, Schumm, 1965) will occur with a mean annual precipitation of 15 to 20 inches. The sediment yield decreases sharply on both sides of the maximum--with higher precipatation, increased vegetation cover retards erosion; with lower precipitation, runoff is insufficient to transport detritus from the barren slopes to the streams and out to the valley. My model incorporates these ideas of Huntington, Gilbert and Schumm (among many others) in that during a transition from the more humid conditions of a glaciation to the more arid conditions of an interglacial period, the range in precipitation crosses the interval of maximum sediment yield and a surge of slope erosion in the foothills and deposition in the valley results.

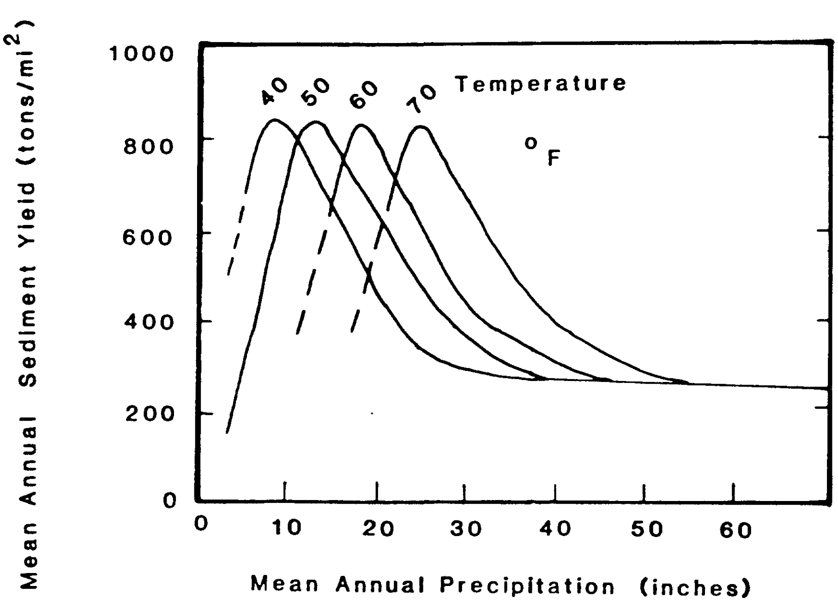

Figure 46: The effect of mean annual temperature and precipitation on sediment yield (from Schumm, 1977).

Alluvial events during glacial epochs

More humid conditions associated with a glacial epoch probably produce stable slopes mantled by a thick regolith. The increase in moisture encourages growth of a thick, dense cover of grasses, herbs, shrus and trees. The abundant moisture combined with the increased organic input promotes chemical and mechanical weathering of the land surface producing the thick regolith of loose, unconsolidated broken rock and earth (Bull, 1979). Thick soils with pronounced argillic and organic-rich horizons develop on the regolith.

Mass wasting and other hill slope processes that would remove the regolith are hindered by the stabilizing influence of vegetation. Erosion by overland flow (sheetwash and rillwash), raindrop impact, gullying and rock falls are reduced; and in forested areas, creep, block glides and slumps are reduced. In unforested areas creep, slumps, glides, soil avalanches and debris flows will be common processes. "Sores" in various stages of healing probably pock-marked the landscape. These processes although sporadic ultimately remove entire layers from the hillslope and the thick soil profiles formed during this time are only preserved on flat or gently inclined surfaces not susceptible to erosion.

Sediment delivered to the stream by these slope processes probably meet with different results in different parts of the drainage basin. In headwater regions, the small ephemeral and intermittent streams are probably choked with sediment and debris as the constant low to high rate of input by creep exceeded the rate of removal by the small streams. In the larger perennial streams, the input of sediment by slope processes is exceeded by the erosive power of discharge, especially that during storms. Creep provides sediment at a generally constant rate and the amount available for stream erosion during any one storm is limited. In many areas, the larger streams are also bordered by broad terraces which can capture and thus shield the stream from sediment delivered by creep. The more sudden, catastrophic processes of earthflows, block glides, slumps and soil disintegration slips can provide sporadic surges of sediment to the stream but also large organic debris and boulders which can locally dam the channel and reduce the ability of streams to carry coarse detritus.

Consequently, the total sediment yield, as well as concentration of sediment in the stream would be low after the initial surge of erosion during prolonged storm runoff reflecting the inability of the slopes to continually provide detritus to the stream. The velocity of stream discharge probably increased with decreasing sediment yield and more stream energy is available to be expended on channel erosion and entrenchment. Paired terraces result from the incision and all the sediment delivered to the stream by slope processes bypasses the upper and middle alluvial-fan and is carried down the entrenched channel to the lower alluvial fan and principally the floodbasin of the San Joaquin River.

Alluvial events during glacial-interglacial transitions

As precipitation decreases in the transition from glacial to interglacial conditions, the dense vegetation of the preceeding period gives way to one of sparse grass and shrubs. Mean annual runoff decreases with decreasing precipitation but is no longer retarded by vegetation; consequently the lag time of peak discharge following storms is reduced, and the effecive surface runoff and amount of peak discharge is increased. The thick mantle of colluvium on the slopes formed during the preceeding period is exposed to erosion by sheetwash, rillwash, raindrop impact, gullies and mudflows. Reduction in the root-mass previously afforded by trees, shrubs, and grasses also exposes the slopes to erosion by earthflows, debris flows, soil avalanches, slumps and accelerated creep in those brief periods when precipitation is sufficient to saturate the colluvial mantle. Removal of the foot of many slopes by gulley erosion will initially enhance erosion by these latter processes but ultimately will assist in stabilizing the slope in the following arid period by draining water from the saturated colluvial layer thereby impeding creep and land sliding.

Sediment delivered to the streams by these slope processes is transported to the valley by increased peak stream discharge. The larger discharges have relatively greater velocities and are capable of transporting large volumes of sediment.

Schumm (1977, Figure 3-1) predicted that slope erosion and sediment yield would continue to increase in response to decreasing vegetation and would reach a maximum when mean anual precipitation decreased to about 15 to 20 inches (Figure 46). Below about 15 inches, erosion and sediment yield decreases sharply largely because runoff is insufficient to transport detritus from the barren slopes to the streams but also for other reasons which I will discuss shortly.

Periods of maximum sediment yield are most likely to produce alluvial-fan deposition and stream aggradation for several reasons: (1) Streams carrying a maximum sediment yield will tend to increase channel gradients through aggradation to improve their ability to transport material, particularly if the sediment load and size supplied exceeds the stream capacity and competence; (2) During a period of decreased precipitation, the streams entered a dry San Joaquin Valley with lowered water table. Streams infiltrate the pervious alluvium and dried up leading to deposition close to the fan-head (Blissenbach, 1954; Schumm and Hadley, 1957; Leopold and Miller, 1954). In these circumstances even the suspended load is deposited, probably contributing to the clay matrix so prevalent in the Coast Range alluvium, (Bull, 1964b; Meade, 1967, 1968); (3) Sudden loss of stream velocity as the stream encounters the relatively flat valley surface and is no longer confined to a single deep channel also contributes to deposition (Bull, 1964, 1968; Verhoogen and others, 1970, page 416).

As shown by Broeker and Van Donk (1970, Figure 2), the transition from glacial to interglacial conditions is relatively abrupt, probably from 2,000 to 4,000 years, while the reverse transition is relatively gradual, averaging about 90,000 years in length. The relatively abrupt transition may contribute to landscape instability by not permitting the landscape to adjust to the changing climate and thus changing slope and stream processes. The thick deposits of relatively unweathered alluvium separated by well-developed zonal buried soils supports a model of a short period of alluviation separated by long periods of slope stability and soil formation. The relatively long transition from interglacial to glacial conditions on the other hand, probably allows vegetation to cover the slopes and protect them against the effects of higher precipitation.

The broad, extensive pediments carved across the foothills of the Diablo Range probably originated by lateral stream corrasion during the transitional period rather than by the alternative process of headward retreat of a former range front. Sedimentary structures such as channeled contacts, laminated bedding, clast imbrication, and cross-stratification are present in the veneer of coarse sandy gravel and coarse sand and strongly indicated deposition by fluvial processes. The veneer of predominantly Franciscan detritus averages 4 m thick (Figure 32) but deposits 8 to 12 m thick are common in former channels. The veneer is laterally continuous with alluvial-fan and stream terrace deposits and is thus interpreted to be coeval

The pediments and coeval terrace and alluvial-fan deposits were probably formed in a wetter climate than the present interglacial climate. A greater amount of water is probably required to erode these surfaces and to transport the gravel veneer composed of detritus far from their source terrain than is contained in the ephemeral and perennial streams of today; although periodic, high intensity storms during interglacial conditions may have contributed to their formation.

The pediments generally are developed over the Cretaceous Great Valley Sequence and younger Tertiary deposits in the foothill belt. They do not extend over terrain underlain by the Franciscan assemblages. Hypothetically, perennial streams flowing from the central Diablo Range probably carried a coarse-grained sediment load, including cobbles and boulders, of resistant Franciscan lithologies. A relatively steep stream gradient is required to transport the coarse bedload across the foothill belt. As the streams aggrade and armor their channels, however, with Franciscan detritus to achieve a steeper gradient, they will erode laterally into the less resistant siltstone, claystone and sandstone of the Great Valley Sequence if the "threshold shear stress" (Bull, 1979) required by the stream water to erode and transport the fine-grained sandstone and shale is less than that required to transport the coarse-grained Franciscan bed load.

Alluvial events during interglacial epochs

The period of landscape instability continues until the progressively decreasing mean annual precipitation falls below about 15 inches. Semi-arid and arid conditions during an interglacial epoch probably approach or are drier than those of today in the west-central San Joaquin Valley. The present climate has a mean annual temperature of about 60°F and a mean annual precipitation of 8 to 10 inches on the valley floor, 10 to 12 inches in the foothills and 12 to 16 inches on the flanks of the central Diablo Range (Figures 6 and 7).

Erosion in the foothills and fluvial deposition in the valley is reduced during this period for several reasons: (1) Generally low stream discharge cannot transport large volumes of material from the drainage basin to the alluvial-fan; (2) The decrease in vegetation encourages gulley erosion which drains water from the colluvial mantle. Slope processes which require ground saturation such as creep and landslides are reduced; and (3) As the weathered mantle is removed during the transitional period and early arid period, the volume available for erosion decreases, and ultimately reduces the rate of erosion. (This is not true in areas underlain by the Cretaceous Great Valley Sequence, however, whose siltstone and shale beds need not be weathered significantly before they can be mobilized). This may partially contribute to the difference in relief between the foothills underlain by the Great Valley Sequence and the central Diablo Range underlain by the Franciscan assemblage where weathering is required to erode some of the more resistant lithologies).

Many slopes, however, remain mantled by colluvium and are unstable due to sparse vegetation. Cloudbursts of sufficient magnitude and intensity (Leopold and Miller, 1954; Leopold, 1951) or short term fluctuations in precipitation (Bryan, 1940), may, therefore, lead to episodes of local aggradation. These episodes may have produced the thin late Holocene veneers of Patterson alluvium and steep mudflow fans debouching from many of the ravines and small streams along the foothill valley margin; and this leads to the expectation that each climatic cycle may produce an alluvial unit composed of fluvial deposits of the transition period overlain by mudflow deposits of the succeeding arid period. Patterson alluvium and the upper member of San Luis Ranch alluvium, therefore, may represent parts of a single depositional unit similar to the early member of San Luis Ranch alluvium and the three members of Los Banos alluvium. Alternatively, the thin veneer of Patterson alluvium may be removed in some places during the succeeding glacial to interglacial transition, either by channel migration on the basin floor or by channel migration of the distributary streams on the alluvial fan.

In summary, I believe that the Coast Range alluvial deposits, their soils and their landforms probably result from climatic fluctuations rather than episodic tectonism in the Diablo Range. Periods of alluviation reflect transitions from more humid to more arid conditions because of changes in vegetation destablized slopes. Periods of surface stablity and soil formation reflect early glacial and possibly peak interglacial climates when vegetation stabilizes slopes or when surface runoff is not sufficient to transport detritus from the hillslopes to the streams and out to the Great Valley.

The recognition of a regional alluvial stratigraphy caused by fluctuations in climate has important social applications. The stratigraphy provides the framework for geologic investigations of site sensitive facilities, such as large reservoirs, nuclear power plants, schools and hospitals. The U. S. Bureau of Reclamation recently conducted a geologic investigation of San Luis Reservoir using the stratigraphy presented in this dissertation (Anderson and others, 1982). Furthermore, the stratigraphic units provide a general approximation of soil development, development shown in greater detail by the soil surveys of the Department of Agriculture. For example: soils developed on Dos Palos alluvium are generally poorly drained and rich in alkali salts, crops planted should be alkali-tolerant and probably leach-irrigated. Soils developed on San Luis Ranch alluvium are some of the most fertile in the San Joaquin Valley, while those on Los Banos alluvium and the Tulare Formation are generally progressively less fertile.

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CALIFORNIA STATE SHEET 1:500,000
CORE LOCATIONS AND DATA

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
1	29/37 33D	100	Dale, et al, 1966	1951	USBR	Gosford
2	29/27 34N	800	Lofgren, 1975	1952	USBR	Rosedale
3	29/27 36N	50	Robinson, 1977	1964	USBR	Gosford
4	30/28 10N	1199	Lofgren, 1975	1952	USBR	Lamont
5	32/29 19H	1000	" "	1952	USBR	Weed Patch
6	11/19-7R	1100	" "	1952	USBR	Mettler
7	32/28-30D	1460	" "	1952	USBR	Coal Oil C.
8	11/21 3B	1500	Meade, 1967	1952	USGS CDWR	Coal Oil C.
9	32/26-10N	90	Croft, 1968	1964	CDWR	Millux
10	32/26-16f	100	Lofgren, 1975	1952?	?	Millux
11	32/25 3A	450	Dale et al, 1966	1941	Western Gulf	Mouth of K.
12	31/25 27F	1000	Lofgren, 1975	1952	USBR	Mouth of K.
13	31/25-15C	1000	Lofgren, 1975	1952	?	Mouth of K.
14	30/25 28A	?	1	1951-2	USBR	Tupman
15	31/24 24	50	Croft, 1969	?	?	Mouth of K.
16	32/24 2A	50	Robinson, 1977	1964	USBR	Mouth of K.
17	30/26 22P	794	Lofgren, 1975	1952	USBR	Stevens
18	30/24 4C	800	Lofgren, 1975	1952	USBR	East Elk H.
19	29/23 35K	60	Spiker, et al, 1978	1969	CDWR	East Elk H.
20	28/25 17C	503	2	1973	Fugro	Rio Bravo
21	28/24 23D	700	3	1952	USBR	Rio Bravo
22	29/25 12m	1250	Lofgren, 1975	1952	USBR	Rosedale
23	28/26 21H	900	Croft, 1972	1952	USBR	Rosedale
24	28/22 16D	50-55	Croft, 1968	1964	CDWR	Lockhern
25	28/22-9D	1300	Croft, 1972	1952	USBR	Semitropic
26	28/22 9B	450	Ives, et al, 1964	1951-3	USBR	Semitropic
27	2H22-20L	52	Croft, 1988	1964	CDWR	Lost Hills
28	27/24 1L	1126	Croft, 1972	1951	USBR	Wasco
29	27/23 1R	1160	Lofgren, 1969	1952	USBR	Wasco SW
30	27/25 1N	1460	Croft, 1972	1951	USBR	Famoso
31	26/23 16R	500	2	1974 ?	Fugro	Wasco NW
32	26/23 22G	400	2	1974	Fugro	Wasco NW
33	26/23 15N	470	2 H14	1974	Fugro	Wasco NW
34	26/23 22C	80 to 300	2 #s H36-51	1974	Fugro	Wasco NW
35	26/23 22A	300	2 #H12	1974	Fugro	Wasco NW
36	26/22 22P	579	1 #NWS1	1973	Fugro	Wasco
37	26/22 22P	100	Croft, 1972	1962	USBR	Lost Hills
38	25/23 29A	800	Lofgren, 1969	1952	USBR	Lost Hills
39	25/23 28D	800	3	1952	USBR	Lost Hills
40	24/24 15H	600	Lofgren, 1969	1952	1USBR	Delano W.
41	25/25/22D	1350	Lofgren, 1969	1952	USBR	Pond
42	25/26 16F	1170	Lofgren, 1969	1952	USBR	Delano E.

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
43	25/27 15	450	[1]	1951-2	USBR	Richgrove
44	25/26 1A	892	Poland, et al, 1975	1959	USBR	Richgrove
45	24/26 36A	2200	Croft, 1972	1959	USGS	Richgrove
46	24/26-36A	1510	Poland, et al,	1959	USBR	Delano East
47	24/26-36A	2200	Lofgren, 1969	1959	USBR,USGS	Delano East
48	25/21 21D	80	Croft, 1968	1964	CDWR	Lost Hills, NW
49	25/21 1N	100	Croft, 1972	1962	USBR	Lone Tree Well
50	24/19 17A	655	[3]	1970	CDWR	Avenal
				?	USBR	Gap
51	23/23 33A	1200	Lofgren, 1969	1952	USBR	Alpaugh
52	23/24 16R	1400	Lofgren, 1969	1951	USBR	Alpaugh
53	24/25 2H	1188	Lofgren, 1969	1952	USBR	Delano East
54	23/25/16N	760	Lofgren, 1969	1958	USGS,USBR	Pixely
55	23/25 9Q	770	Lofgren, 1969	1951	USBR	Pixely
56	22/25 36N	out-crop	Robinson, 1976	1976	USBR	Sausolito School
57	23/26 8R	900	Lofgren, 1969	1951	USBR	Sausolito School
58	27/27 30D	1246	[3]	1970	CDWR USBR	Decor
59	23/27 3D	172.7	Hilton, et al, 1980	1947	USBR	Decor
60	23/27 1A	423	Hilton, et al, 1960	1947	USBR	Decor
61	32/29-19A	1199	Lofgren,1975	1952	USBR	Weed Patch
62	21/18 17N	300	4 No. D2506	1962-5	USBR	La Cima
63	21/18 23D	276	4 No. 846	1962-5	USBR	La Cima
64	20/18 34N	157	4 No. 843	1962-5	USBR	Huron
65	20/18 31R	212	4 No. DL 503	1962-5	USBR	Huron
66	20/17 35N	296	4 No. 842	1962-5	USBR	Huron
67	20/17 32R	540	Leblanc, 1970	1966	USBR	Guijarral Hills
68	20/16 36P	399	4 No. 837	1962-5	USBR	Guijarral Hills
69	20/17 21E	414	4 No. 838	1962-5	USBR	Guijarral Hills
70	20/17 11N	300	4 No. 839	1962-5	USBR	Huron
71	20/18 6D	1007	Bull 1975	1964	USBR	Huron
72	20/18 6B	607	Miller, 1967	1929	Shell Oil	Huron
73	20/18 6A	200	[4]DK 507	1962-5		Huron
74	19/18 33E	151	[4]DK 507	1962-5	USBR	Huron
75	19/18 27N	242	Miller, 1967	1929	Shell Oil	Huron
			Davis, et al 1959			
76	20/16 105	49	[4] 830	1962-5	USBR	Guijarral Hills
77	20/17 6D	300	[4] 831	1962-5	USBR	Guijarral Hills
78	19/17 30A	301	[4] 832	1962-5	USBR	Harris Ranch
79	19/17 22J	2203	Croft, 1972	1957	[6]	Calflax
80	19/17 9P	200	[4] DK 501	1962-5	USBR	Harris Ranch
81	18/16 36P	200	[4] DJ 506	1962-5	USBR	Harris Ranch
82	19/16 5A	205	[4] PV 901	1962-5	USBR	Harris Ranch
83	18/16 33A	1070	Bull, 1975	1964	USBR	Harris Ranch
			Croft, 1972			
84	18/16 34D	150	[4] DJ 504A	1962-5	USBR	Harris Ranch
85	18/16 23A	120	[4] 826	1962-5	USBR	Harris Ranch

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
86	18/17 5N	105	[4] 827	1962-5	USBR	West Side
87	17/17 27N	610	[5] 828	1962	USBR	Five Point
88	17/17 23R	141	[4] 829A	1962-5	USBR	Five Point
89	17/17 23J	241	[4] 829	1962-5	USBR	Five Point
90	18/17 35R	147	[4] 833	1962-5	USBR	Calflax
91	18/18 30R	95	[4] 834	1962-5	USBR	Calflax
92	18/18 22A	100	[4] 835	1962-5	USBR	Calflax
93	18/15-3A	401	[4] 822	1962-5	USBR	Tres Pecos
94	18/15 4N	540	Leblanc, 1970, 822	1966	USBR	Tres Pecos
95	18/15 3A	401	[4] 822	1962-5	USBR	Tres Pecos
96	17/15 36A	200	[4] DH 507	1962-5	USBR	Tres Pecos
97	17/15 25F	out-crop	Sullivan et al, 1970	1962-4	USBR	Tres Pecos
98	17/16 30A	1500	Miller, et al, 1971	1952	USBR	Tres Pecos
99	17/15 31D	200	[1]	1951-2	USBR	Lilllis R.
100	17/15 28A	441	Leblanc, 1970	1966	USBR	Tres Pecos
101	17/15 14Q	2,315	Poland, et al 1975	1969	USBR	Tres Pecos
102	17/15 13D	200	[4]	1951-2	USBR	Tres Pecos
103	17/15 36A	126	[4] 823	1962-5	USBR	West Side
104	16/16 35R	186	[4] 824	1962-5	USBR	West Side
105	16/17 20N	150	[4] 825	1962-5	USBR	San Joaq.
106	16/16 24D	564	[5] 806A	1963	USBR	San Joaq.
107	16/16 1R	55	Leblanc, 1970	1964	USBR	San Joaq.
108	16/17 4R	100	[4] J4	1962-5	USBR	Helm
109	17/14 14A	480	Leblanc, 1970	1966	USR	Lillis R.
110	17/15 6P	385	[4] 820	1962-5	USBR	Lillis R.
111	16/15 34N	2007	Miller, et al 1971	1958	Land Subs.	Tres Pecos
112	16/15 33E	194	[4] SG 506	1962-5	USBR	Tres Pecos
113	16/15 22R	150	[4] 807	1962-5	USBR	Cantua Cr.
114	16/16 18N	521	Davis, et al, 1959	pre 1959	Private	Cantua Cr.
115	16/15 13A	150	[4] 806	1962-5	USBR	Cantua Cr.
116	16/16 5R	85	[4] 821	1962-5	USBR	San Joaq.
117	16/16 3E	100	[4] J6D	1962-5	USBR	San Joaq.
118	15/16 31N	807	Bull 1975 Robin et al 1960	1967	CDWR	Cantua Cr.
119	17/14 2D	525	Leblanc 1970	1966	USBR	Lillis R.
120	16/14 26A	406	Leblanc 1970	1966	USBR	Levis
121	16/14 25A	?	Bull 1964	pre-1964	[6]	Levis
122	16/14 13H	230	[4] SG 504	1962-5	USBR	Levis
123	16/14 28D	30	Bull 1964	1964	[6]	Levis
124	16/14 21N	30	Bull 1964	1964	[6]	Levis
125	16/14 21L	30	Bull 1964	1964	[6]	Levis
126	16/14 20D	356	Leblanc 1970	1960	USBR	Levis
127	16/14 16N	2027	Croft, 1972	1959	CDWR	Levis
128	16/14 16Q	30	Bull 1964	1964	[6]	Levis

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
129	16/14 16K	30	Bull 1964	1964	[6]	Levis
130	16/14 16A	30	Bull 1964	1964	[6]	Levis
131	16/14 9N	481	Leblanc, 1970	1966	USBR	Levis
132	16/14 10E	220	[4] SG 510	1962-5	USBR	Levis
133	16/14 2N	200	Leblanc, 1970	1966	USBR	Levis
134	16/14 4K	175	[4]	SG-502	USBR	Levis
135	16/13 1A	400	Leblanc, 1970	1966	USBR	Levis
137	15/15 18N	175	[4] 804	1962-5	USBR	Levis
138	15/15 8B	250	[4] 818A	1962-5	USBR	Tranquil.
139	15/15 9D	524	Leblanc, 1970	1963	USBR	Tranquil.
140	15/15 8G	524	[5] #818	1962		Tranquil.
141	15/16 26A	85	Leblanc, 1970	1964	USBR	San Joaq.
142	15/16 13J	66	Leblanc, 1970	1964	USBR	Jameson
143	15/16 123	733	Miller, et al, 1971	1950	USBR	Cantua Cr.
144	15/16 28A	800	Miller, et al, 1971	1950	USBR	Cantua Cr.
145	15/16 17L	800	Miller, et al, 2972	1950	USBR	San Joaq.
146	15/16 18D	564	[1]	1951-2	USBR	Tranquil.
147	14/15 28L	151	[4] 819	1962-5	USBR	Tranquil.
148	14/15 25H	705	Miller, et al, 1971	1951	USBR	Tranquil.
149	15/14-15E	800	Miller, 1971	1951	USBR	Coit Ranch
150	15/13 16N	339	[4] 813	1962-5	USBR	Monocline R.
151	15/13 14R	780	Leblanc, 1970	1966	USBR	Monocline R.
152	15/13 11E	190	[4] SF 501	1962-5	USBR	Chaney R.
153	15/13 11D	962	Bull 1975	1964	USBR	Chaney R.
154	15/12 12E	?	Bull 1964	Pre-1964	[6] USBR	Chaney R.
155	15/12 2A	500	Leblanc, 1970	1966	USBR	Chaney R.
156	14/13 30N	275	[4] 809	1962-5	USBR	Chaney R.
157	14/12 26H	501	Leblanc, 1970	1966	USBR	Chounet R.
158	14/13 27N	200	[4] OF-516	1962-5	USBR	Chaney R.
159	14/14 29N	149	[4] 814	1962-5	USBR	Coit R.
160	14/14 22N	150	[4] 815	1962-5	USBR	Coit R.
161	14/14 13E	499	[4] 816, Leblanc 1970	1963	USBR	Coit R.
162	14/15 8C	174	Leblanc, 1970	1962	USBR	Tranquil.
163	13/15 35E	735	Miller, et al, 1971	1951	USBR	Mendota
164	13/15 35D	433	Bull 1975	1966	CDWR	Mendota
165	13/16 2C	750	Millel, et al, 1971	1952	USBR	Gravely
166	12/17 8G	500	Miller, et al, 1971	1953	USBR	Boknita
167	11/17 24K	?	Davis, et al, 1959	Pre-1959	Private	Madera
168	11/17 14R	4@ 60	[7]	1977	CDWR	Madera
169	11/17 13N	2@ 60	[7]	1977	CDWR	Madera

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' 199 Quadrangle
170	11/18 8Q	810	Miller, et al, 1971	1953	USBR	Madera
171	11/18 8E	?	8	1977	P.G.E.	Madera
172	11/16 10N	500	Miller, et al, 1971	1952	USBR	Bonita R.
173	11/15 33P	850	Miller, et al, 1971	1952	USBR	Firebaugh NE
174	13/14 15D	897	Leblanc, 1972	1948	CDWR	Firebaugh
175	13/14 21N	151	4 812	1962-5	USBR	Firebaugh
176	13/14 31N	153	4 811	1962-5	USBR	Firebaugh
177	14/13 11D	1500	Miller, et al, 1971	1957	6	Chaney R.
178	14/13 17R	225	4 DE 531	1962-5	USBR	Chaney R.
179	14/12 29C	250	Leblanc, 1970	1966	USBR	Chounet R.
180	14/12 21B	340	Leblanc, 1970	1966	USBR	Chounet R.
181	14/12 12J	280	Leblanc, 1970	1966	USBR	Chaney R.
182	14/13 7E	200	4 DE 529	1962-5	USBR	Chaney R.
183	14/12 12H	936	Miller, et al, 1971, Bull 1975	1964	USBR	Chaney R.
184	13/13 31M	150	Leblanc, 1970	1966	USBr	Broadview F.
185	13/12 36D	242	4 808	1962-5	USBR	Broadview F.
186	13/13 30D	160	Leblanc, 1970	1966	USBR	Broadview F.
187	13/12 31G	?	Bull 1964	1964	6 USBR	Hammonds R.
188	13/12 20R	220	4 SF 501	1962-5	USBR	Hammonds R.
189	13/12 34N	210	4 SE 505	1962	USBR	Hammonds R.
190	13/12 20D	665	Bull 1975	12961	USBR	Hammonds R.
191	13/12 17X	200	Leblanc, 1970	1967	USBr	Hammonds R.
192	13/11 12P	240	4 SC-502	1961	USBR	Hammonds R.
193	13/11 2L	200	4 DC 518	1962	USBR	Hammonds R.
194	12/12 25D	420	Miller, et al, 1971	1952	USBR	Oxalis
195	12/11 22A	271	Leblanc, 1970	1959	CDWR	Laguna R.
196	20/19 31P	686	Leblanc, 1970	1962	USBR	
197	12/12 20J	430	Miller, et al, 1971	1952	USBR	Hammonds R.
198	12/12 15K	581	Leblanc, 2970	2959	CDWR	Dos Palos
199	12/12 16H	10105	Bull 1975 and Meade, 1967	1957	6	Dos Palos
200	12/11 17K	400	5 DC-513	1962	USBR	Charleston School
201	12/11 7G	254	5	1961	USBR	Charleston School
202	12/11 6N	198	4	1961	USBR	Charleston School
203	12/10 1G	175	5 D710	1962	USBR	Charleston School
204	12/10 1B	350	5	1963	USBR	Charleston School
205	11/10 27R	243	5	1964	USBR	Charleston School

Core Hole	Location	Depth (ft)	Reference 11/	Date Drilled	Drilled By	7.5' Quadrangle
206	11/11 22Q	598	Miller, et al, 1971	1952	USBR	Charleston School
207	11/11 2J	600	5	1952	USBR	Dos Palos
208	15/12 23Q	850	Miller, et al, 1971	1951	USBR	Tumey Hills
209	19/18 15C	1022	Miller, 1967	1929	Shell Oil	Calflax
210	13/12 28D	200	Leblanc, 1970	1963	USBR	Hammonds Ranch
211	10/18 1B	?	8	1977	PGE	Daulton
212	11/10 4E	out-	Berger, et al, 1965	1962-5	USBR	Volta
213	10/13 32A	616	Leblanc, 1970	1958	CDWR	Santa Rita Bridge
214	10/14 8B	1002	Miller, et al, 1971	1952	USBR	Bliss Ranch
215	9/15 33B	600	5	1953	USBR	Chowchilla
216	9/16 22R	831	5	1953	USBR	Le Grande
217	9/17 25P	175	8	1977	PGE	Kismet
218	10/17 12A	175	8	1977	PGE	Kismet
219	10/17 20L	175	8	1977	PGE	Berenda
220	10/14 34E	900	Page, et al, 1967	1965	Calif. State	Bliss Ranch
221	9/13 33C	950	Balding & Page, 1971	1965	Calif. State	Santa Rita
222	9/14 1B	352	" " " "	1961	Calif. State	El Nido
223	9/11 20J	800	5	1952	USBR	San Luis Ranch
224	9/10 19B	600	5	1952	USR	Ingomar
225	9/9 23L	602	Hotchkiss, 1972[5]	1952	USBR	Ingomar
226	8/9 26H	582	5	1952	USBR	Ingomar
227	8/10 21D	600	5	1952	USBR	Gustine
228	8/9 11 C	8	Balding & Hotchkiss, 1969	1948	USBR	Gustine
229	7/10 23K	303	Balding & Page, 1971	1961	Calif. State	Gustine
230	7/14 23J	out-crop	Rubin, 1975	1975	USGS	Merced
231	5/10 25N	226	Balding & Page, 1971	1969	Calif. State	Ingomar
232	4/14 30H	205	Balding & Page, 1971	1958	USBR	Snelling
233	3/13 7	806	7	1977	PGE	Cooperstown
234	3/11 33N	Sample @ 17'	Rugin, 1976	1975	7	Denar
235	4/8 33G	815	Rubin, 1976	1976	PGE	Brush Lake
236	21/26 1Q	700	Lofgren, 1969	1951	USBR	Cairns Corner
237	3/5 5R	900	Hotchkiss, 1972	19?	?USBR	Tracy
238	2/6 10Z	320	Hobbs et al, 1963	1961	CDWR	Lathrob
239	21/24 31D	1180	Lofgren, 1969	1950	USBR	Taylor Wier

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
240	21/26 6F	900	Lofgren, 1969	1951	USBR	Cairns Corner
241	20/25 14K	1000	Lofgren, 1969	1951	USBR	Tulare
242	20/23 8D	730	Lofgren, 1969	1952	USBR	Waukena
243	19/22 19A	700	Croft, 1972	19?	USBR	Remnoy
244	18/22 36P	750	Croft, 1972	1951-2	USBR	Remnoy
245	19/25 7K	820	Croft, 1972	1951	USBR	Visalia
246	18/26 30N	700	Croft & Gordon, 1968	1951	U R	Exeter
247	18/23 12H	800	Croft, 1972	1951-2	USBR	Traver
248	17/25 24C	200	10	1961	USBR	Ivanhoe
249	17/25 24B	200	10	1961	USBR	Ivanhoe
250	17/25 11C	150	10	1961	USBR	Ivanhoe
251	16/25 34F	60	Crawford, et al, 1965,BR 34C	1947	USBR	Ivanhoe
252	16/25 36D	59	" " BR 36F	1947	USBR	Stokes Mtn
253	16/26 30A	50	" " BR 30F	1947	USBR	Stokes Mtn.
254	16/25 15E	100	" " BR 15E CID 15I	1947	USBR	Stokes Mtn.
255	16/25 9D	110	" " BR 961 CDW 8D1	1947	USBR	Orange Cove South
256	15/25 19A	120	" " AR 19E	1947	USBR	Orange Cove South
257	15/24 14D	91.5	" " BR 14C	1947	USBR	Orange Cove North
258	15/24 5A	83.5	" " AID 7C	1947	USBR	Wahtoke
259	14/20 14H	Out-crop	7	1976		Fresno South
260	13/20 24H	254	7	1974	CDWR	Fresno South
261	12/19 33B	140	5	1953	USBR	Herndon
262	12/19 33A	199	5	1958	USR	Herndon
263	12/18 13R	700	Miller, et al, 1971	1952	USR	Gregg
264	11/19 7R	2200	3	1951	USBR	Gregg
265	12/19 28P	295	5	1958	USBR	Herndon
266	22/18 11R	287	4 DM 503	1962-5	USBR	Kettleman City
267	21/19 17R	251	4 847	1962-5	USBR	Kettleman City
268	20/19 31P	686	844	1962	USBR	Westhaven
269	20/19 33N	300	Leblanc, 1970	1966	USBR	Westhaven
270	21/19 2C	156	4 845	1962-5	USBR	Westhaven
271	20/18 13C	501	Miller, et al, 1971	1936	Seaboard Oil Corp	Westhaven
272	20/18 13C	1881	Miller, et al, 1971	1929	Shell Oil	Westhaven
273	19/18 27R	140	4 801	1962-5	USBR	Vanguard
274	19/18 26H	3072	Miller, et al, 1971	1929	Shell Oil	Westhaven

Core Hole	Location	Depth (ft)	Reference[11/]	Date Drilled	Drilled By	7.5' Quadrangle
275	19/18 24R	145	Miller, et al, 1971, 802	1962-5	USBR	Vanguard
276	19/19 17P	3835	Miller, et al, 1971	1929	Shell Oil	Vanguard
277	19/19 16N	651	Leblanc, 1970, 803A	1952; 1963	USBR	Vanguard
278	19/19 15A	100	[4] 841 Friant	1962-5	USBR	Vanguard
279	18/19 20P	696	Leblanc, 1970	1967	USBR	Vanguard
280	21/29 20D	400	3	1951	USBR	Globe
281	11/25 2N	Out-crop	Robinson, 1977	1977	USBR	Patterson Mtn. NW

FOOTNOTES

(1) I. E. Klein, 1951-1952, unpublished information.

(2) San Joaquin Nuclear project, early site report, appendix 2.5F-1A, 2A, and 2.5g, unpublished.

(3) U. S. Bureau of Reclamation, Central Valley Project, 1951-1954, unpublished.

(4) U. S. Bureau of Reclamation, San Luis Project, unpublished. Map No. 805-207-943.

(5) U. S. Bureau of Reclamation, Friant Project, unpublished Map No. 214-208-3247.

(6) U. S. Bureau of Reclamation, Interagency Committee on Land Subsidence, 1961-1964, unpublished.

(7) D. Marchand, 1977, unpublished examination of Calif. Div. Water Resources core holes.

(8) Madera Nuclear Project, early site report by Fugro, unpublished Pacific, Gas and Electric Report.

(9) Stanislaus Nuclear Project, early site report by Woodward and Clyde, unpublished Pacific, Gas and Electric Report.

(10) U. S. Bureau of Reclamation, San Joaquin Valley Feasibility Study, Vol. II, Profile R-R', unpublished.

(11) For references refer to text bibliography.