UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

QUATERNARY STRATIGRAPHY AND INTERPRETATION OF SOIL DATA FROM THE AUBURN, OROVILLE, AND SONORA AREAS ALONG THE FOOTHILLS FAULT SYSTEM, WESTERN SIERRA NEVADA, CALIFORNIA

BY

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This report is preliminary
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reviewed for conformity with
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Introduction

For several years following the 1975 Oroville Earthquake (Sherburne and Hauge, 1975) a large number of trenches were excavated in the western Sierra Nevada foothills (herein referred to as the foothills) to assess Late Cenozoic activity along the Foothills fault system. During 1976 and 1977 the authors visited about fifty trenches excavated across lineaments and faults in the Sonora, Auburn, and Oroville areas of the foothills (figure 1). These trenches were made accessible to us by the California Department of Water Resources (DWR), Pacific Gas and Electric, the U.S. Bureau of Reclamation (USBR), the U. S. Army Corps of Engineers, and Woodward-Clyde Consultants (WCC). One of several interesting new findings to emerge from these trench studies was the exposure of multiple, sheet-like colluvial units, separated by buried soils, throughout a broad region in the foothills. These deposits, which laterally interfinger with alluvium forming terraces in some valleys, were first recognized and described by Page and others (1976), Swan, Hanson, and Page (1977), Swan and Hanson (1977), and Woodward-Clyde Consultants (1978), who noted their probable climatic significance. Recent studies in the Oroville, Auburn, and Sonora areas include those of Woodward-Clyde Consultants and Associates, 1976, Shlemon, 1977, 1978; Borchardt, Rice, and Taylor, 1978; Borchardt, Taylor, Rice, 1978, and Beggar, 1978.

In selected trenches we sampled and, in some cases, described relict and buried soils formed on the sequence of colluvial and alluvial deposits. Because degree of soil development is related to age and because soil age is critical to the assessment of Quaternary fault movement in the foothills, the California Division of Mines and Geology requested that some of these samples be analyzed and interpreted. The California Department of Water Resources, Division of Safety of Dams, provided funds for analyses of the U. S. Geological Survey samples. Analyses were performed by R. E. Meixner under the direction of M. J. Singer in the laboratories of the Soils and Plant Nutrition section of the Department of Land, Air, and Water Resources, University of California, Davis. Sample locations along with additional information are given in table 1. Analytical data are reported in Appendices I.-IV.

The purpose of this paper, which builds upon the earlier work described above, is sixfold: 1) to describe and informally name six Quaternary stratigraphic units in the foothills, 2) to describe a similar sequence of deposits, including glacial outwash, along the eastern edge of the San Joaquin Valley (figure 1), 3) to suggest a correlation between the two sequences, 4) to discuss the possible climatic significance of the multiple episodes of colluviation and alluviation indicated by the stratigraphic record of the region, 5) to summarize the properties of soils formed on each stratigraphic unit in the foothills and the usefulness of some soil properties as a means of distingushing the units, especially where buried, and 6) to compare relict soils formed on deposits about 9,000 to 10,000 years old in the foothills with those of similar age elsewhere in central California.

We are indebted to Glenn Borchardt, Ed Helley, Bill Page, Roy Shlemon, and Bert Swan for their insights concerning Quaternary deposits, soils, erosional processes, and geologic history of the foothills. Peter Birkeland provided some unpublished data on post-Tioga soils along the eastern Sierra Nevada escarpment and Burke summarized this data.

Quaternary Colluvial and Alluvial Stratigraphy of the Foothills

A sequence of colluvial and associated alluvial deposits separated by buried soils were revealed in the fault investigation trenches noted above (Page *in* Woodward-Clyde Consultants and Associates, 1976, Swan, Hanson, and Page 1977; Swan and Hanson, 1977, Woodward-Clyde Consultants, 1977[1/]. These trenches have been studied and described by Akers and McQuilkin (1975), California Department Water Resources (1977); Swan and others (1977-1978), Frei and others, (1977), Shlemon (1977, 1978), and Borchardt, Taylor and Rice (1978 a, b). To clarify terminology, we informally designate six stratigraphic units in the foothills--Keystone (youngest), Sonora, Wyandotte, Oroville, Bowie Flat, and Auburn (oldest)--(figure 2). All units except the Bowie Flat and Auburn are known to include both colluvial and alluvial facies. Units are distinguished by 1) position in vertical sequences of deposits, separated by buried soils, 2) degree of relict and buried soil profile development on the units, and 3) in the case of alluvial deposits, topographic positions in terrace sequences.

The six units are preserved in varying degrees throughout the foothills, as many as four occurring in one location. Distinctive soil properties associated with the extensive Sonora and Oroville units (see below) make regional correlation possible and facilitate identification of other units preserved in superpositional succession with the Sonora and Oroville units.

Keystone Deposits

The youngest unit, informally named Keystone, is herein defined to encompass all alluvium and colluvium bearing very weak, immature soils lacking B horizons. Some of the alluvium is historic and related to mining activities

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[1/] In the remainder of the text these three works will be collectively referred to as Swan and others, 1977-1978.

during the 19th century (Swan and others, 1977-78). Keystone alluvium is associated with one or more low benches that are, in places, incised into Sonora and older colluvium (fig. 3). Keystone colluvium, recognizable as a disturbed, active layer above Sonora colluvium, occurs only on steep slopes, especially along the walls of deeply-incised canyons. Charcoal recovered by E. J. Helley from Keystone colluvium exposed at about 20-30 cm depth in USBR trench BHT-1A (near Auburn, of Frei and others, 1977, for trench locations in the Auburn area) gave a carbon-14 age of 300±40 years B.P. (USGS 191); wood from 90 cm depth in USBR trench BHT-64, collected by R. T. Kilbourne, gave a carbon-14 age of 270±55 years B.P. (USGS 211)[2/] (E. J. Helley, 1978, written commun.). Charcoal in young alluvium and colluvium has yielded ^{14}C ages from modern to 1325±170 years B. P. (Woodward-Clyde Consultants, 1978, table C.5-9). The Keystone unit as defined here may include more than one episode of deposition.

Soils formed on Keystone deposits are immature, lacking B or AC horizons[3/] but displaying thin A and Cox horizons. These soils were not sampled or described in detail and are not discussed further in this report. The Keystone unit is named for deposits associated with narrow alluvial terraces filling incisions in Sonora colluvium along upper Green Spring Run about 0.6 km east of Keystone, section 24, T1S, R13E, Chinese Camp 7 1/2-minute quadrangle.

Sonora Deposits

The Sonora unit, named for extensive young colluvium in the vicinity of Sonora (fig. 1), is informally assigned to the most widespread colluvial and

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[2/]radiocarbon determination by Stephen W. Robinson in the laboratories of the U.S. Geological Survey, Menlo Park, California.

[3/]soil nomenclature in this report follows Soil Survey Staff, 1968, as modified by Birkeland, 1974.

alluvial deposit in the foothills. In the larger drainages Sonora colluvium interfingers with Sonora alluvium along the back edges of stream terraces. The colluvial slopes grade smoothly to the terraces (figs. 3, 4) and both colluvium and alluvium display similar soils, except where the alluvium and colluvium differ substantially in texture or mineralogy. Sonora terraces, which stand 0.5 to 2 m above Keystone levels, are in some places incised into Wyandotte terraces (fig. 3). However Sonora colluvium usually rests on bedrock (fig. 5) that may or may not possess a residual soil, or covers eroded remnants of buried soils formed on Oroville, or less commonly, Wyandotte colluvium. Carbon fragments from basal alluvial silt that we consider to be Sonora in Bayley House Pit 7 (Pilot Hill 7-1/2 quadrangle, Auburn area) yielded a carbon-14 age of 9130±170 years b.p. (Swan, Hanson, and Page, 1977). Several younger ages (table C. 5-9 in Woodward-Clyde Consultants 1977), have also been determined from organic soils formed on deposits that may be correlative with the Sonora. The younger dates are thought to reflect contamination by mixing and/or leaching, as suggested by Borchardt, Taylor, and Rice, 1978 p.8) We regard the Bayley House Pit 7 date (9130±170) as the most reliable age presently available for the Sonora unit (see section on stratigraphic relations for other evidence), although it represents a maximum date for the 2.5 m of allvium above the dated charcoal.

Relict soils on Sonora deposits (see below for more complete discussion) have cambic or very weak argillic B horizons defined by textural, structural, color, and pH contrasts with the overlying A horizons. Available laboratory data (tables 2 and 3) indicate significant development of this soil.

Wyandotte Deposits

Wyandotte deposits normally occur as buried remnants beneath Sonora colluvium (fig. 3) and are not preserved extensively. In many places, Wyandotte deposits overlie Oroville colluvium and alluvium. Wyandotte alluvium is preserved in a few locations as a terrace 0.5 to 3 m above the Sonora terrace. In these places, it bears a moderately developed relict soil with an argillic B horizon approximately .5 m thick, more strongly developed than the B horizon formed on Sonora deposits. The Wyandotte is informally named for alluvium and colluvium exposed in several DWR trenches along the west fork of Wyandotte Creek, about 6-1/2 miles east of Oroville in section 19, T 19 N, R 5 E, Bangor 7-1/2 minute quadrangle.

Oroville Deposits

Oroville colluvium, like the Sonora colluvium, is widely distributed throughout the western Sierra Nevada foothills. It is commonly buried by Sonora colluvium and in places by both Sonora and Wyandotte colluvium. Alluvial facies and terrace surfaces associated with the Oroville are preserved as terraces 1-4 m above Wyandotte terraces in a few of the larger valleys. In several areas, including the valley of Wyandotte Creek, alluvium comprising Oroville stream terraces interfingers laterally with Oroville colluvial deposits mantled by Wyandotte and Sonora colluvium. Oroville deposits appear to be the oldest that are clearly related to the present system of minor drainageways in the foothills. The soil formed on Oroville deposits -the younger or upper Paleo B soil of Swan and others (1977-1978)- has a distinctive prismatic B horizon which usually contains large amounts of clay relative to underlying and overlying horizons, even where buried by Wyandotte deposits. The Oroville unit is informally named for colluvial and alluvial deposits in the Cleveland Hills area about 10 km east of Oroville, where it has been exposed in numerous WCC and DWR trenches.

Bowie Flat Deposits

Pre-Oroville colluvial deposits have been found at two locations in the Sonora area (Price #1 trench and Bowie Flat #7 trench, Woodward-Clyde Consultants) and at one location in the Auburn area (trench ST 107). In the Sonora area trenches, Bowie Flat colluvium underlying Oroville colluvium a prismatic, clay-rich soil which is at least as strongly developed as the soil formed on Oroville deposits where buried by Sonora colluvium. In both Sonora area trenches, the Bowie Flat colluvium is overlain by the three successive Oroville, Wyandotte and Sonora colluviums, such that a four-layer sequence has been preserved (figs. 6, 7, 8) (see also Woodward-Clyde Consultants, 1978, figs. C. 5-6, C.5-7). The argillic B horizon formed on the Bowie Flat colluvium prior to burial by Oroville colluvium is truncated at the top and grades downward into lower B and oxidized C horizon at about 1.3 m below its eroded surface. This buried soil has strong but less than maximum possible development. The Bowie Flat unit is informally named for colluvium exposed in WCC trench Bowie Flat #7, located in the SW 1/4, SW 1/4, section 8, TIN, R13 E, Melones Dam 7.5' quadrangle.

Auburn Deposits

The Auburn unit is named for a deposit exposed in USBR trench ST 107 near the town of Auburn. Excavation of this trench (Frei and others, 1977) revealed a strongly weathered alluvial deposit exposed beneath Sonora colluvium (fig. 9). The argillic B horizon of the soil formed on these gravelly deposits is clay rich (41%) and redder (10R 4/4 d) and thicker (about 2 m) than B horizons of any soil observed on the other units. The contrast between the degree of development of buried soils formed on Bowie Flat and Auburn deposits suggest that the Auburn may be older. We cannot be certain that these units are of different age, however, because we have not seen Bowie Flat deposits superimposed over Auburn deposits.

Climatic Significance of the Foothill Quaternary Sequence

The sequence of colluvial and alluvial deposits separated by buried soils and periods of stream incision in the foothills clearly demonstrates that slope processes and stream aggradation have been episodic in the foothills. The broad regional extent of episodic colluviation and alluvation strongly suggest a climatic cause, especially since there appears to be little if any evidence for tectonic control. Helley (1967, 1978) showed that the Chowchilla River basin, an unglaciated watershed on the western slope of the Sierra Nevada, possessed the same geomorphic and stratigraphic sequence of alluvial terrace and fan deposits as the glaciated Merced River to the north (Arkley, 1962b) and the glaciated San Joaquin River to the south (Janda, 1965, 1966). Subsequent mapping by Marchand (1976a, b, c, d, e, f) and Marchand and Allwardt (1978) verified that small,unglaciated drainages heading in the Sierra Nevada foothills were alluviating their courses at approximately the same time that the major westward-flowing rivers draining the core of the range were depositing glacial outwash. Therefore the climatic and vegetational changes associated with glaciation and deglaciation and outwash deposition could be responsible for colluviation and alluviation in unglaciated terrain such as the foothills. Several models invoking elimatic control of foothill colluviation and alluviation have been proposed and some are discussed below.

Swan and his coworkers have hypothesized that cooler and perhaps wetter glacial climates caused colluviation of slopes and alluviation of small valleys in the foothills, whereas relatively warm and perhaps drier interglacial conditions, similar to the present, were conducive to landscape stability and soil formation. Slopes today are relatively stable in the foothills, except in a few restricted areas of very high relief. This stability is reflected by the soil formed on the widely distributed Sonora colluvium, indicating stability since deposition ceased.

Borchardt, Rice, and Taylor (1978) have suggested that young foothill colluvium (Sonora of this paper) was deposited during a brief, early Holocene "pluvial" event occurring during the glacial-to-interglacial transition. In this alternative climatic model,foothill deposition would be out of phase with glaciation in the Sierra Nevada to the east and would follow outwash deposition in the Central Valley to the west. Our observations, outlined below, support a modified form of this model. According to these authors, neither the early Wisconsin nor the late Wisconsin glacial stades are represented in the foothills.

Some foothill-derived late Modesto alluvium in the northeastern San Joaquin Valley is pre-Altithermal and post-Wisconsin in age. Cross cutting relations and several exposures in the Lodi area of the Central Valley (Marchand and Atwater, 1979) indicate that late Modesto foothill-derived alluvium from the unglaciated Calaveras River postdates late Modesto glacial outwash from the Mokelumne River. If late Modesto outwash was deposited about 10,000 to 14,000 years b.p. (Marchand and Allwardt, 1977), then the late Modesto Calaveras alluvium must be younger than 14,000 years and perhaps younger than 10,000 years. In many places a buried A/Cox/Cn soil representing several thousand years of nondeposition is formed on local alluvium beneath Holocene deposits believed to be about 3,000 to 4,000 ^{14}C years old (post-Modesto 2 unit of Marchand and Allwardt, 1977). An unoxidized buried soil showing similar development is formed on late Modesto outwash and locally derived alluvium beneath intertidal deposits of the Sacramento-San Joaquin Delta. The oldest demonstrably intertidal deposits of the delta are about 6,000-7,000 ^{14}C years B.P. (Atwater, 1979; Shlemon and Begg, 1975) The foothill-derived late Modesto alluvium of the San Joaquin Valley therefore appears to have been laid down between about 10,000 and 7,000 years ago and its deposition requires the existence of drainage basin conditions that would supply sediment load in excess of stream transport capability. The geomorphic and stratigraphic relations of late Modesto and Sonora alluvium and colluvium with dated deposits and the degree of soil profile development on them indicate an early Holocene (9,000 years B.P.) age for both deposits.

In our opinion the evidence presented above, together with the Bayley House radiocarbon date of 9130 years b.p., supports many aspects of the climatic model of Borchardt, Rice and Taylor (1978) who have equated times of colluviation and local stream aggradation in the foothills with periods of rapid glacial to interglacial transition. It seems plausible that the rise of the forest-oak woodland and oak woodland-grassland boundaries in the western Sierra Nevada during this climatic transition may have exposed weathered bedrock and pre-existing colluvium to active slope processes associated with a climate wetter than today. The result may have been extensive sheet colluviation in the foothills, overloading of streams, and resultant aggradation and fan alluviation (see Bull, 1979, p. 460-461 for a geomorphic threshold concept applied to the Pleistocene-Holocene climatic change in the arid Southwest). We agree with Swan and others (1977 and 1978) that extensive, sheetlike foothill colluviation could only have taken place under a moisture regime wetter than that of the middle and late Holocene. Probable age relations between climate-related events during the late Wisconsin and Holocene in central California are depicted in figure 14.

Quaternary Colluvial and Alluvial Stratigraphy of the Eastern San Joaquin Valley

The sequence of Quaternary deposits along the eastern edge of the San Joaquin Valley is remarkably similar to that described above for the Sierra Nevada foothills. The stratigraphic units of the northeastern San Joaquin Valley, earlier described by Arkley (1954, 1962a), Davis and Hall (1959), Janda (1965, 1966), and Janda and Croft (1967) include glacial outwash, nonglacial alluvium and colluvium and have recently been differentiated in detail by Marchand and Allwardt (1977, and in press). The entire area east of the lower San Joaquin River between Fresno and Sacramento has been mapped

(Marchand, 1976a, b, c, d, e, f; Marchand and Harden, 1978; Bartow and Marchand, 1979a, b,; Marchand and Bartow, 1979; Marchand and Atwater, 1979; Helley, 1978) or is presently being mapped at 1:24,000 or 1:62,500 scale. Ages of glacial outwash units are controlled by ^{14}C dating from 0-45,000 years, uranium trend dating (Rosholt, 1978) from 40,000 to 600,000 years, and magnetostratigraphy of sediments and K-Ar dating of associated volcanic materials for units 600,000 years and older.

Although colluvial units have not been shown on the published maps, they occur extensively in the gently rolling terrain of the easternmost San Joaquin Valley. Relations between sideslope colluvium, nonglacial alluvium, and glacial outwash are well demonstrated along Little Dry Creek (Fig. 1) above its confluence with San Joaquin River near Friant (Fig. 10). The schematic cross-section of figure 11 depicts a typical sequence of alluvial terraces, such as occur in the Little Dry Creek area, incised into Turlock Lake and older deposits in the low rolling terrain of the easternmost San Joaquin Valley. Three colluvial units can be recognized in this area as belonging to 1) the upper member of the Modesto Formation [4/] 2) the lower member of the Modesto (?), and 3) to the upper unit of the Riverbank Formation.

The youngest extensive colluvium in the eastern San Joaquin Valley is a facies of the upper member of the Modesto Formation (late Modesto). Present slopes are relatively stable and Holocene colluvium is restricted to a few swale fillings in areas of relatively high relief. Late Modesto colluvium mantles slopes, forms colluvial fans, and fills swales in both the low and higher foothills. These colluvial surfaces merge smoothly with late Modesto

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[4/]In this report, San Joaquin Valley stratigraphic terms such as Modesto are restricted to th San Joaquin Valley and to areas such as that of figures 10-13 where correlation with Valley stratigraphy can be demonstrated.

alluvial terraces (figure 4). Colluvial and alluvial deposits beneath these geomorphic surfaces interfinger along valley margins and upvalley near the heads of small drainages (figs. 10 ,11 and 12). Late Modesto stream terraces emerging from unglaciated foothill drainage basins are consistently graded to the lowest of up to four glacial outwash terraces along major Sierran rivers such as the San Joaquin (fig. 10).

In granitic foothill terrain or areas underlain by arkosic deposits, a continuum of morphologically similar soils (Hanford, and Visalia soil series) are found developed on colluvium, local alluvium, and glacial outwash of the upper member of the Modesto Formation (for descriptions of and data for Hanford and other age-diagnostic soils formed on upper Modesto alluvium, see table 5 and Arkley, 1962b, 1964; Ulrich and Stromberg, 1962; Huntington, 1971; Marchand and Allwardt, 1977, and in press; and Harden and Marchand, 1977). Weakly developed Hildreth and Marguerite soils have formed on late Modesto alluvium and local colluvium in areas underlain by the Mariposa slate and other relatively unweathered metamorphic rocks.

Colluvial facies of the lower member of the Modesto Formation (early Modesto) may be preserved in low foothills areas where Greenfield or Chualar soils (Huntington, 1971; Arkley, 1962, 1964; Ulrich and Stromberg, 1962) have been mapped on arkosic deposits in swales or extending upslope from minor drainageways (fig. 13; see also Marchand, 1976f, sheets 7 and 8: areas mapped early Modesto(?) -map unit m 1?- may be equivalent to Wyandotte colluvium in areas underlain by metavolcanic rock). No good exposures of early Modesto colluvium, have yet been found, so its existence is speculative. Early Modesto alluvial terraces, often in the form of strath surfaces, extend well back into the foothills along many small and intermediate sized streams, including Little Dry Creek in Fresno County (fig. 10), the Fresno and Chowchilla Rivers, and Dry Creek (Merced County). The back edges of these terraces, with which Wyandotte deposits are tentatively correlated, are commonly mantled by late Modesto colluvium (fig. 11), which would bury any lower Modesto or Wyandotte colluvium that was present.

The oldest recognized colluvial unit in the eastern San Joaquin Valley appears to have been deposited contemporaneously with the upper unit of the Riverbank Formation (late Riverbank). In the southern part of the Yosemite Lake 7-1/2 minute quadrangle (Marchand, 1976b, sheet 5), gravelly colluvial deposits derived from the Mehrten and Laguna Formations (map unit rg) mantle erosional slopes that truncate the North Merced pediment. Downslope, these colluvial gravel slopes merge to form colluvial-alluvial terraces which merge downstream with the alluvial surface of late Riverbank age. In this area, the rg colluvial-alluvial terraces are graded to levels topographically below remnants of the middle unit of the Riverbank (middle Riverbank). The soils formed on the rg colluvium and alluvium are comparable in development to the San Joaquin (weak variant) and Madera soils that characterize the upper unit of the Riverbank. In the Friant 7-1/2 minute quadrangle (figs. 10 and 12), narrow swale fillings of colluvium (unit r3c) north of Little Dry Creek lie topographically below remnants of the middle Riverbank and are graded to elevations along the creek which lie topographically above the projection of nearby early Modesto terraces (fig. 12).

Stratigraphic, Geomorphic and Age Relations Between the Foothills and Eastern San Joaquin Valley Quaternary Sequences

The sequences of colluvial and alluvial deposits separated by buried soils in the foothills and the adjacent San Joaquin Valley are remarkably similar, as noted above. The two sequences appear to have evolved concurrently, presumably in reponse to a common climatic cause. The interfingering of alluvium and colluvium in both areas indicates that these processes occurred concurrently, or nearly so, and we attribute alluviation of fans emerging from unglaciated and tectonically stable drainage basins as a response to upstream colluviation. Widespread colluviation and alluviation are not occcurring today and did not take place during middle or late Holocene time (the Keystone appears to be very restricted geographically) in either the foothills or in areas of the eastern San Joaquin Valley receiving sediment from unglaciated watersheds. The carbon-14 date from Bayley House Pit 7 substantiates a correlation of Sonora deposits with the close of the Tioga glaciation of the Sierra Nevada (Adam, 1967) and cessation of late Modesto alluviation (Marchand and Allwardt, 1977) and deposition of the lacustrine "A clay" in the Tulare and Buena Vista lake basins of the San Joaquin Valley (Janda and Croft, 1967).

The late Riverbank colluvium (r3c) of the Little Dry Creek area (fig. 10) consists primarily of volcanic and arkosic deposits derived from the Auberry Formation of Janda (1966) and overlying trachyandesite of Kennedy Table (Huber, 1977). The soil formed on this colluvium is comparable in development to soils formed on the late Riverbank in andesitic alluvium and to the post-Oroville (youngest paleo B of Page in Woodward Clyde Consultants and Associates, 1976, and Swan and others (1977-1978)) soil, formed on colluvium and alluvium derived from metavolcanic rocks in the foothills. We conclude that the Oroville deposits of the foothills are probably equivalent in age to the late Riverbank of the San Juaquin Valley. This correlation is further supported by the observation that both the late Riverbank and the Oroville cover extensive areas and represent the oldest deposits that are clearly related to the present topographic network of small drainages. Many small drainageways in the eastern San Joaquin Valley are incised into alluvial fans or terraces of the middle Riverbank and filled by late Riverbank alluvium and colluvium (see Marchand, 1976e, sheet 2; Marchand 1976f, sheet 6). These drainageways are therefore post-middle Riverbank, pre-late Riverbank in age. We infer, but cannot prove, a similar age for parts of foothill drainage net.

The foothill and San Joaquin Valley sequences are correlated in figure 2. We believe the correlation of the Sonora with the late Modesto and the Oroville with the late Riverbank to be on a reasonably firm basis, given the geomorphic, stratigraphic, pedologic, and radiometric evidence presented above. If these two correlations are accepted, the correlation of the Wyandotte with the early Modesto and Keystone with the post-Modesto appear reasonable, although field evidence is much less complete. The climatic event that caused Wyandotte deposition seems to have been shorter or of less magnitude than those that led to Oroville and Sonora deposition, which were much more extensive. The correlations of the Bowie Flat with the middle Riverbank and the Auburn with the upper unit of the Turlock Lake Formation are speculative, based on development of buried soils and position in the stratigraphic sequence.

Woodward-Clyde Consultants (1977) have proposed correlations between the foothills and the San Joaquin Valley from investigation of a three-terrace sequence along Vizard Creek, a tributary of the Stanislaus River near its fan apex. They project the highest (oldest) terrace above the level of the Turlock Lake Formation (upper unit) on the Stanislaus River and conclude that this terrace pre-dates the Turlock Lake. This highest Vizard Creek terrace, however, stands at an elevation of (130-138m about 3.2 km upstream from its confluence with Stanislaus whereas remnants of the younger Turlock Lake (upper unit of Marchand and Allwardt, 1977) attain an elevation of about 140 m 2.4 km downstream from the confluence. The highest Vizard Creek terrace therefore projects below and post-dates the younger unit of the Turlock Lake, which contains the 600,000-year-old Friant Pumice Member; this terrace therefore probably correlates with the Riverbank Formation. The presence of a bedrock knickpoint between the Woodward-Clyde study area and the confluence, however, makes definite correlations difficult. On the basis of the soils information provided by Woodward-Clyde, we would tentatively correlate the lowest Vizard Creek terrace with the late Modesto and the Sonora, the second with the early Modesto and Wyandotte, and the highest with the late Riverbank or Oroville.

Soil Development in the Foothills

Soils in the western foothills of the Sierra Nevada have formed as residual soils on intrusive and metamorphic basement rock and on Tertiary gravels and volcanic rocks; they have also formed on colluvium and alluvium derived from all of these rock types. Most of the residual soils are very weakly developed, and perhaps because of erosion rates that exceed soil formation rates, probably date from late Quaternary time. Thick, red saprolitic profiles, however, have formed in places on Tertiary and pre-Tertiary bedrock along major drainage divides and in other areas of the landscape where erosion rates are low. Rock beneath the B horizon of these saprolitic soils is deeply weathered and kaolinite tends to be the dominant clay mineral (X-ray diffraction data not shown). These old residual soils may have been forming since the Tertiary. They pass as buried soils beneath Tertiary deposits along the northeastern edge of the San Joaquin Valley and they may show the imprint of a tropical or subtropical climate (Hendricks, 1962).

Soils formed on colluvium in the foothills are extremely variable in their properties. Colluvial soils are subject to slope movement, especially in rugged terrain, during and after their development, and to erosional truncation and burial during succeeding periods of colluviation. In the foothills, colluvial parent materials have been derived from a wide variety of plutonic (primarily granitic), metamorphic (primarily slate, schist, greenstone, and metavolcanic rocks), and volcanic (primarily andesitic) sources. They have in many places formed on materials derived from the old residual saprolites and consequently contain mineral grains, clay, and iron oxides reworked from the preexisting soils.

In the foothills, alluvium contains less indication of reworked weathered materials than colluvium. Otherwise provenance of alluvial parent materials is variable and similar to that of the colluvium. Both alluvial and colluvial soils in the foothills, especially those formed on Oroville and older deposits, often contain abundant swelling clays (table 2) and may be subject to seasonal swelling, drying, and cracking.

Interpretation of foothill soil development in terms of time is complicated by the problems of reworking, swelling clays, slope movement, and variable parent materials. Nonetheless a number of soil properties provide a basis for recognizing deposits of different ages. Some of the more diagnostic properties of relict and buried colluvial soils are summarized in table 2 and discussed below. The values in this summary table are based on the data of Appendixes I, IV and on data from Swan, Hanson, and Page (1977). Extensive physical, chemical, and mineralogical analyses and interpretations of soils in the Auburn area may also be found in Borchardt, Taylor, and Rice (1978) and Borchardt, Rice, and Taylor (1978).

Relict Soils Formed on Sonora Deposits[5/]

Relict soils developed on Sonora deposits typically have cambic or weak textural B horizons 50-70 cm thick with few to common, moderately thick clay skins bridging grains and filling pores. B horizon structure is moderate and medium to coarse subangular blocky. Sonora soils are medium to slightly acid (A horizon pH 5.7 to 6.0) and maximum bulk densities of B horizons average about 1.6 (table 2). Less-than-2 micron clay is about 22 percent and less-than-1 micron about 16 percent. Cation exchange capacity (CEC) is about 25 percent. Smectite and kaolinite, judging from the data of Swan, Hanson, and Page (1977), are present in approximately equal proportions, but vermiculite and vermiculite-chlorite intergrade clay minerals are generally absent. Organic carbon declines relatively slowly with depth to a value of about 0.4 in the B or upper C horizon (soil FA-1, app. II). Dithionite-extractable free iron oxides average about 2.2 percent. When B horizons are compared with A horizons (table 3), Sonora soils show average less-than-2 micron and less-than-1 micron clay increases of 26 percent, an average free iron increase of 9 percent, and about 5 percent increase in pH. These changes demonstrate small but significant profile development in these young soils.

Buried Soils Formed on Wyandotte Deposits

Soils older than Sonora have been identified only where buried. B horizons of pre-Sonora soils have been preserved as remnants beneath Sonora deposits and erosion surfaces. Presumably the clay-rich B horizons are less readily eroded than are A horizons and erosion would tend to strip the A and leave the B. Because the colluvial deposits are commonly thin and occur in

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[5/]In this report, soils formed on Sonora deposits are referred to as Sonora soils. Other soils are named in similar fashion.

superposition with one or more other colluvial units, unaltered parent material is frequently absent. Material below a remnant B horizon is commonly another buried B. In fact the whole question of "what is fresh parent material?" becomes very complex. It is therefore impossible to examine soil development of these older soils through horizon ratios and thicknesses of horizons. Comparison must be made in terms of properties pertaining to the preserved buried B horizons of these older soils.

The buried argillic B horizon of the Wyandotte soil shows medial development, has moderately thick clay films bridging grains, and a few thick pore fillings. Structure is moderate to strong, medium to coarse subangular blocky. Maximum B horizon bulk density averages about 1.8 and clay contents average about 37 percent for less-than-2 micron and 32 percent for less-than-1 micron clay (table 2). Cation exchange capacity averages almost 40 percent, significantly greater than for Sonora soils. Free iron averages 2.7 percent and minimum B or C horizon organic carbon is about 0.3 percent with a large standard deviation. These latter two values appear to represent small, but perhaps significant differences compared to Sonora values. Wyandotte smectite content, based from data of Swan, Hanson, and Page (1977), is greater than kaolinite. A concomitant increase from Sonora B horizon in vermiculite and vermiculite-chlorite intergrade clays can also be seen. Wyandotte soils therefore show signficantly greater development than Sonora soils, even though buried by Sonora deposits. This contrast is best shown by clay contents, cation exchange capacities, and clay mineralogy and to a lesser extent by free iron oxides and organic carbon.

<u>Buried Soils Formed on Oroville Deposits</u>

Oroville soils have been buried by Wyandotte and/or Sonora deposits. The Oroville soil (Paleo B of W. D. Page in Woodward-Clyde Consultants and

Associates, 1976, and Swan and others, 1977-1978) is readily distinguished from younger soils by its pronounced prismatic B horizon often marked by slickensides and stress cutans indicative of swelling clays. Clay films are common and thick, bridging grains and filling pores. The 2-micron clay and cation exchange capacity data of table 2 suggest that the Oroville soil beneath Sonora deposits is more strongly developed than under Wyandotte deposits. The Oroville soil therefore appears to have undergone further development during post-Wyandotte, pre-Sonora time, although much of its development had been attained prior to Wyandotte deposition. This conclusion, however, assumes that Wyandotte was not deposited, then eroded from the Oroville soils studied.

Oroville soils buried under Wyandotte deposits show about 41 percent less-than-2 micron clay and about 36 percent less-than-1 micron clay. Maximum B horizon bulk density averages about 1.9, free iron oxides are 3.1 percent, and minimum organic carbon is 0.19. These values suggest slightly greater development than Wyandotte soils under Sonora Deposits, but the differences are small and the standard deviations are large.

Where buried by Sonora deposits, Oroville soils show nearly 60 percent less-than-2 micron clay and CEC averages about 54 percent. Smectite content appears to be about twice that of kaolin minerals and vermiculite minerals total about 7 percent. The clay mineralogy appears to be significantly different than that of Wyandotte soils and the clay and CEC values are clearly much higher. We would conclude that Oroville soils, especially where exposed beneath Sonora deposits, show stronger development that Wyandotte soils and formed over a longer time span.

Buried Soils Formed on Bowie Flat Deposits

Bowie Flat soils preserved under Oroville deposits in the Price and Bowie Flat trenches (see above) are generally comparable to the buried Oroville soils but seem to be somewhat thicker. Maximum less-than-2 micron clay averages about 52 percent, less-than-1 micron clay about 47 percent, and CEC about 47-48 percent. Maximum bulk density is significantly greater than in Wyandotte soils and Oroville soils buried by Wyandotte. It would appear that the buried Bowie Flat profile is more or less comparable in development to the Oroville profile where buried by Sonora and that the time to form these soils should also be roughly comparable[6/]. If the Oroville deposits were laid down about 140,000 years b.p., as suggested by the correlation of figure 2, and the Sonora about 8,000-10,000 years b.p., then about 130,000 years should be added to the age of the Oroville to obtain the approximate age of the Bowie Flat. The resultant value, about 270,000 years, would suggest a tentative correlation of the Bowie Flat with the middle unit of the Riverbank Formation, as indicated in figure 2. If foothill colluvial deposits are correlative with San Joaquin Valley alluvial units on a one-to-one basis, then colluvial deposits correlative with the middle Riverbank should underlie colluvial deposits correlated with the late Riverbank. Obviously this Bowie Flat correlation is based on a number of assumptions which could be legitimately questioned, including approximately linear rates of soil formation. More conclusive evidence regarding the age of pre-Oroville deposits in the foothills awaits the careful study of more exposures and alternative means of correlation and dating.

[6/] This conclusion rests on the assumption that soil development effectively ceases upon burial. As discussed earlier, it is difficult to assess the validity of this assumption. It is probably valid where burial is deep and less valid where burial is shallow.

Buried Soils Formed on Auburn Deposits

The B horizon of the Auburn soil, preserved beneath Sonora deposits in USBR trench ST 107 in the Auburn area, is over a meter thick (base was not exposed) and displays continuous, thick films as bridges, coatings on clasts, pore fillings, and ped face coatings. Its texture, very cobbly clay, is too coarse for prismatic structure to develop, but the fine matrix is strongly aggregated into medium to coarse angular blocks. Clay content of the Auburn profile is more comparable to Wyandotte soils than to the older soils, but when the sand content of this gravelly deposit is taken into account through multiplication by the sand/silt ratio (discussed below), the Auburn profile shows slightly greater clay than the Oroville and Bowie Flat soils analyzed. Maximum cation exchange capacity for the Auburn soil, about 22 percent, is very low compared to other soils in the sequence. This value may reflect abundance of kaolinite, which has a low exchange capacity; x-ray diffraction shows kaolinite to be the dominant clay mineral in the B horizon of this soil. Free iron content (average maximum = 4.5 percent) is significantly higher than for any other soil studied and minimum organic carbon in the B or C horizons is quite low. Field and thin section morphology of this soil place it in a maximal development category.

As noted above, we do not know that this soil is older than the Bowie Flat soil, but some if its properties suggest considerable antiquity. In figure 2 we have tentatively correlated the Auburn with the upper unit of the Turlock Lake Formation.

Soil Properties as Age Indices in the Foothills Sequence

Several properties of relict and buried soil profiles appear to be useful as measures of soil age in the foothills. Field observable parameters such as B horizon structure, clay films, and in some cases color and thickness may be helpful in this regard. Clay content (both less-than-2 and less-than-1 micron), bulk density, cation exchange capacity, and semiquantitative clay mineralogy appear to be the most reliable laboratory indices of age. Adjustment of clay percentages by the sand/silt ratio may be a useful computation, at least for this group of soils, as it should minimize the effects on textural differences in parent materials. Free iron oxides and minimum organic carbon content at depth also show progressive changes with time. However, standard deviations of most properties tend to be large in relation to the differences between age groupings of soils. Thin section examination was helpful, but less productive than for other chronosequences we have studied (Harden and Marchand, 1977) because of the abundance swelling clays and reworked preexisting soil materials.

Some other properties such as pH, exchangeable cations, and phosphorus fractions (Appendix I; Swan and others, 1977-1978), appear to be affected by burial. In general, soil pH and cation content tend to increase in these soils with age rather than decrease, as it would be expected in a simple leaching progression with time. Cations and pH properties seem to be dominated by the present leaching regime and do not preserve the imprint of past soil profile development.

We have found several soil properties, for example organic carbon, to be valuable tools in the recognition of buried soils where upper B or A horizons are preserved. In humid and strongly oxidizing environments, however, A horizon carbon is rapidly lost following burial (Follmer, MacKay, and Lineback, 1979). Organic carbon values show a smooth decrease with depth (app. II). Abrupt increases in carbon content, such as those shown in soil FA-1 coincide with buried profiles (desingated IIB). Some changes in soil properties across a buried soil in profile FA-1 are summarized in table 4.

Foothill Soil Development Compared with that in the San Joaquin Valley and the Eastern Sierra Nevada

Soils about 9,000 to 10,000 years old from three areas in central California are compared for various soil properties in table 5. Examination of the data suggests that processes and rates of soil formation in the foothills are different from those in the two comparison areas of central California. In particular the clay mineralogy, pH, iron oxide content, and particle size distribution in the foothills soils appear quite different from soils of similar age in the San Joaquin Valley and the eastern Sierra Nevada.

To better understand the causes for such differences, soils in table 5 are grouped according to the conditions under which they formed. Of the five soil-forming factors discussed by Jenny (1941), two, topography and time, are similar for all of these soils. Sites of 0-5% slope were selected for sampling. The Sonora, Tioga, and late Modesto, deposits are all known to be about 9,000 to 10,000 years old (this paper; Marchand and Aldwardt, 1977; Adam, 1967). Climate, and vegetation differ between the three areas, but are relatively uniform within each area. Parent materials are similar in some places and different in others and are grouped into metavolcanic-volcanic (andesitic in all cases), volcanic-metamorphic, arkosic-volcanic and arkosic[7/] source materials.

We attempt to separate the effects of climate from the effects of parent materials on soil development, using a step-by-step comparison of soils formed under different conditions. We first compare soils developed on arkosic

[7/] In this report the term arkosic refers to a mineralogy dominated by quartz and alkali feldspars with lesser amounts of plutonic hornblende, biotite, and other heavy minerals. Volcanic parent materials have less quartz and K-feldspar and more calcic plagioclase, pyroxene, volcanic hornblende, and opaque minerals.

alluvial deposits (referred to as arkosic soils) of the San Joaquin Valley to arkosic soils of the Tioga till in the eastern Sierra Nevada. The differences in properties between these soils are considered to indicate their differences in climate-vegetation. Secondly, by comparing arkosic and arkosic-volcanic soils of the eastern Sierra, the influence of volcanic parent material is observed relative to the arkosic soils in an essentially constant climate/vegetation regime. Thirdly, the influence of volcanic-metamorphic lithologies relative to arkosic deposits can be observed by comparing soils of volcanic-metamorphic-arkosic and volcanic-metamorphic parent materials to arkosic parent materials within the relatively constant climate/vegetation regime of the eastern San Joauin Valley. We might attribute some of these soil differences to volcanic influences if those same differences were found in the volcanic-arkosic versus arkosic comparison of the eastern Sierra Nevada. Finally, volcanic soils of the foothills are compared to volcanic-metamorphic soils of the foothills to observe another parent material effect. These comparisons allow us to isolate the effects of climate and parent material on soil development and to identify factors responsible for the strong development of the foothills soils.

Table 5 presents selected data from several published and unpublished sources. In most cases large numbers of samples have been analyzed and standard deviation represents laboratory and soil variability. In some cases, however, the number of samples is small. These data, almost exclusively iron oxide and clay mineralogy data, are still taken to represent soil trends.

The effects of two climates can be determined by comparing soils formed on Late Modesto arkosic alluvium in the San Joaquin Valley to soils formed on Tioga till and outwash along the eastern side of the Sierra Nevada. Both soils look quite similar in the field and display A/AC/Cox/Cn profiles.

Table 5 demonstrates the similarity of soil color, and clay mineralogy. Iron-oxide content and A horizon pH are slightly higher in the San Joaquin Valley. Negative percent clay (less than 2 micron) change from A to B horizon probably represents the fining upward alluvial sequence or eolian additions of clay to the surface.

To examine the effects of volcanic parent material relative to arkosic parent material, soils of arkosic and arkosic-volcanic parent materials of the eastern Sierra Nevada are compared. Both of these soils have A/AC/Cox/Cn profiles. Data in table 5 show that soils developed on volcanic parent material, however, are more acidic in the A horizon, redder, slightly brighter, and more iron-rich. The differences in color and iron oxide could be due to higher initial iron content of andesitic parent materials or to greater weatherability of andesite because of its higher base content. Greater A horizon acidity in the andesitic soils could be due to greater organic acid content. Information on the amount of organic matter and on total chemistry of parent materials would aid interpretation. The data suggest that clay buildup in soils formed from andesitic parent matrials may be greater than for arkosic parent materials. There is a marked increase in percent clay change from A to B horizons, indicating incipient B horizon development in the volcanic soils. Clay data support the hypothesis than andesitic materials are less resistant to weathering. Whereas illite and kaolinite are dominant in arkosic-derived soils, smectite and vermiculite are significant clays in the presence of volcanics. The greater amounts of bases (i.e. calcium and potassium) in andesite probably accounts for the presence of these clays. It is evident from this comparison that the influence of andesitic parent material is significant in these relatively young soils. Although both soils are equivalent in age, the color, iron oxides and acidity of the soils formed from andesitic parent materials represent a slightly greater degree of development than observed in arkosic soils from the same area.

Within the eastern San Joaquin Valley, soils are formed on parent materials of arkosic, arkosic-volcanic-metamorphic, and volcanic-metamorphic detritus. Again, climate is similar for these soils and soil differences can be attributed to differences in parent material. The volcanic detritus of these parent materials is andesitic; metamorphic components include quartzite, slate, schist, and greenstone. Both soils of arkosic-volcanic-metamorphic and soils of volcanic-metamorphic parent material have cambic or weak argillic B horizons; they are redder, brighter, and more acid in the A horizon than soils of arkosic materials and horizon differentiation of clay is greater. Soils of arkosic-volcanic-metamorphic materials have properties intermediate in value between soils of arkosic and soils of volcanic-metamorphic materials. Clay mineralogy becomes dominated by smectites over vermiculite and kaolinite as the parent material becomes dominated by volcanic and metamorphic detritus and the arkosic component decreases. In the eastern Sierra Nevada soils, we found that volcanic influence caused soils to be redder, slightly brighter, richer in iron, more acidic in A horizons, better developed in terms of clay increase, and characterized by abundant, smectite and vermiculite clays. Therefore, in the San Joaquin Valley we might attribute much of the soil differences to the influence of the volcanics. However, the contrast in clay percentage between arkosic and volcanic-metamorphic-derived soils is considerable, whereas the clay contents of arkosic and arkosic-volcanic-derived soils in the Sierra Nevada differ only slightly. Therefore, one might infer that clay content is enhanced by the presence of metamorphic rocks, perhaps by metavolcanic rocks.

One more comparison of parent materials can be made by contrasting soils derived from metavolcanic rock with soils of volcanic parent materials in the foothills. Table 5 indicates that these soils are quite similar. Limited data suggest the metavolcanic rocks produce soils that are slightly brighter, more iron rich and less acid, but the lack of replication and the overlap of values complicates interpretation. Percent clay change from A to B horizons is greater in soils from metavolcanic materials but amounts of clay are actually less. Replication is good for the clay data, so these differences might be significant.

Soils of the foothills have been noted for their bright-red colors and high clay contents. Table 5 also demonstrates they are high in iron oxides and have considerable amounts of smectite and kaolinite clays. Their development, compared to soils of similar age especially to those of arkosic materials, is strong. A closer examination of the data, using information from previous comparisons, attempts to isolate the factors responsible for their development.

Many parent materials of the foothills appear to have been reworked from pre-existing soils, as discussed earlier in this paper. Soil colors and amounts of iron and clay can be substantial at the start of soil formation. Therefore, when comparing soils of the foothills to soils of other areas, one must use the data cautiously. However percent clay change should represent in situ soil development because soil formation will differentiate horizons in a previously uniform deposit.

When foothills soils of volcanic materials are compared to San Joaquin Valley soils of volcanic-metamorphic material, the color, pH, and amount of clay are quite similar. However, iron oxide content and percent clay change are significantly greater in the foothills soils. In comparison to soils of arkosic materials, one might attribute the bright-red color and clay mineralogy of foothills soils mainly to volcanic influences, because volcanic rocks significantly affected color in previous comparisons. Their high iron content can be attributed to volcanic rocks, to reworking of pre-existing old soils, and/or to climate, because we found that iron oxides were responsive to all of these factors. Percent clay change is strikingly large in the foothills soils, even in eroded profiles. Climate and parent material differences,taken by themselves, affected this property to a much lesser extent in isolated comparisons. We conclude that the combined influence of parent material and climate is responsible for this noticeable difference in clay development.

In summary, we find that (1) andesitic volcanic materials significantly promote rates of soil development (2) mixed metamorphic materials and to a lesser extent metavolcanic materials affect clay content and field morphology, but not other properties noted; (3) foothills soils, although similar in some respects to San Joaquin Valley soils of volcanic-metamorphic parent materials, are more strongly developed due to differences in both climate and parent material; 4) climatic contrasts between these areas affects iron-oxide content, pH, and to some extent clay content and clay change.

Summary

We have described and informally named a sequence of Quaternary colluvial and alluvial deposits in the western foothills of the Sierra Nevada, building upon the earlier work of Page, Swan, and Hanson. The stratigraphic units of this sequence are recognizable from superpositional sequence, from the morphology of relict and buried soils formed on each unit, and from geomorphic relations of stream terraces.

A strikingly similar sequence of colluvial and nonglacial alluvial deposits along the eastern margin of the northeastern San Joaquin Valley is also described. These deposits can be correlated with well dated outwash deposits emerging from several large, glaciated Sierra Nevada drainage basins. The foothill and eastern San Joaquin Valley colluvial-alluvial sequences can be correlated on the basis of available radiocarbon dates, soil formation, and, in the case of two units, physical continuity between deposits and soils in the foothills and the San Joaquin Valley.

Widespread colluviation and nonglacial alluviation in both areas is shown to be episodic and probably related to Quaternary climatic and vegetational changes. Radiometric and stratigraphic evidence indicate that periods of colluviation and alluviation probably occurred during rapid glacial-to-interglacial climatic transformations. The last widespread colluvial-alluvial event occurred about 9,000 years ago, following glacial outwash deposition in the San Joaquin Valley and prior to Holocene sea level rise in the Sacramento-San Joaquin Delta.

Quantitative physical, chemical, and mineralogical properties can be used to distinguish the relict and buried soils formed on different ages of deposits in the foothills. Some soil properties such as clay content, bulk density, clay mineralogy, cation exchange capacity, and dithionite-extractable iron (in oxidized horizons) are not severely affected by burial and indicate progressive trends with soil age. Other properties such as pH, exchangable cations, and phosphorus change rapidly following burial and appear to be useful time indices only for relict soils. Buried clay-rich B horizons may act as 'sinks' for cations, phosphorus, and other mobile but exchangeable constituents leached from overlying profiles.

Soils in the Sierra Nevada foothills acquire the characteristics of old soils more rapidly than do soils of similar age in the San Joaquin Valley and along the eastern escarpment of the Sierra Nevada. Much of the color and clay content of Quaternary foothill soils is inherited from pre-existing residual soils. Horizon ratios of several properties indicate somewhat faster soil development in the foothills compared with areas to the east and west, independent of parent material. This higher rate of soil formation is probably attributable to a combination and possibly the interaction of greater precipitation and soil moisture, vegetative differences and parent material differences. Soils formed on volcanic or metavolcanic parent materials throughout the region appear to form more rapidly than do soils of the same age on arkosic parent materials.

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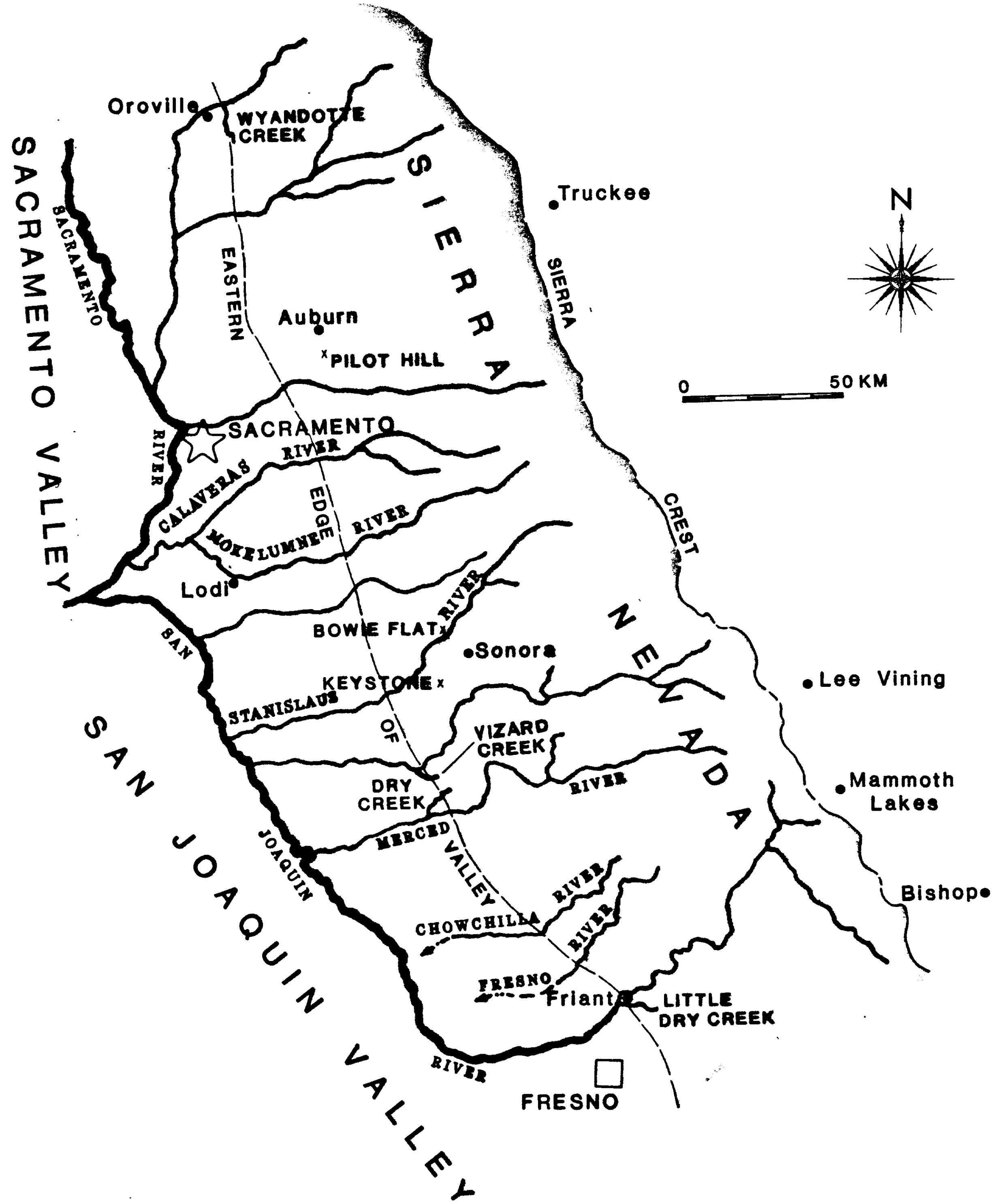


Figure 1. Index map showing locations referred to in text, figures, and tables.

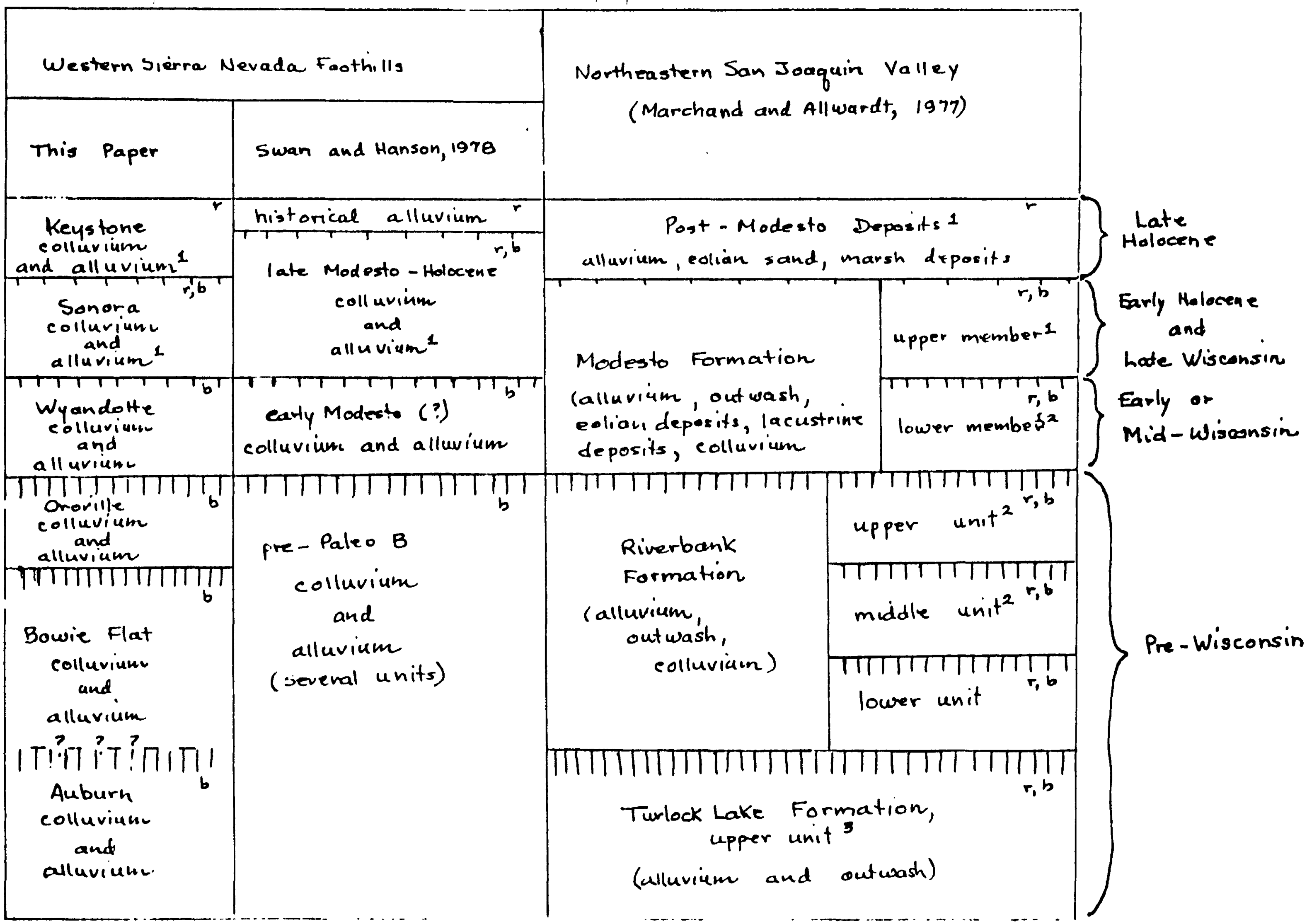
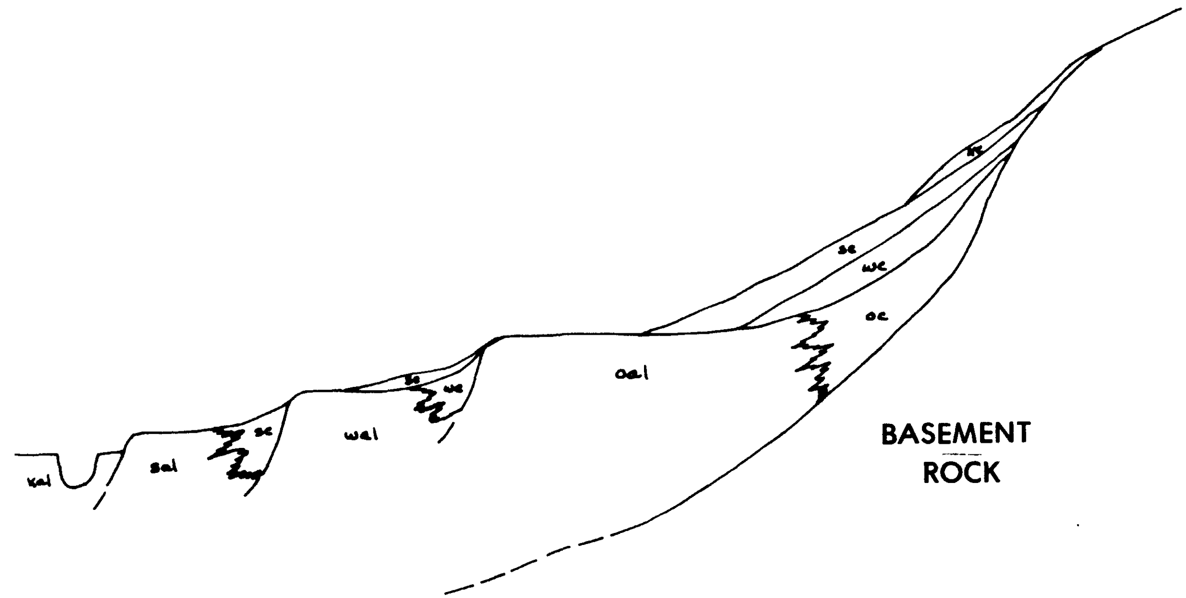


Figure 2. Proposed sequence of informally-named stratigraphic units, western Sierra Nevada foothills and correlation with units of Swan and Hanson, 1978 and with units in the northeastern San Joaquin Valley r = relict soil, b = buried soil. Length of vertical hachures indicate relative degree of soil profile development within the sequence.

1 = age based in part on radiocarbon dating
2 = age based in part on uranium trend dating by J. N. Rosholt (1978)
3 = age based in part on potassium-argon dating of associated volcanic deposits

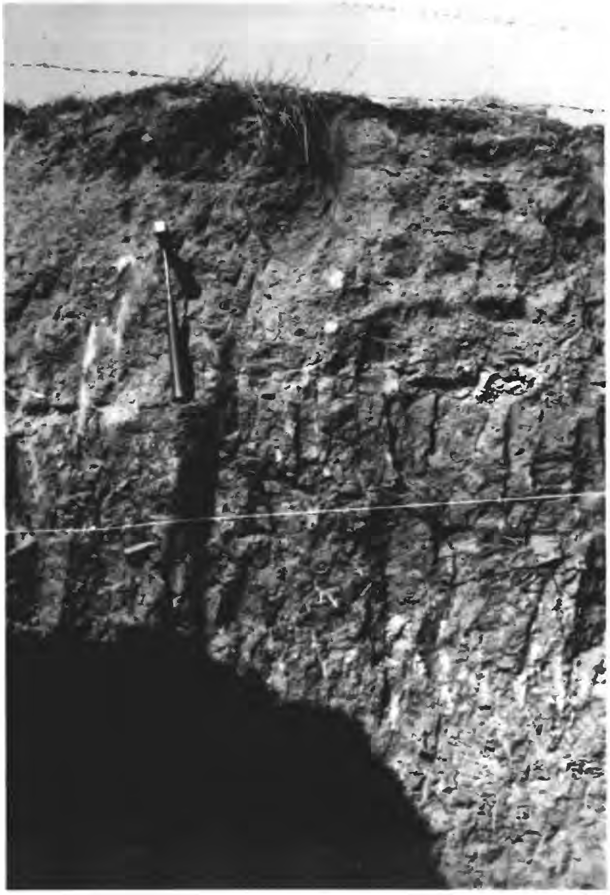


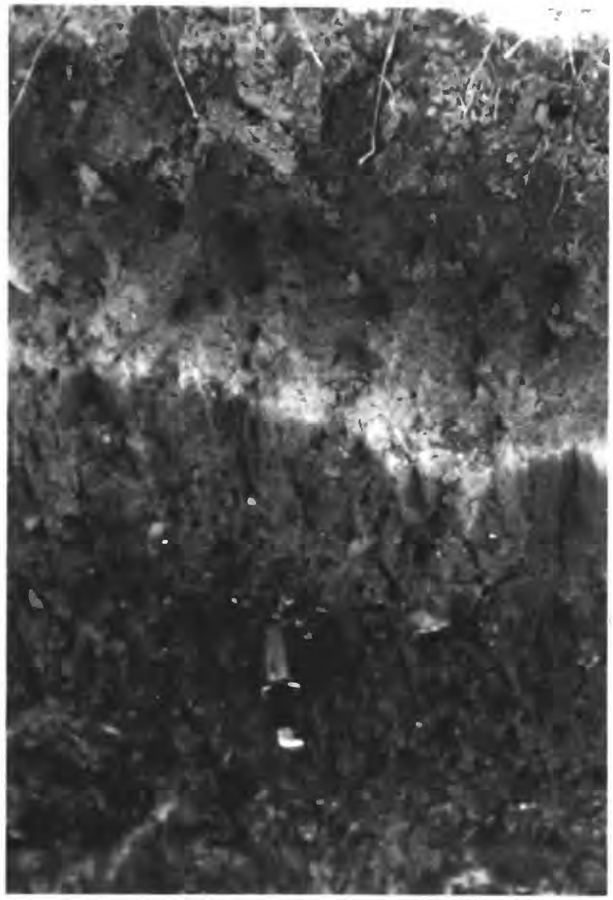
FOOTHILL SEQUENCE

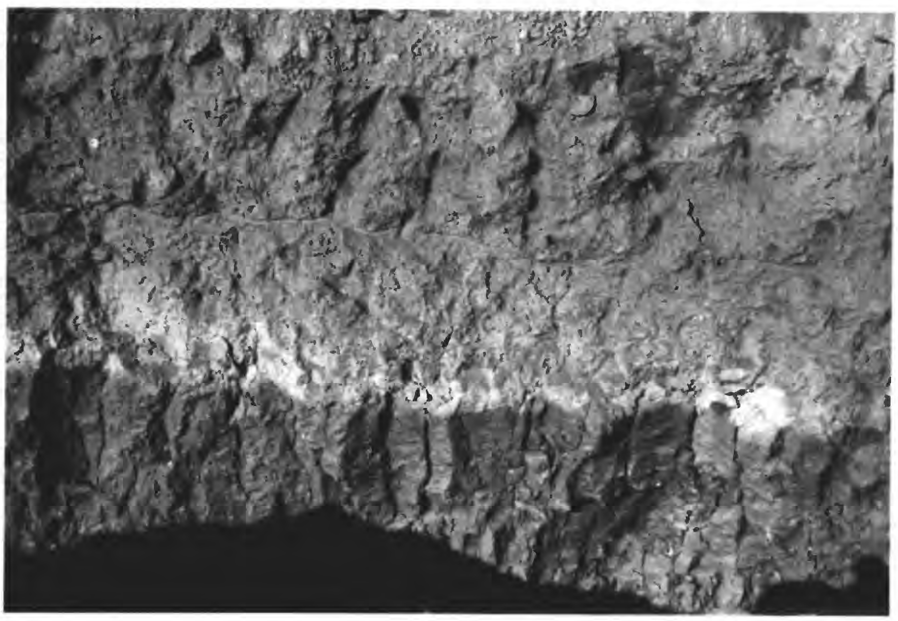
Alluvium	Colluvium	
kal	kc	Keystone (late Holocene)
sal	sc	Sonora (late Wisconsin or early Holocene)
wal	wc	Wyandotte (early or mid-Wisconsin?)
oal	oc	Oroville
bfal	bfc	Bowie Flat (Pre-Wisconsin)
aal	ac	Auburn

Figure 3. Schematic cross section showing relations between four of the six ages of foothills colluvium and alluvium. Section is based on surface and trench exposures in the valley of the west fork of Wyandotte Creek, east of Oroville. Spacing and length of hachures indicate relative degree of soil profile development.

Figure 9. Photograph of Sonora colluvium overlying Auburn alluvium, USBR trench ST 107, Auburn area.



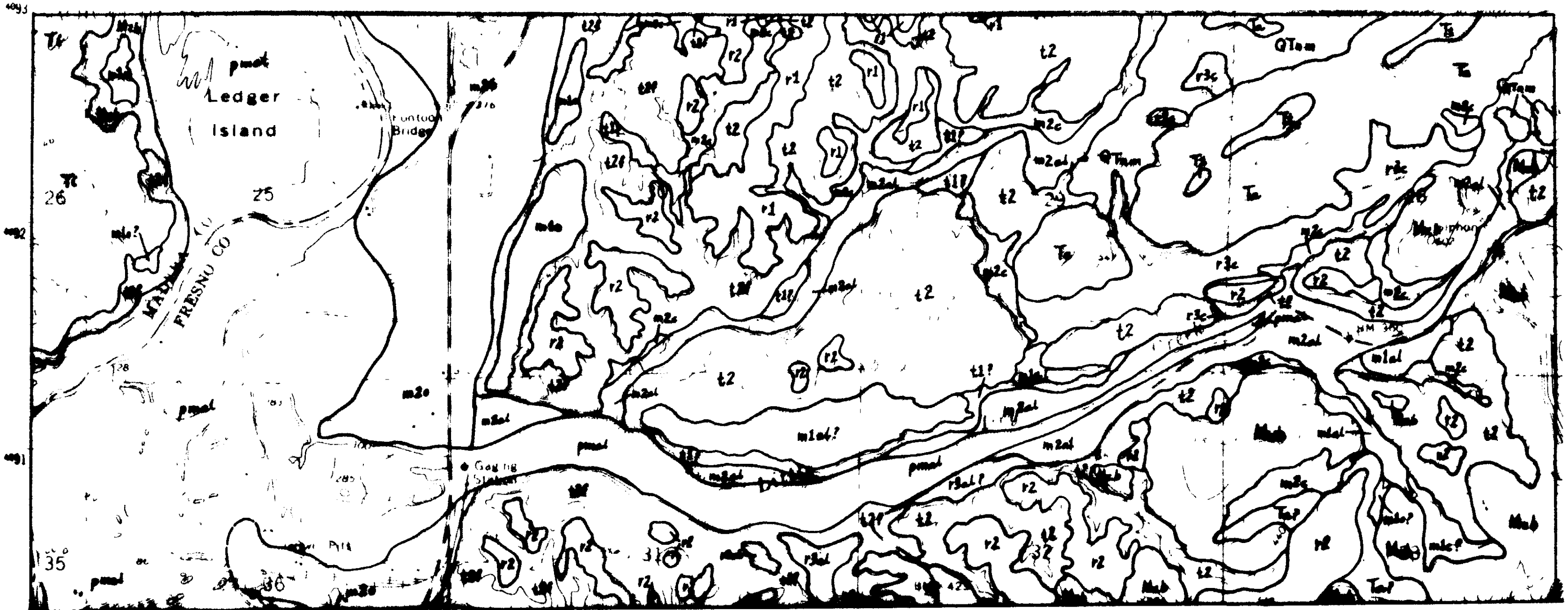




Figures 6, 7, 8. Photographs showing superposition of Sonora, Wyandotte, Oroville, and Bowie Flat units in Woodward-Clyde's Bowie Flat trench #7, Sonora area.

Figure 5. Photograph of Sonora colluvium overlying Mehrten conglomerate in USBR trench GT-1, Auburn area.

Figure 4. Photograph showing Late Modesto (upper member = Sonora) terrace along Little Dry Creek, Fresno County, incised and filled by post-Modesto (= Keystone) deposits. Swale in center (background) is underlain by colluvium that grades into the terrace alluvium. Both colluvium and alluvium bear soils mapped as the Visalia series (Huntington, 1971).



Alluvium	Colluvium	Outwash	
pmal	pmc		**Post Modesto**
m2al	m2c	m2o	**late Modesto**
m1al	m1c	m1o	**early Modesto**
r3al	r3c	r3o	**late Riverbank**
r2al	r2c	r2o	**middle Riverbank**
		r1o	**early Riverbank**
		t2	**upper Turlock Lake**
		t1	**lower Turlock Lake**
	QTnm		**North Merced Gravel**

Figure 10. Geologic map depicting relations between colluvial and alluvial deposits along the lower reaches of Little Dry Creek, near its confluence with the San Joaquin River, Fresno County.

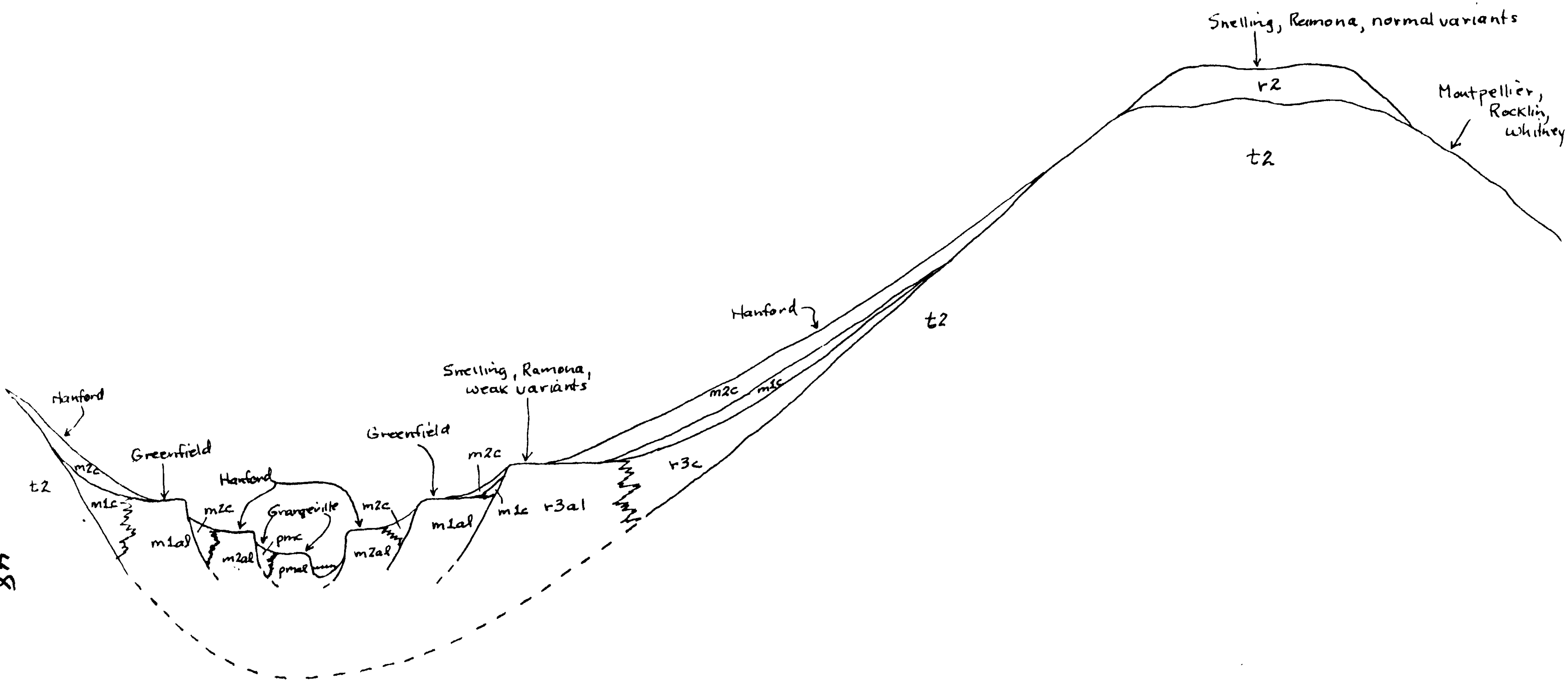


Figure 11. Schematic cross section showing relations between colluvium and alluvium along secondary drainages tributary to the major westward flowing rivers. Characteristic soil series are shown by arrows. Diagram is for terrain underlain by arkosic Turlock Lake Formation. Soil series would be different in terrain underlain by other lithologies but stratigraphic and geomorphic relations would remain unchanged. pm = Post-Modesto; m2 = Modesto Formation, upper member; m1 = Modesto Formation, lower member; r3 = Riverbank Formation, upper unit; t2 = Turlock Lake Formation, upper unit; al = alluvium, c = colluvium.

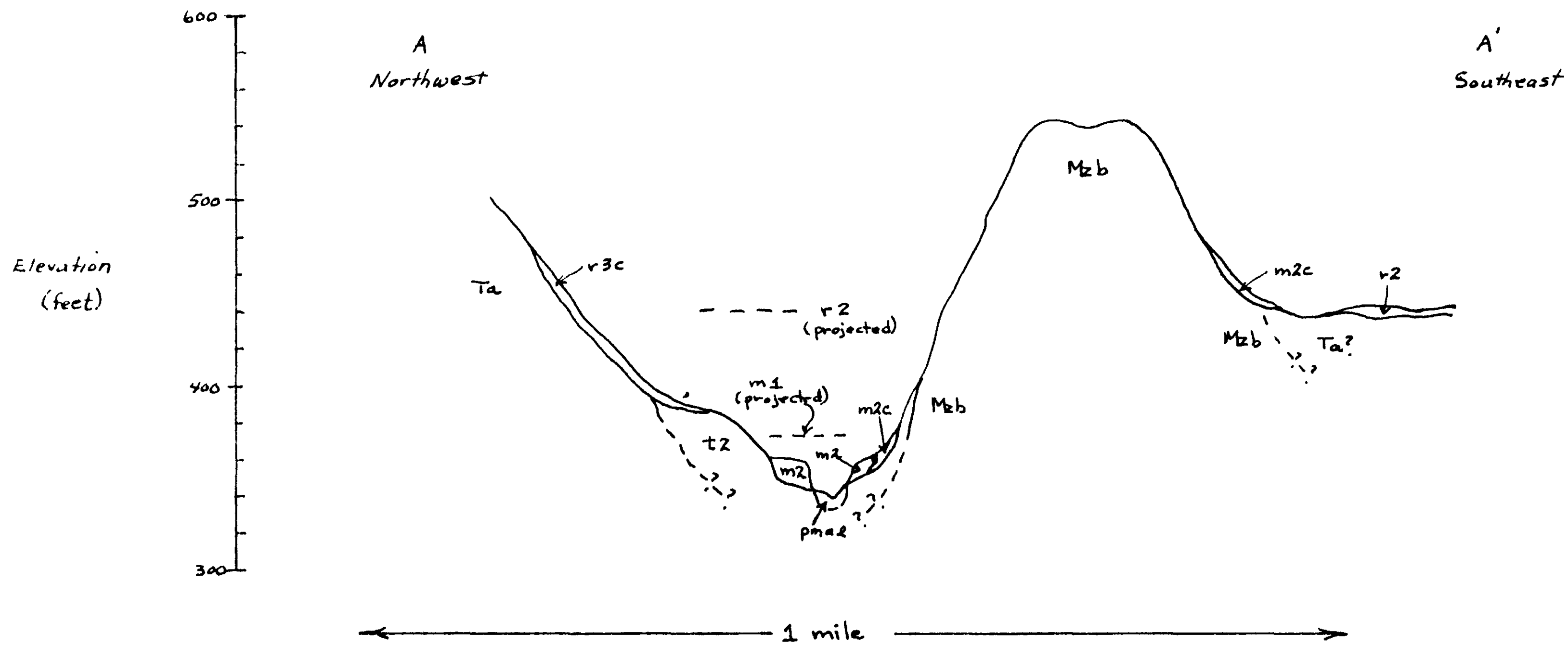


Figure 12. Geologic section across Little Dry Creek within area of figure 10, showing relation of mZc and r3c surfaces and deposits to alluvial terraces graded to San Joaquin River outwash terraces.

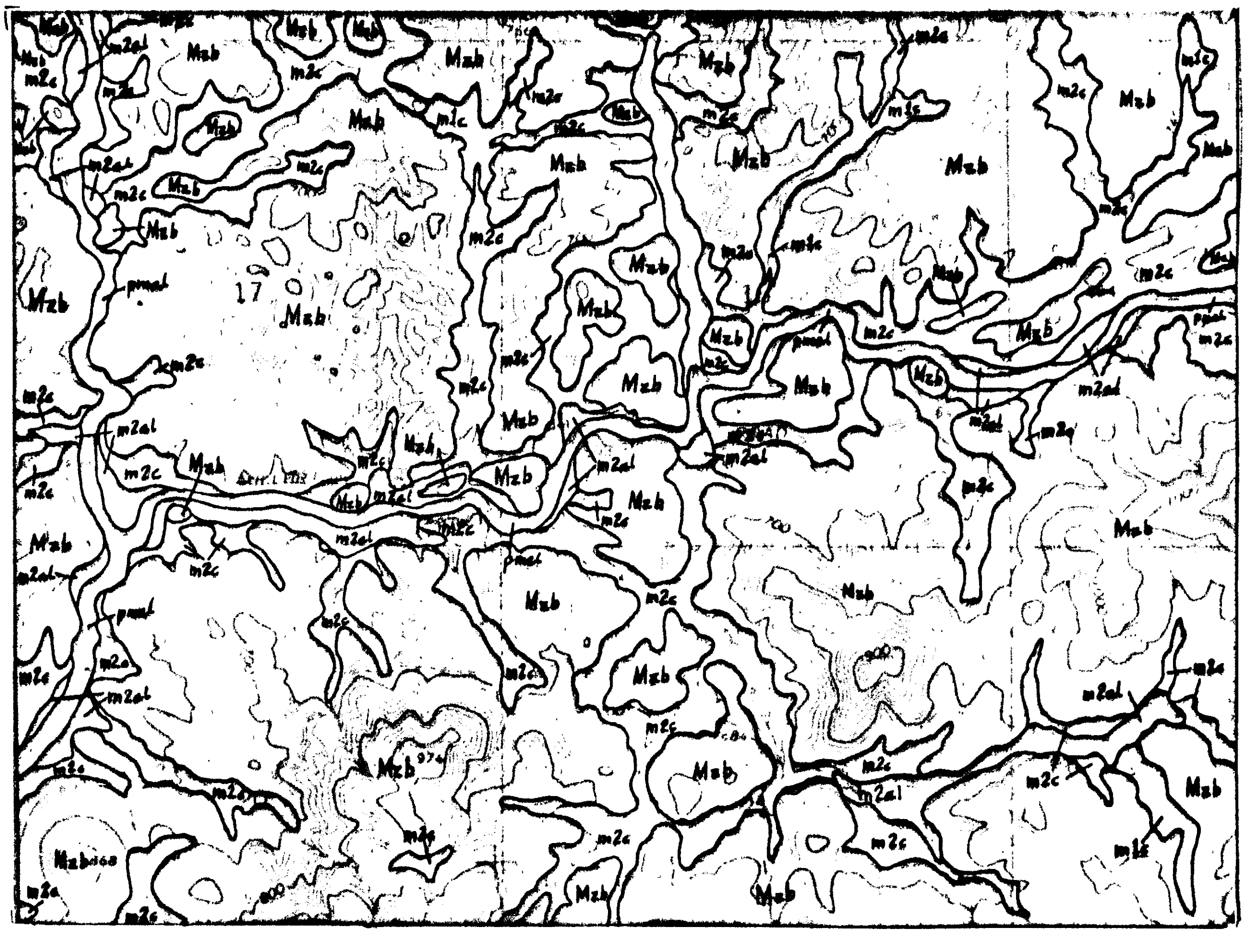


Figure 13. Geologic map depicting relations between colluvium and alluvium in the foothills east of Friant, Fresno County. See fig. 10 for explanation of units.

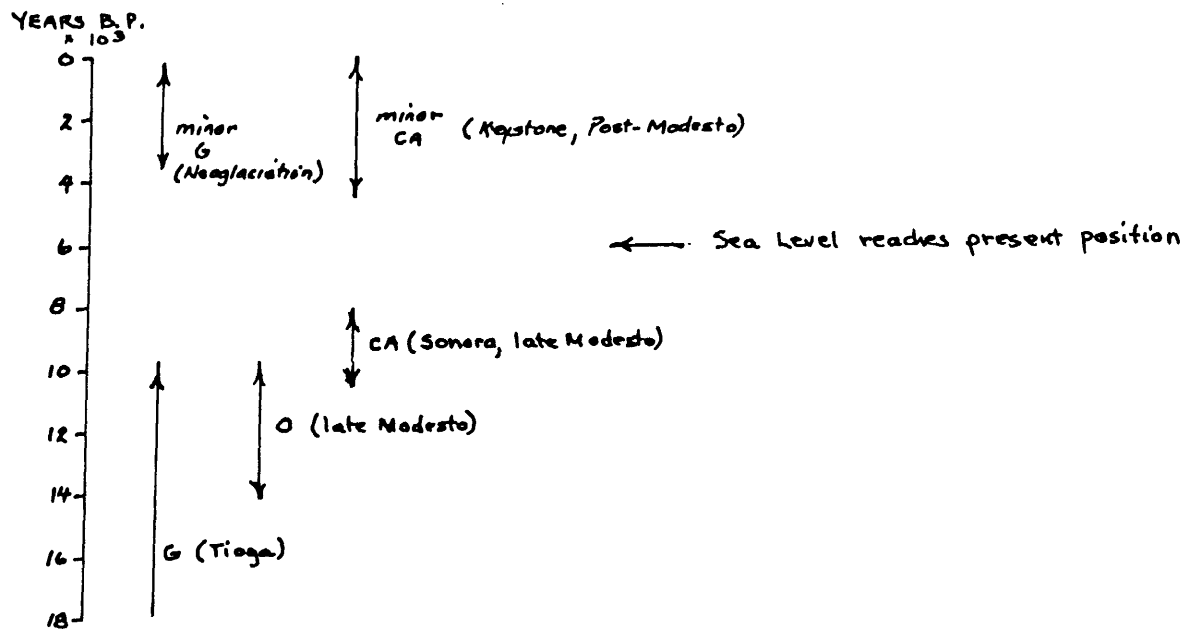


Figure 14. Probable time relations between glacial outwash, colluvial, alluvial, and eustatic sea level events during the late Wisconsin and Holocene, Sierra Nevada and Central Valley.

G = glaciation in Sierra Nevada
O = outwash deposition in eastern San Joaquin Valley
CA = colluviation and alluviation in Sierra Nevada foothills and eastern San Joaquin Valley

Table 1. Explanation of U.S.G.S. soil samples from three areas (Auburn, Sonora, Oroville) in the [illegible]

Sample ID	Soil Horizon	Depth (cm)	Geologic Unit	Location
FA-1	A	0-30	Sonora	U.S.B.R. trench BHT-53, South Wall
FA-1	B1	30-50	"	"
FA-1	B21t	50-65	"	"
FA-1	B22t	65-80	"	"
FA-1	IIBtb	~55	Pre-Sonora infilling	U.S.B.R. trench BHT-53, South Wall (right side of fault)
FA-1-L	IIB1b	105-116	Pre-Sonora infilling	U.S.B.R. trench BHT-53, left side of fault
FA-1-L	IIB2b	116-127	"	" " "
FA-2, unit 1	A	10-30	Wyandotte?	WCC Spenceville trench #1, North Wall
FA-2, unit 2	B2g	30-65	"	" "
FA-2, unit 3	B3g	65+	"	" "
FA-3	Btb	not recorded	Wyandotte?	WCC Spenceville trench #4, South Wall
FA-4	IIBtb (in shear zone)	not recorded	Oroville?	WCC trench across Rescue Lineament South Wall
FA-5	IIB21tb	110-140	Wyandotte	U.S.B.R. trench BHT-86-1, North Wall (Railhead)
FA-6	IIIB2tb	153-175	Oroville (residual soil)	U.S.B.R. trench BHT-86-2, North Wall (Railhead)
FA-7	A	0-40	Sonora	U.S.B.R. trench ST-107, South Wall
	B	40-107	"	" " "
FA-7	IIB22tb	107-172	Auburn	U.S.B.R. trench ST-107, South Wall
	IIB23tb	172-220	"	" " "
	IIB24tb	220+	"	" " "
FA-8	IIB2tb	not recorded	Oroville??	U.S.B.R. trench ST-65, South Wall
FS-1, #2	AC	not recorded	Sonora	WCC trench Price #1
FS-1, #1	IIBb	not recorded	Wyandotte	WCC trench Price #1
FS-1, #3	IIIB2tb	not recorded	Oroville	WCC trench Price #1
FS-1, #4	IVB2tb	not recorded	Bowie Flat	WCC trench Price #1
FS-2	A	0-31	Sonora	WCC trench Bowie Flat #7
FS-2	B	31-51	"	" "
FS-2	IIBtb	51-76	Wyandotte?	WCC trench Bowie Flat #7
FS-2	IIIB2tb	76-94	Oroville	WCC trench Bowie Flat #7
FS-2	IIIB2tb (red phase)	76-94	"	" "
FS-2	IIIB3b	94-104	"	" "
FS-2	IVB2b	104-119	Bowie Flat	WCC trench Bowie Flat #7
FO-1	B	not recorded	Sonora	DWR trench #12
FO-2	IIBtb	not recorded	Wyandotte	DWR trench #15
FO-2	IIIBtb	not recorded	Oroville (residual soil)	DWR trench #15
FO-3	Ap	0-25	Sonora	DWR trench #17
"	B2t	25-70	"	"
"	B3	70-80	"	"
"	Cg	80+	"	"
FO-4	Ap	0-20	Sonora	DWR trench #8
"	B21t	20-60	"	"
FO-4	IIB22tb	not recorded	Wyandotte	DWR trench #8
"	IIB23tb	" "	"	"

FA = Auburn area FS = Sonora area FO = Oroville area

For trend locations see Frei and others (1978) (Auburn area), California Department of Water Resources Bulletin 203 (Oroville area), Woodward-Clyde Consultants, 1979 (Sonora area), and Biggar, 1978.

Table 2.--Comparison of some of the more diagnostic properties for soils formed on colluvium of five informally designated geologic units.

Geologic Unit:	Sonora[3] (relict soil)			Wyandotte[3] (under Sonora)			Oroville[1] (under Wyandotte)+			Oroville[2] (under Sonora)+			Bowie Flat[1] (under Oroville)			Auburn[1] (under Sonora)	
Soil Property	$\bar{x}$	σ	N	$\bar{x}$	σ	N	$\bar{x}$	σ	N	$\bar{x}$	σ	N	$\bar{x}$	σ	N	$\bar{x}$	N
% <2μ clay max.	22.2	5.9	19	37.3	6.5	9	40.8	9.4	4	58.6	5.4	10	52.4	11.0	2	41.2	1
% <1μ clay max.	15.9	7.3	6	32.0	8.3	6	35.6	10.7	4				46.7	13.1	2	38.4	1
(sand/silt)(max.<2μ clay), $\bar{x}$	14.1	5.1	6	30.0	10.5	6	39.3	25.9	4				42.7	20.1	2	46.3	1
" 1 "	10.1	5.3	6	23.6	9.2	6	34.8	25.7	4				38.4	20.5	2	43.1	1
B horizon Bulk Density, $\bar{x}$	1.61	0.19	3	1.84	0.04	4	1.89	0.19	3				2.03	0.13	2		
Cation Exchange, $\bar{x}$ Capacity	25.4	8.9	14	38.7	6.8	10	40.2	9.6	4	53.7	13.5	14	47.5	10.3	2	22.2	1
Dithionite Extr. Iron, $\bar{x}$	2.2	0.5	5	2.7	0.8	3	3.1		1							4.5	1
% organic C in B or C, min.	0.41	0.11	5	0.32	0.20	3	0.19	0.09	2							0.14	1
Smectite, %	13	12	10	18	10	7				2.5	18	13					
Illite, %	1.2	1.2	10	1.4	2	7				0.9	1.0	13					
Kaolinite, %	13	10	10	8.2	8.5	7				12	13	13					
Chlorite, %	3.5	3.2	10	3.9	5.4	7				2.4	2.6	13					
Vermiculite-Chlorite, %	0.5	1	10	2.1	2.7	7				2.6	4.1	13					
Vermiculite, %	0	0	10	2.1	2.7	7				4.5	6.8	13					
Thin Section Classification[4]	1.8	1.0	7(N)	5		1(N)	4		1(N)							6	1(N)
				4.6?	1.1	5(V)	5.8	1.0	4(V)				5.5	0.7	2(V)		

N = No. of soil profiles
\+ Some soil profiles in this group are residual on bedrock
1 Source: U.S.G.S. data
2 Source: WCC, 1978, Tables C-1, D-1, Figs. A-15 to A-32.
3 Source: U.S.G.S. and WCC data
4 Two informal sequences of relative development from 0 (least developed) to 7 (most developed): N = normal sequence, v = sequence in vertisolic samples (abundant swelling clays)

SONORA SOILS

		B MINUS A	PERCENTAGE CHANGE:
<2u CLAY			
	$\bar{X}$	5.06	26
	RANGE	0,6 TO 10.6	3 TO 58
<1u CLAY			
	$\bar{X}$	5.98	26
	RANGE	0 TO 8.6	0 TO 53
FREE IRON			
	$\bar{X}$	0.22	9
	RANGE	0.1 TO 0.4	2 TO 21
pH			
	$\bar{X}$	0.32	5
	RANGE	0.1 TO 0.5	2 TO 11
ORGANIC CARBON		(A MINUS B)	
	$\bar{X}$	0.82	99
	RANGE	0.53 TO 1.02	76 TO 127

Table 3. Contrasts between A and B horizons for five relict soil profiles formed on Sonora colluvium.

Analysis	Post-Sonora surface soil[1]		Buried soil, right side of fault[2]	Buried soil, left side of fault[3]	
	$\bar{x}$	σ		$\bar{x}$	σ
% Sand	31.0	1.2	25.3	16.1	1.6
% Silt	40.9	2.4	25.3	18.6	1.5
% <2 μ clay	28.1	2.3	49.4	65.4	0.1
% <1 μ clay	21.5	2.9	45.0	61.3	0.0
% Very coarse sand	2.5	0.2	4.2	1.1	1.1
% Coarse sand	5.6	0.7	5.2	3.0	0.6
% Medium sand	3.9	0.4	2.9	2.2	0.2
% Fine sand	9.9	0.5	7.3	5.2	0.1
% Very fine sand	9.0	0.3	5.7	4.5	0.4
pH	5.8	0.1	5.6	5.0	0.0
% Iron oxides (Dithionite)	2.1	0.2	1.1	0.61	0.01
Cation Exchange Capacity (meq/100g)	27.0	1.8	33.8	42.1	1.3
Extractable Calcium (meq/100g)	12.8	0.7	18.4	26.7	1.9
Extractable Magnesium (meq/100g)	3.1	0.4	6.0	10.5	0.7
Extractable Potassium (meq/100g)	0.51	0.06	0.40	0.23	0.01
Extractable Sodium (meq/100g)	0.10	0.02	0.18	0.31	0.04
Fe Phosphorus	98.0	43.0	16.8	6.3	2.5
Ca Phosphorus	79.0	18.0	6.0	8.7	0.9

Table 4. Summary of soil data for sample group FA-1, U.S.B.R. trench BHT-53, Auburn area, analyses by R. Meixner under the direction of M. J. Singer, University of California at Davis.

	SONORA		LATE MODESTO			TIOGA	
	FOOTHILLS (metavolcanic)[1,2]	FOOTHILLS (volcanic)[1,2]	SAN JOAQUIN VALLEY (volcanic, metamorphic)[3,4,5]	SAN JOAQUIN VALLEY (arkosic with some volcanic, metamorphic)[3,4]	SAN JOAQUIN VALLEY (arkosic)[3,4,6]	EASTERN SIERRA NEVADA (arkosic with some volcanic)[2,7,8,9,10]	EASTERN SIERRA NEVADA (arkosic)[7,10]
Reddest Hue[b]	5 YR (20)	5 YR (6)	5 YR to 10 YR <u>7.5 YR</u>[a] (7)	7.5 YR - <u>10 YR</u>[a] (12)	10 YR (19)	7.5 YR - 10 YR (6)	10 YR (4)
Highest Chroma[b]	4-6 (20)	4 (6)	3-6 <u>4</u>[a] (8)	<u>3</u>-4[a] (12)	<u>3</u>-4[a] (19)	3-4 (6)	<u>3</u>-4[a] (4)
Maximum Dithionite Iron[b]	2.21 ± 0.60 (4)	2.05 (1)	1.09 (1)	0.61 (1)	0.91 (1)	1.1 ± 0.1 (3)	0.36? (1)
Minimum A Horizon pH (1:1 or satn)	6.1 ± 0.5 (5)	5.7 (1)	6.3 ± 0.6 (8)	6.6 ± 0.4 (7)	6.7 ± 0.5 (7)	5.9 ± 0.2 (3)	6.2 ± 0.6 (4)
Maximum < 2 micron clay[b]	21.6 ± 6.8 (13)	26.4 ± 6.0 (5)	26.4 ± 6.2 (6)	13.9 ± 5.1 (5)	9.4 ± 3.4 (12)	5.0 ± 2.4 (4)	4.7 ± 0.9 (4)
% A to B[c] Horizon Clay Change	46.1 ± 18.7 (11)	41.7 ± 16.6 (4)	14 ± 16 (6)	44 ± 55 (5)	-10 ± 20 (11)	15 ± 56 (4)	-10 ± 12 (4)
Dominant Clay Minerals[b,d]	S ≈ KH (3)	S ≈ KH (1)	S > KH,V (1)	S ≈ KH ≈ M (1)	I > KH > M (2)	S,V ≈ I,KH (9)	I > KH (8)

Table 5. Comparison of some properties of soils about 9,000 to 10,000 years old in central California. Number of soil profiles upon which mean values are based is given in parentheses. Value following ± symbol is one standard deviation. Sources of information:

1. This paper
2. Swan, Hansen, and Page, 1977
3. Unpublished U.S.G.S. data
4. Published soil survey, eastern San Joaquin Valley (eastern Fresno, Madera, Merced, eastern Stanislaus, San Joaquin, Stockton, Lodi areas)
5. Unpublished data supplied by R. J. Arkley
6. Harden and Marchand (1977)
7. Burke and Birkeland (1979)
8. Alexander (1974)
9. Birkeland (1964 and oral commun., 1979)
10. Birkeland and Janda (1971)

[a] Underlined value is most typical

[b] For horizon in B position

[c] $\% \text{ change} = \dfrac{\% \text{ in B} - \% \text{ in A}}{\text{avg. \% of A and B}}$

[d] S = smectite
KH = kaolinite and/or halloysite
M = mixed layer
I = illite (mica)
V = vermiculite

Appendix I. Particle size distribution for foothill soil samples. FA = Auburn area, FS = Sonora area, FO = Oroville area.

Sample	total sand (%)	silt (%)	<2 μm clay (%)	<1 μm clay (%)*	VCS (%)	CS (%)	MS(%)	FS(%)	VFS(%)
FA-1 A	30.9	44.3	24.8	17.3	2.3	5.5	3.7	10.6	8.8
FA-1 B1	30.5	40.5	29.0	21.6	2.4	5.2	3.9	9.6	9.4
FA-1 B21	29.9	40.2	29.9	23.6	2.6	5.2	3.6	9.4	9.0
FA-1 B22	32.7	38.6	28.7	23.4	2.8	6.6	4.5	9.8	8.9
FA-1 IIBb	25.3	25.3	49.4	45.0	4.2	5.2	2.9	7.3	5.7
FA-1-L IIB1b	17.2	17.5	65.3	61.3	1.9	3.4	2.4	5.2	4.2
FA-1-L IIB2b	14.9	19.6	65.5	61.3	0.3	2.6	2.1	5.1	4.7
FA-5 IIB2t	11.2	41.1	47.7	42.9	1.6	2.0	1.1	2.6	3.8
FA-6 IIB2tb	21.8	36.5	41.7	35.8	3.8	4.2	1.9	5.1	6.7
FA-7 A	23.6	59.1	17.3	11.6	2.8	3.7	2.4	6.2	8.5
FA 7 B	21.5	53.3	25.2	20.0	1.8	2.9	2.6	6.3	8.0
FA-7 IIB22tb	26.2	36.8	37.0	34.4	1.5	5.7	3.5	7.3	8.0
FA-7 IIB23tb	31.1	27.7	41.2	38.4	1.8	6.8	4.6	8.9	9.1
FA-7 IIB24tb	28.1	44.4	27.5	25.5	1.6	5.2	3.7	8.0	9.5
FA-8 IIB2t	21.9	41.5	36.6	33.0	1.3	3.5	4.8	7.1	5.3
FA-2 unit 1	26.0	37.7	36.3	29.2	6.3	5.4	2.6	6.0	5.8
FA-2 unit 2	21.8	38.4	39.8	31.9	4.2	3.8	2.0	5.2	6.5
FA-2 unit 3	19.7	43.2	37.1	35.6	3.9	3.1	1.9	4.9	5.9
FA-3 Bt	29.1	31.8	39.1	21.8	6.6	6.3	3.6	6.6	6.0
FS-1 #1	29.7	30.0	40.3	34.8	7.0	7.2	3.1	6.5	5.9
FS-1 #2	33.4	43.7	22.9	19.1	4.9	7.6	7.0	8.8	5.1
FS-1 #3	28.0	19.0	53.0	49.7	10.5	6.7	2.7	4.2	3.9
FS-1 #4	19.4	20.5	60.1	55.9	3.4	4.6	2.3	4.6	4.6
FS-2 A	36.7	46.2	17.1	10.8	5.6	6.6	3.7	9.5	11.3
FS-2 B	37.2	45.1	17.7	11.4	5.6	6.5	3.9	9.3	11.9
FS-2 IIBb	37.7	45.1	17.2	11.0	6.6	6.0	3.8	9.4	11.9
FS-2 IIIB2b	25.2	36.8	38.0	33.0	2.8	3.5	2.4	7.1	9.3
FS-2 IIIB2b (red phase)	33.0	35.0	32.0	27.1	5.2	5.9	3.0	8.1	10.9
FS-2 IIIB3b	42.8	30.8	26.4	20.7	12.1	10.7	4.4	8.0	7.6
FS-2 IVBb	21.6	33.8	44.6	37.4	2.7	3.2	2.0	6.3	7.4
FO-2 B2tb (ml?)	35.2	34.8	30.0	22.7	1.7	5.3	5.5	12.7	10.0
FO-2 B2tb (beneath ml)	33.3	36.2	30.5	23.8	1.9	7.0	5.3	10.7	8.4
FO-3 Ap	28.6	58.4	13.0	9.3	4.4	5.8	3.3	6.8	8.2
FO-3 B2t	24.5	51.9	23.6	17.9	3.2	4.8	2.7	6.2	7.5
FO-3 B3	29.5	50.8	19.6	14.8	4.4	6.1	3.6	6.9	8.6
FO-3 Cg	34.0	44.6	21.4	16.0	5.4	7.8	4.3	8.7	7.8
FO-4 Ap	46.3	43.9	9.6	3.4	8.4	9.1	6.3	11.4	11.2
FO-4 B21t	40.8	48.5	10.7	3.2	5.1	8.5	5.9	11.0	10.3
FO-4 IIB22t	27.7	30.3	42.0	37.6	3.5	5.6	3.8	7.8	6.9
FO-4 IIB23	35.8	37.3	26.9	23.8	8.3	10.4	4.0	6.5	6.6

*The amount of clay in the 2-1 μm fraction is determined by substracting the <1 μm from <2 μm percentages. The <2 μm fraction includes all clay smaller than 2 μm.

Appendix II. Selected characteristics of foothill soil samples. FA = Auburn area; FS = Sonora area; FO = Oroville area

Sample	pH 1:1 (H_2O)	Fe oxide (%)	CEC (meq/100 g)	Ca^{2+} (meq/100 g)	Mg^{2+}	K^+	Na^+	organic carbon(%)	gravel free* bulk density (g/cm)
FA-1 A	5.8	2.1	29.6	13.5	2.7	.46	.09	1.31	
FA-1 B1	5.7	2.2	25.9	11.9	3.1	.50	.11	.53	
FA-1 B21	5.8	2.1	26.0	13.0	3.0	.47	.09	.41	
FA-1 B22	5.9	1.8	26.5	12.9	3.6	.59	.12	.37	
FA-1 IIBb	5.6	1.1	33.8	18.4	6.0	.40	.18	.52	
FA-1-LIIB1b	5.0	.61	43.0	25.3	10.0	.23	.28	.39	
FA-1-L IIB2b	5.0	.60	41.2	28.0	11.0	.22	.34	.21	
FA-5 IIB2t	5.2	2.3	46.6	15.7	17.0	.29	.47	.18	
FA-6 IIIB2tb	5.4	3.1	44.0	20.1	23.2	.24	.45	.12	
FA-7 A	5.7	4.1	19.4	6.3	2.4	1.0	.42	1.49	
FA-7 B	5.6	4.2	18.1	7.2	3.6	.56	.08	.47	
FA-7 IIB22tb	5.8	4.8	22.2	8.3	5.5	.32	.14	.19	
FA-7 IIB23tb	6.0	4.6	22.2	9.2	5.9	.19	.22	.19	
FA-7 IIB24tb	6.0	4.2	22.2	10.2	8.0	.10	.45	.14	
FA-8 IIB2t	5.6	.51	39.8	20.0	18.1	.17	.46	.13	
FA-2 unit 1	6.6	2.0	41.8	24.4	11.4	.11	.40	.83	1.69
FA-2 unit 2	7.5	1.6	42.2	27.1	15.9	.12	1.14	.23	1.86
FA-2 unit 3	7.4	1.4	46.7	30.4	17.3	.14	1.24		1.90
FA-3 Bt	7.4	2.2	42.3	31.7	7.7	.16	.72		1.81
FS-1 #1	6.9	3.6	31.4	3.0	15.3	.23	.10	.55	
FS-1 #2	7.0	2.7	25.8	6.6	11.0	.10	.11	1.09	
FS-1 #3	7.3	2.1	51.4	1.5	43.3	.21	.14	.25	1.67
FS-1 #4	7.8	1.2	54.8	1.1	36.3	.26	.20		1.93
FS-2 A	5.9	2.6	20.0	10.7	6.7	.09	.19	.92	1.68
FS-2 B	6.0	2.9	16.6	8.0	6.8	.05	.20	.39	1.74
FS-2 IIBb	6.2	2.2	17.9	6.9	7.6	.05	.19		1.69
FS-2 IIIB2b	6.4	1.9	31.2	8.3	21.8	.12	.39		2.00
FS-2 IIIB2b red phase	6.7	2.2	29.0	6.4	19.2	.11	.73		2.04
FS-2 IIIB3b	6.9	1.4	28.2	7.1	19.3	.10	.47		
FS-2 IVBb	7.9	.86	40.2	9.2	31.0	.12	.95		2.12
FO-2 B2tb (ml?)	6.2	1.5	38.3	20.2	19.6	.13	.32		1.87
FO-2 B2tb (beneath ml)	6.0	.68	35.7	30.0	3.9	.13	.50		1.99
FO-3 Ap	6.2	1.7	20.2	11.3	3.8	.22	.31	1.26	1.54
FO-3 B2t	6.9	2.1	19.0	18.1	2.3	.09	.33	.28	1.74
FO-3 B3	7.0	1.8	25.5	17.4	5.6	.10	.37		1.82
FO-3 Cg	7.2	1.1	30.7	24.1	6.2	.13	.43		1.82
FO-4 Ap	5.8	1.6	23.0	9.6	1.9	.11	.17	1.24	1.24
FO-4 B21t	6.3	1.8	21.6	10.6	1.6	.10	.22	.56	.56
FO-4 IIB22t	6.3	1.2	39.8	22.6	7.5	.14	.43		
FO-4 IIB23	6.6	.80	38.5	21.2	16.3	.15	1.23		

*Blanks in a column appear in cases where the analysis was not requested.