# Soils Developed in Granitic Alluvium near Merced, California

U.S. GEOLOGICAL SURVEY BULLETIN 1590–A

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By J.W. HARDEN

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SOIL CHRONOSEQUENCES IN THE WESTERN UNITED STATES

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

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## FOREWORD

This series of reports, "Soil Chronosequences in the Western United States," attempts to integrate studies of different earth-science disciplines, including pedology, geomorphology, stratigraphy, and Quaternary geology in general. Each discipline provides information important to the others. From geomorphic relations we can determine the relative ages of deposits and soils; from stratigraphy we can place age constraints on the soils. Field investigations and mineralogic and sedimentologic studies provide information on the nature and types of deposits in which soils form. As a result of our work, we have estimated rates of soil formation, inferred processes of soil formation from trends in soil development with increasing age, and obtained information on the types of weathering that occur in various areas. In return, soil development and soil genesis have provided data on the age of landforms, the timing and duration of sedimentation, and, in some cases, the history of climatic fluctuations.

Between 1978 and 1983, a coordinated and systematic study was conducted on soil development in different types of geologic deposits in the Western United States. The goals of this project, led by the late D.E. Marchand and subsequently by M.N. Machette, were to learn whether rates of chemical, physical, and mineralogic transformations could be determined from soil chronosequences; how these rates vary in different mineralogic and climatic environments; and how accurately soils can be used for such problems as estimating the ages of deposits, periods of landscape stability, and timing of fault movements. This series of reports presents data from several soil chronosequences of that project.

More than 100 analyses on more than 1,000 samples were performed on soils collected in the Western United States. Some results have appeared in various books, journals, and maps (for example, Harden and Marchand, 1977, 1980; Burke and Birkeland, 1979; Dethier and Bethel, 1981; Marchand and Allwardt, 1981; Meixner and Singer, 1981; Busacca, 1982; Harden, 1982a, b; Harden and Taylor, 1983; Machette, 1983; Machette and Steven, 1983; Busacca and others, 1984; Machette and others, 1984; Reheis, 1984). In the reports in this series, the basic field information, geologic background, and analytical data are presented for each chronosequence, as well as some results additional to the previous publications.

One of the most significant aspects of these chronosequence studies is that in every study area, many soil parameters change systematically over time, or with the age of deposits. As Deming (1943) emphasized, it is this recurrence of correlation in such different conditions that is most significant to geologic and pedologic studies. In relatively moist areas, such as coastal and central California, such soil properties as percent clay or reddening of soil colors change most systematically over time. In more arid regions, such as in the Bighorn Basin of Wyoming, calcium carbonate and gypsum contents best reflect the relative ages of the deposits. A few parameters—for example, elemental composition of sands or clays—appear to be comparable between areas so diverse in climatic setting.

Numeric age control has enabled us to estimate rates of soil development. In some places, we have been able to compare rates between different areas. For example, in central California, rates of clay accumulation were found to be most rapid during the initial stages of soil development; these rates declined with increasing age. The straightest lines for regression were on a log-log scale. In coastal California, rates of clay accumulation appeared to be much higher than in central California. This difference in rates could be due to parent material (the coastal soils that we studied were formed on reworked shale and sandstone, whereas central California soils were developed in granitic alluvium), and (or) the differences in rates could be due to eolian additions of clay. In the Bighorn Basin of Wyoming, rates of clay accumulation, as well as most other soil properties, increased linearly over time, with no apparent decrease in initial rates.

The data we present here suggest many opportunities for further interpretation. For example, we may learn how climate, vegetation, and mineralogy affect the rates of clay formation or organic-matter accumulation. In some study areas, we present data for rare-earth elements, which could be used to examine how each element reacts in different weathering environments. These examples are only a fraction of the possible future studies that could be conducted on the data presented here.

J.W. Harden
Editor

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SOIL CHRONOSEQUENCES IN THE WESTERN UNITED STATES

# Soils Developed in Granitic Alluvium near Merced, California

*By* J.W. Harden

Abstract

Terrace and fan deposits along the Merced River in the San Joaquin Valley, Calif., have been approximately dated and range in age from about 0.2 to 3,000 ka. Soils were sampled on nine deposits to establish a soil chronosequence in an area with a Mediterranean climate, grassland vegetation, and sandy granitic parent material. Soil samples were analyzed for several morphologic, chemical, physical, and mineralogic properties, many of which vary systematically with age. Properties showing the most systematic changes over time include: (1) field descriptions of clay films, total texture (texture plus wet consistence), rubification (color hue plus chroma), and dry consistence; (2) depletion or concentration of Ca, Mg, Na, Fe, Al, and Ti relative to Zr, the most stable constituent; and (3) other physical and extractive-chemical characteristics, including clay mineralogy, dithionite- and oxalate-extractable Fe content, and total (titratable) soil acidity. Changes in soils over the 3,000-ka age span demonstrate that significant chemical differentiation, mineralogic transformations, and morphologic changes occurred as a result of soil development. The high correlation of soil characteristics with age provides a means to use the soils for correlating and dating late Cenozoic deposits.

## INTRODUCTION

Alluvium in the northeastern San Joaquin Valley, Calif., offers an opportunity to study soils in an exceptionally well dated, widely spanned age sequence. Nine principal units of terrace and fan deposits range in age from about 0.2 to 3,000 ka; the ages of many of these deposits have been established or approximated by radiometric dating. Deposition of each unit was relatively rapid; major depositional events were separated by periods of stream entrenchment and slow sedimentation (hiatuses). Older, nested terrace and fan deposits are isolated above modern stream channels and flood deposits, and as a result, the ages of many of these deposits (particularly the Pleistocene deposits) closely approximate those of the surfaces and soils. In this study, soils along the Merced River were sampled in relatively flat, grass-covered areas, and a soil chronosequence was established; that is, the soils differ in age but appear to have formed under similar conditions of climate, vegetation, slope position, and parent material (Jenny, 1941).

Both the soils and geology in the Merced area have been mapped and studied in detail by Arkley (1962a, b) and Marchand and Allwardt (1981); their work is carefully reviewed here to evaluate radiometric ages and site-specific data that affect interpretation of the soil chronosequence. For example, uncertainty of age assignments is analyzed in this report, and soil-development rates are estimated by considering the uncertainties in radiometric ages (and their relation to surfaces and soils). These rates are estimated for several soil parameters, including morphologic, bulk or total chemical, and extractive-chemical characteristics. The morphologic characteristics have been reported previously (Harden, 1982a) but are reexamined in this report to provide a more complete discussion of the soils. Other data are presented here for the first time.

The wide age range represented by the chronosequence of this study permits an evaluation of the time dependence of soil (and soil property) development. Some soil characteristics, such as color hue and chroma, clay mineralogy, and the morphologic soil-development index (Harden, 1982a), change systematically over time. Other properties, including clay films and percent loss of certain elements from size separates, change significantly in the older Pleistocene and Pliocene soils. Another set of characteristics, including organic-carbon content and dry consistence, change systematically in the younger Holocene and latest Pleistocene soils.

Acknowledgments.--Innumerable people played important roles in the planning, excavation, analytical, and interpretative stages of this work. My project leader, the late Denis Marchand, conducted the geologic investigations and guided and supported this study throughout most of its history. M.J. Singer, A.J. Busacca, R. Meixner, and Peter Janitkzy not only conducted many of the soil analyses but also contributed many ideas and tests in the planning and execution of the work. E.M. Taylor was fundamental in all of the data compilation and contributed many ideas toward data analysis and future studies. C. Terhune and S. Walker spent countless hours in organizing the data presentation. M.N. Machette accepted and succeeded in the difficult task of continuing leadership of this work after the loss of Marchand. R. Mark contributed many ideas to the methods of data analysis and helped identify limitations that might be overcome in future work. G. Dembroff helped with some of the calculations. In conjunction with my doctoral dissertation, R.J. Arkley, Hans Jenny, H.E. Doner, and Clyde Wahrhaftig were helpful in their guidance and encouragement of this work. B.F. Atwater encouraged consideration of the effects of age uncertainties, which clearly strengthened the arguments and their validity. K.L. Pierce helped to clarify many of the main points of the manuscript, and J.C. Tinsley encouraged presentation of these ideas. Last, I thank the landowners of my excavation sites, without whom I could not have proved worthy of spending wisely the taxpayers' money: thanks go to the J.J. Stevinson Corp., M. Cotta, F. Moiser, R. Jones, C. Matheson, R. Armstrong, M. MacNeilson, L. Roedner, A. Spence, Mrs. A. Arkelian, Turlock Lake State Park, and the Circle J Ranch.

## GEOGRAPHIC SETTING

The Merced River heads in the Sierra Nevada and flows through the Sierran foothills and the eastern San Joaquin Valley before joining the lower San Joaquin River to the west (fig. 1). The Sierra Nevada, glaciated several times during the Pleistocene, is underlain by granitic and dioritic rocks. Glacial outwash of the Merced River is the parent material for most of the soils discussed in this study; with the possible exception of Holocene alluvium, it is composed of granitic debris and minor mafic minerals derived from the metamorphic terrane of the foothills.

The study area has a Mediterranean climate in which most of the rain (mean annual precipitation, 30 cm) falls during the cool winters. Because evapotranspiration is low during the rainy season, rainfall is effective in penetrating and leaching the soil. During the dry summers, the soils are readily desiccated by evapotranspiration. The effective wet-dry cycles constitute a xeric soil-moisture regime (Soil Survey staff, 1975). The mean annual temperature near the study area is about 16 $^{o}$C, and the soil-temperature regime is thermic (Soil Survey staff, 1975).

## GEOLOGIC SETTING

### Previous work

In the 1950's, R.J. Arkley mapped the soils in much of the northeastern San Joaquin Valley (Arkley, 1954, 1962b) and began to elucidate the relation between soil development and the surficial geologic deposits in this area (table 1). Arkley (1962a, p. 3) differentiated soils developed in "recent alluvium, young alluvium, moderately old alluvium, high terrace gravels, and very high terrace gravels," and proposed a glacial origin for the deposits along the major streams heading in the Sierra Nevada. Davis and Hall (1959) used Arkley's mapping and designated three Pleistocene formations, which they named, from youngest to oldest, the Modesto, Riverbank, and Turlock Lake Formations.

The influence of Quaternary glaciations in the Sierra Nevada on deposition in the valley became widely recognized when Arkley (1962b), Wahrhaftig and Birman (1965), and Janda and Croft (1967) compared the glacial sequence of the Sierra (Blackwelder, 1931, 1932; Birman, 1954, 1957, 1964; Matthes, 1960; Birkeland, 1964) with the alluvial, glaciogenic sequence of the valley. Glacial deposits are not well preserved on the west slope of the Sierra, but similar (major unit) time stratigraphies and rock compositions are found in deposits along glaciated river drainages in both the Sierra Nevada and the San Joaquin Valley. Janda and Croft also used (1) the stratigraphy of subsurface cores in a confined basin, (2) available radiometric ages correlating valley units with glacial deposits, and (3) the regional similarity of glaciated river drainages in the northeastern San Joaquin Valley to link the origin of alluvial fans to glaciation in the Sierra Nevada. Janda (1965, 1966) and Janda and Croft (1967) subdivided the Modesto and Turlock Lake Formations on the basis of erosional unconformities and buried soils; with extensive fieldwork and limited age control, they proposed a sedimentation model of several cyclical, climatically induced periods of alluviation separated by periods of nondeposition and soil formation.

Helley (1966) extended Janda's (1966) model to the unglaciated Chowchilla River basin in the San Joaquin Valley. Helley's stratigraphy is strikingly similar to that of the glaciated river basins nearby, and he concluded that alluviation in the Chowchilla drainage nearly coincides with alluviation in these glaciated river drainages. Helley further inferred that sedimentation over much of the San Joaquin Valley was probably induced by changes in erosion rates, landscape stability, and precipitation patterns of climatic origin which also were manifest as cycles of Sierra Nevada glaciation.

In the late 1970's, D.E. Marchand mapped the late Cenozoic deposits between Bakersfield and Stockton (including the Merced area) and established a widespread regional time stratigraphy that emphatically supports a climatic control on sedimentation in the eastern San Joaquin Valley. Marchand used the soil maps by Arkley (1962b), Ulrich and Stromberg (1962), and Huntington (1971) to examine soil differences in relation to geomorphic landform

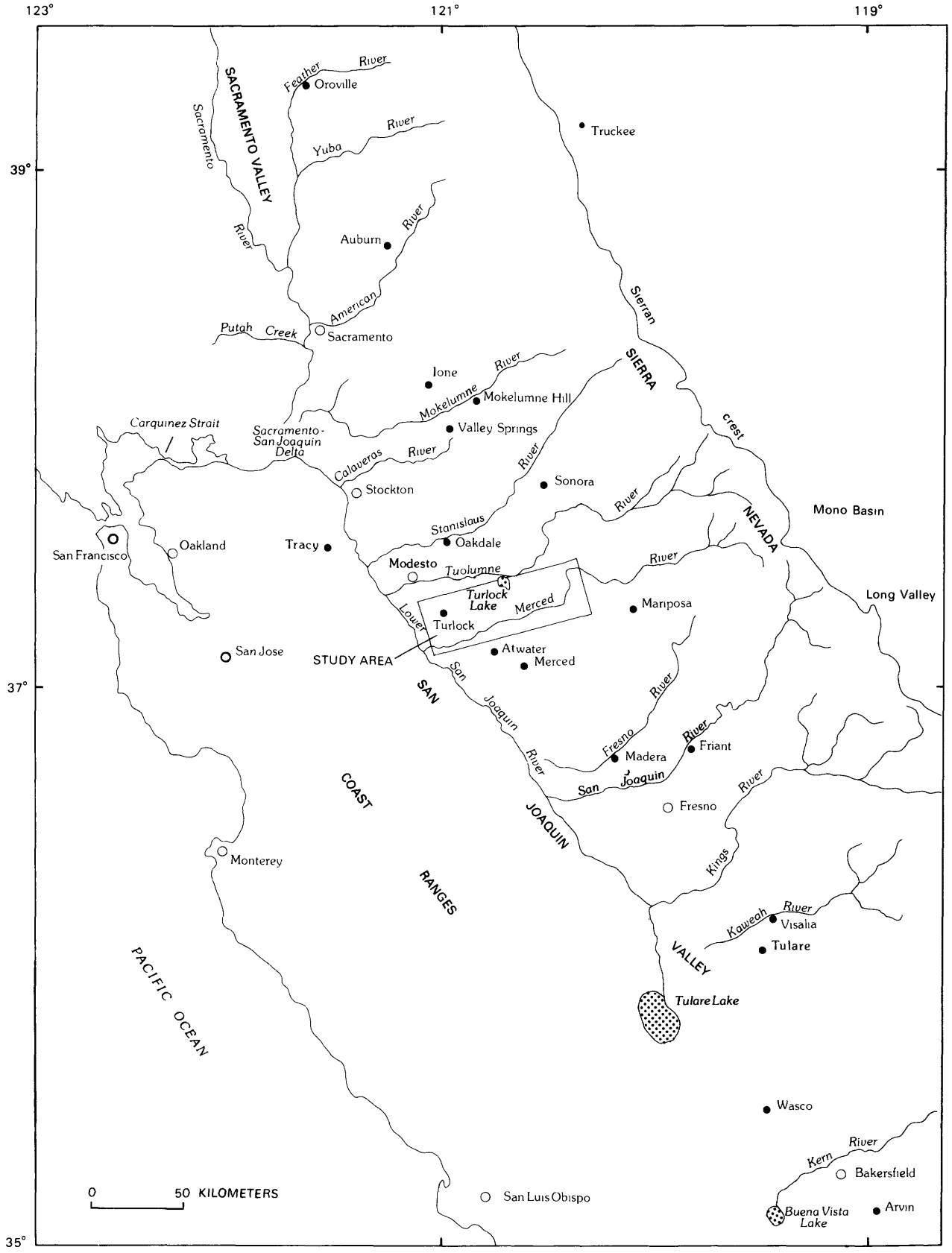


**Figure 1.** Central California, showing location of study area.

**Table 1.** Generalized map units and taxonomic classes of soils of the Merced chronosequence

[Units and approximate ages from Marchand and Allwardt (1981). Soil series from Arkley (1984). Taxonomic subgroups from Soil Survey staff (1975)]

| Unit | Approximate age (ka) | Soil series | Taxonomic subgroup |
|---|---|---|---|
| Post-Modesto deposits | 0.2-3.0 | Grangeville, Hanford | Typic xerorthent. |
| Modesto Formation | | | |
| Upper member | 10 | Hanford, Honcut | Do. |
| Lower member | 40 | Greenfield | Typic haploxeralf. |
| Riverbank Formation | 100-300 | Snelling | Do. |
| Turlock Lake Formation | | | |
| Upper member | 600 | Montepellier | Do. |
| China Hat Gravel Member of the Laguna Formation. | 3,000 | Corning (acid variant) | Ultic palexeralf. |

differences. From detailed mapping of the geology on large-scale maps (Marchand, 1976b, c, d, e, f, g) and from additional radiometric ages (Marchand and Allwardts, 1981), Marchand (1977) (1) concurred with the sedimentation models of Arkley (1962a), Helley (1966), and Janda and Croft (1967); (2) subdivided the Pleistocene formations into even more units than Janda and Croft (1967) had recognized; and (3) extended the climatic model of sedimentation to correlate with other climatic histories recorded in continental and marine records. Marchand (1976b, c, d, e, f, g) separated as many as 24 mappable units but fewer time-stratigraphic units, 9 of which were sampled for this soil-chronosequence study. Although Marchand used soils to help recognize and map the alluvial deposits, each of the nine units chosen for this study was also was recognized on the basis of (1) geomorphic expression of terrace and fan surfaces, (2) buried soils and unconformities, and (3) regional extent along different river systems within the eastern San Joaquin Valley. Thus, major regional rather than local control of sedimentation was identified.

The late Cenozoic history and chronology of the San Joaquin Valley as defined by Marchand (1977) and Marchand and Allwardt (1981) were used in this study for the chronology of Merced River deposits in this study. Some new ages are available and have been added to this report. Most of the radiometric ages reported here were determined on deposits correlated with those along the Merced River. Discussions of regional geology and age control are included below; in addition, more site specific details are discussed for the Merced area, in the context of the regional mapping.

## Origin of deposits and regional late Cenozoic stratigraphy

Throughout the eastern San Joaquin Valley, tectonic uplift and tilting and cyclical patterns of sedimentation have created a sequence of nested Quaternary alluvial terraces that are incised into older units near the Sierran foothills and open into alluvial fans to the west. Successively younger fans spread westward over older fans; thus, many alluvial units grade westward from surface to subsurface expression (Marchand and Allwardt, 1981). Tectonic uplift and tilting of the Sierra Nevada are shown by depositional and erosional gradients in Tertiary and Quaternary units that increase with increasing age (Marchand, 1977; Huber, 1981). Westward shift of fan apices in the Quaternary units over time suggests relative subsidence of the valley, a tectonic trend demonstrated by Croft (1968, 1972) in subsurface lacustrine deposits.

Although tilting and uplift of the Sierra Nevada have occurred during the late Cenozoic, several lines of evidence support a climatic control on pulses of alluviation in the eastern San Joaquin Valley. Janda and Croft (1967, p. 175) discounted eustatic control on deposition because alluvial units are found along the Kings and Kaweah Rivers, which drain internally into the Tulare Lake basin; similar stratigraphies in open and closed drainages indicate that sedimentation was not controlled by eustatic fluctuations in sea level. Janda and Croft discounted a tectonic origin for alluvial-fan deposition[1] for the following two reasons. (1) Quaternary alluvium predates the last major tilting of the Sierra Nevada, which occurred before deposition of the Turlock Lake Formation. More recently, however, Huber (1981) argued that tectonic deformation has continued and even accelerated during the late Cenozoic, although he also supported a glacial origin of alluvium in Sierran drainages in the San Joaquin Valley. (2) No major unconformities were recognized in the San Joaquin

[1]More recently, Atwater and others (1987) proposed that the Tulare Lake basin was not closed during parts of early and middle Wisconsin time.

Basin subsurface to indicate episodic subsidence that would have caused the episodic alluviation found upstream.

As Marchand (1977) and Marchand and Allwardt (1981) indicated, a climatic control of sedimentation is supported by several features. (1) Unweathered granitic silt and very fine sand resembling glacial rock flour are found at the bases of deposits in glaciated drainages (Arkley, 1962a; Janda, 1965) whereas coarse sand and gravel, also typical of glacial outwash, commonly overlie the silt near fan apices. (2) At least two alluvial units, the upper member of the Modesto Formation and the upper unit of the Turlock Lake Formation, are nearly contemporaneous with glacial events. A minimum age for the Tioga glaciation in the Sierra Nevada (Adam, 1967) and ages for the end of the main stade of the Wisconsin glaciation of midcontinental North America (Frye, 1973, p. 277) approximately correspond to the minimum age for the upper member of the Modesto Formation. The upper unit of the Turlock Lake is contemporaneous with the end of marine oxygen-isotope stage 16, a time characterized by glacial conditions (Shackleton and Opdyke, 1976). (3) Uranium-trend ages (Rosholt, 1978, 1980; J.N. Rosholt, written communs., 1978, 1980, 1982) also coincide with the marine record for oxygen-isotope stages (Shackleton and Opdyke, 1976) of the end of glacial conditions.

**Age control on alluvial units**

The soils in this study compose the following time-stratigraphic units, from youngest to oldest[2]: post-Modesto deposits; the upper and lower members of the Modesto Formation; the upper, middle, and lower units of the Riverbank Formation; the upper unit of the Turlock Lake Formation; and the China Hat Gravel Member of the Laguna Formation (fig. 2; table 2). Most of the age information is from Marchand and Allwardt (1981), except for some uranium-trend ages reported more recently (J.N. Rosholt, written commun., 1982) and some new $^{14}C$ ages obtained by B.F. Atwater (unpub. data, 1984).

Uncertainties in the ages (table 2) are associated both with the regional correlations of units and with local conditions at the sampling sites. Any available ages must be related to the geomorphic surface at the site of soil sampling. Subdivision of the formations is especially subject to uncertainty in the ages; for example, in some areas, multiple terraces in a major unit could represent only a local phenomenon, such as recent aggradation, and thus make regional correlation invalid. A strong argument for subdividing alluvial units on a regional scale is that similar numbers of subunits occur along the major Sierran streams. For example, three surfaces are commonly associated with the Riverbank Formation; this regionwide repetition of stratigraphy suggests a regional rather than a local control of sedimentation.

A major problem with identification and age assignment of subunits is that they must be correlated by using soil and geomorphic characteristics, which may not differ significantly for the age span considered. A good example of this problem occurs along the Tuolumne River (see Marchand and Harden, 1978), where four subunits or phases all have Hanford soils developed on them within the upper member of the Modesto Formation. Marchand and I distinguished these subunits throughout the quadrangle, but unless all four terrace levels are adjacent to each other, the differentiation is ambiguous, as we indicated by queries on our map. The uncertainty of stratigraphic assignment and correlation with dated localities varies among the different soil-sampling localities. Age control is discussed below, and sampling localities are considered for each stratigraphic unit to assess the reliability of age estimates (table 2).

Post-Modesto deposits

Post-Modesto alluvial deposits are divided into four units, all of which were mapped by Marchand and Allwardt (1981) along major Sierran streams in the northeastern San Joaquin Valley. Post-Modesto IV deposits, not sampled for this study, generally consist of unvegetated alluvium of channels and point bars. Post-Modesto III (PM3) deposits, which form part of the modern flood plains, are 2 to 3 m above the modern stream channels (figs. 2, 3). Although no datable material has been found within post-Modesto III deposits, very mature oak trees on the surface suggest that this surface is more than a few years old. Although I estimated that post-Modesto III deposits are 0.2 ka old (table 2), the surface could be as old as about 3 ka on the basis of the age of post-Modesto II (PM2) deposits, or as young as a few years if there has been recent aggradation on the surface.

Post-Modesto II deposits, extensive along the Merced River near Snelling, form a surface about 3 to 5 m above the modern channel (fig. 3). Marchand and Allwardt (1981, p. 63-64) reported $^{14}C$ and U-Th ages that range from about 2 to 4.5 ka, but the dated deposits are situated near Oroville and Stockton. A very conservative maximum age of 8.3 ka (sample Beta-2787) was provided by B.F. Atwater (written commun., 1983) on wood fragments in San Joaquin River deposits below the post-Modesto II surface near the mouth of the Tuolumne River. A more reasonable age estimate for post-Modesto II deposits is about 3 ka (table 2), but the post-Modesto II surface and soil could be younger if covered more recently by flood deposits.

Modesto Formation

The Modesto Formation is divided into two members (Marchand and Allwardt 1981). The upper member, which may include as many as four phases of alluvial filling and incision, may be as old as about 27 to 29 ka at its base and as young as 8 or 9 ka at its

[2]The U.S. Geological Survey's convention of discussing units in the order of decreasing age is not followed here because this report focuses on the genesis of soils rather than on the evolution of geologic units.

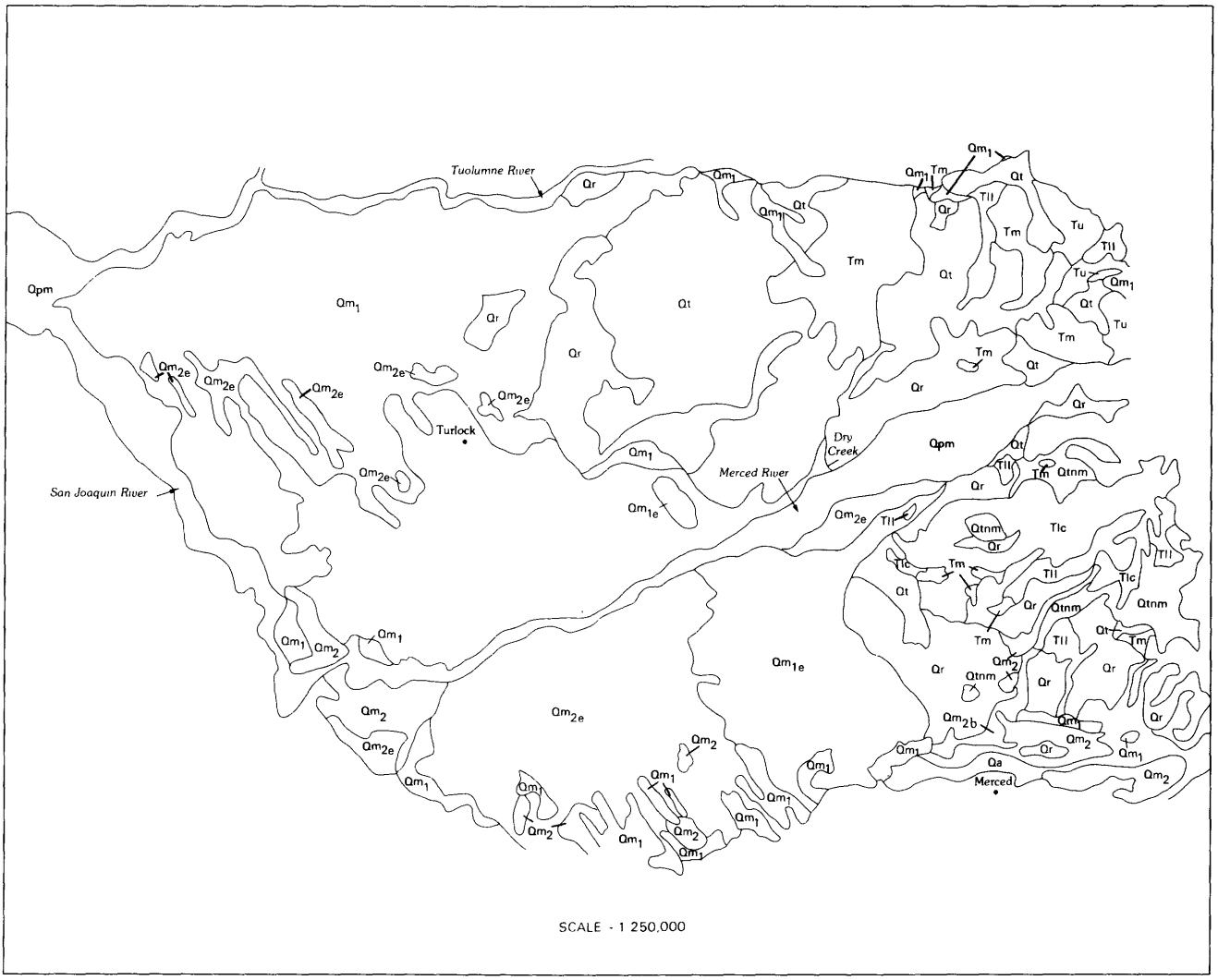


**Figure 2.** Geologic map showing late Cenozoic deposits along the Merced River. Geology compiled from Marchand (1976a, b, c, d) and Marchand and Allwardt (1981).

surface. The upper member appears to be correlative with the Tioga glaciation, which ended before about 9.8 ka (Adam, 1967), and with the end of marine oxygen-isotope stage 2 of Shackleton and Opdyke (1976). The minimum constraining age of 8.23 ka is based on charcoal in San Joaquin River deposits that are set into the upper member at the toe of the Tuolumne River fan (table 2). The maximum constraining age of 31.24 ka is based on $^{14}C$ data on charcoal in deposits beneath the same late Modesto fan (table 2). Marchand and Allwardt (1981, p. 57) also cited a constraining (maximum) uranium-series age of about 29 ka by E.L. Begg on bone in basin alluvium mapped by Marchand and Allwardt as the lower unit of the Modesto Formation.

Both soil-sampling localities in the upper member of the Modesto Formation display features which suggest that the surface and soil are within the younger end of the age range of this unit. Site M31 is only 3 m above the modern stream channel (much like post-Modesto II deposits), and its elevation appears to be somewhat low for the longitudinal profile of the terrace (fig. 3). The surface of site M46 is located along the projected profile of upper-member terraces (fig. 2), but the terrace is incised into, and somewhat younger than, the extensive eolian phase of the upper member (table 1). Both sites M31 and M46 were assigned an age of 10 ka, which corresponds to the closing phase of the glacial stage, but the surface and soils could be anywhere from about 8.2 to 14 ka (table 2).

The age of the lower member of the Modesto Formation is somewhat ambiguous. Marchand and Allwardt (1981, p. 57) referred to the uranium-series age of 29 ka determined by E.L. Begg as a minimum age for the lower member. Atwater and others (1986), in their recent work on the Tulare Lake bed, tentatively correlated it with an early phase of the Tioga glacial deposits of the late Wisconsin glaciation and estimated an age of about 20 to 26 ka. Marchand

## EXPLANATION

| | |
|---|---|
| Qpm | Post-Modesto deposits (Holocene) |
| | Modesto Formation (Pleistocene)-- Consists of: |
| | Upper Member -- Divided into: |
| $Qm_2$ | Alluvial deposits |
| $Qm_{2e}$ | Eolian deposits |
| $Qm_{2b}$ | Basin deposits |
| | Lower Member--Divided into: |
| $Qm_1$ | Alluvial deposits |
| $Qm_{1e}$ | Eolian deposits |
| Qr | Riverbank Formation (Pleistocene) |
| Qt | Turlock Lake Formation (Pleistocene) |
| Qtnm | North Merced Gravel (Pleistocene or Pliocene) |
| | Laguna Formation (Pliocene)-- Consists of: |
| Tlc | China Hat Gravel Member |
| Tll | Lower part |
| Tm | Mehrten Formation (Pliocene and Miocene) |
| Tu | Sedimentary and volcanic rocks, undivided (Tertiary) |

**Figure 2.** Continued

and Allwardt (1981, p. 57) reported a uranium-trend age (Rosholt, 1980) of 95±45 ka on an early Modesto terrace, but this age has been modified because of new calibrations. The revised uranium-trend ages are 42±16 ka for the alluvial terrace (sample M12, fig. 3) and 43±34 ka for the alluvial fan farther downstream (sample M14 of J.N. Rosholt, written commun., 1982). If deposition of the major Sierran streams coincided with the later parts of glacial events, then deposition of the lower member might have coincided with the later part of isotope stage 4, at about 65 ka (Shackleton and Opdyke, 1976). A tentative age of 40 ka was used for terrace deposits of the lower member of the Modesto Formation (table 2), which corresponds to the ages determined by J.N. Rosholt and is in the central part of the estimated age range from 20 to 70 ka.

### Riverbank Formation

The Riverbank Formation was divided by Marchand (1976a, b, c, d, e, f; 1977) into three units. The upper unit is separated in the subsurface from the middle and lower units by a disconformity and a buried soil (Marchand and Allwardt, 1981, p. 40). The upper unit was correlated with oxygen-isotope stage 6, on the basis of Marchand's model of sedimentation (Marchand, 1977) and on uranium-trend ages for soil sample R9 of this report (see fig. 3; table 2); its age of 140±40 ka generally coincides with the end of marine oxygen-isotope stage 6 at about 127 ka (Shackleton and Opdyke, 1976). This uranium-trend age, however, does not overlap the 260±60-ka uranium-trend age of sample R10 from the middle unit of the Riverbank Formation (table 2), which is compatible with the end of marine oxygen-isotope stage 8 at about 250 ka (Shackleton and Opdyke, 1976). Hansen and Begg (1970) determined an open-system uranium-series age of about 103 ka on bone from within Riverbank deposits at the Teichert Quarry in the Sacramento Valley (Shlemon, 1967). Marchand and Allwardt (1981, p. 41) considered this bone to be within the middle unit but that this age should be regarded only as a minimum for the middle unit. Subsequent uranium-trend data on the unit adjacent to the Teichert Quarry yield an age of 120±40 ka (J.N. Rosholt, written commun., 1982). Because the uranium-trend age corresponds to late Riverbank ages along the Merced River, and because this age does not overlap ages within the middle unit, I believe that the Teichert unit correlates with the upper unit of the Riverbank. In this case, the uranium-series age determined by Hansen and Begg would be a minimum for all units of the Riverbank Formation.

Separation and correlation of the upper and middle units of the Riverbank Formation pose problems in the Snelling area, where the soils were sampled. Sampling sites are from Marchand and Allwardt's (1981) "reference section" for the three subunits, but topographic distribution in the study area may be less clear cut than their geologic map indicates. Topographic profiles of the Riverbank terraces (fig. 3) demonstrate that the upper unit is about 2 to 3 m above the middle unit. Because stream profiles appear to converge below the Merced River-Dry Creek confluence, the surfaces near the sampling sites are difficult to separate. The surfaces of sites R9 and R33 appear to be typical of those of stream profiles of the upper unit, but samples R2, R10, and R32, mapped on the middle unit, occur at low elevations for the middle unit and could be from either the middle or upper unit. One of Marchand's (1977) mapping criteria for subdivision of the Riverbank Formation is that the middle unit is more extensive than the upper and lower units. Apparent convergence of the terrace at sites R2, R10, and R32 with an extensive Riverbank surface along Dry Creek (fig. 2) supports Marchand's original claim that this terrace is one of the middle unit. Differentiation of the Riverbank units is a critical argument for interpreting the soil data because the soils of this study do not notably differ between the middle and upper units. These soils may be similar because they are developed in similar-age deposits, or the rate of soil development in this area may have declined after about 100 to 300 ka. If the sampling sites from the upper and middle units of the Riverbank are actually on the same unit, their age is bracketed by 103 ka as a minimum (U-series age on bone) and by 305 ka as a maximum (oldest U-trend age on the upper and middle units of the Riverbank). These two units, however, were assigned ages of 130 and 250 ka, respectively (table 2), on the basis of the later parts of oxygen-isotope stages 6 and 8 and on J.N. Rosholt's dating.

A minimum age for the lower unit of the Riverbank Formation appears to be provided by a uranium-trend age of about 260 ka on the middle unit; the maximum age is limited by a K-Ar age of about

## Table 2. Age controls for alluvium in the northeastern San Joaquin Valley, California

[Map units from Marchand and Allwardt (1981). Underscores indicate most reliable ages. Approximate ends of marine oxygen-isotope stages from Shackleton and Opdyke (1976). Comments on reliability of ages compiled since report by Marchand and Allwardt (1981). n.a., not available]

| Map unit | Soil sample (this study) | Pertinent radiometric ages from the Central Valley (ka) | | | Inferred correlation with marine oxygen-isotope stages | | Other evidence for age control | Approx age of surface (ka) | Comments | Inferred uncertainty of age estimate (ka) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Stratigraphically above unit (limiting minimum) (sample) | Within unit (sample) | Stratigraphically below unit (limiting maximum) (sample) | Stage | Approximate date of end of stage (ka) | | | | |
| Post-Modesto deposits | | | | | | | | | | |
| pmIII | PM15<br>PM19 | 0 | n.a. | [1]3.33±0.06<br>(Beta-2788) | --- | --- | In most places, unit pmIII terraces cut into unit pmII. | 0.2 | Mature oak trees on terraces along the Merced River. Historical flooding suggests a younger age. | 0-1 |
| pmII | PM8<br>PM13<br>PM14<br>PM15<br>PM17<br>PM18 | n.a. | 3.33±0.06<br>(Beta-2788) | 14.1±0.2<br>(USGS-38)<br>[4]8.23±0.08<br>(Beta-2787) | --- | --- | Unit pmII terraces cut into unit pmI, where present. | 3 | Historical flooding suggests a younger age, although less flooding than in unit pmIII would corroborate relative age (Marchand and Allwardt, 1981, p. 62). | 1-8.3 |
| Modesto Formation | | | | | | | | | | |
| Upper member (m2) | M31<br>M46 | [4]8.23±0.08<br>(Beta-2787) | [5]14.1±0.2<br>(USGS-38)<br>[7]31±21<br>(USGS-M31) | [6]31.24±0.32<br>[8]29.407±0.207 | 2 | 13 | Tulare Lake dam formed 26 ka; highest lake stand of the Wisconsin glaciation. | 10 | Stream profiles suggest that sample localities are within late phase or possibly younger unit. | 8.3-14 |
| Lower member (m1) | M12 | [9]14.1±0.2<br>(USGS-38) | [10]29.407±2.027<br>42±16<br>(USGS-M14) | [11]103±6 | 4 | 70 | Lower member buried or eroded by upper member in many places; argillic horizon suggests that unit m1 is significantly older than unit m2. | 40 | Intermediate between available ages. | [12]20-70 |
| Riverbank Formation | | | | | | | | | | |
| Upper unit (r3) | R9<br>R33 | [13]42.4±1.0<br>42±16 | [14]103±6<br>[7]140±40<br>(USGS-R9)<br>[7]145±20<br>(USGS-R33) | [7]260±45<br>(USGS-R10)<br>[16]615±31 | 6 | --- | Soil separating unit r3 from units r2 and r1 indicates a significant difference in the age of the units. At least two units with strong soils separate unit r3 from unit t2. | 130 | Late isotope stage 6. U-trend age for maximum. | [15]103-305 |
| Middle unit (r2) | R2<br>R10<br>R32 | [16]103±6 | [7]260±45<br>(USGS-R10) | [17]615±31 | 8 | 250 | Sample sites possibly of same age as for unit r3. | 250 | Late isotope stage 5. U-trend age for maximum. | 103-305 |
| Lower unit (r1) | R30 | [11]103±6 | n.a. | [16]615±31<br>[7]570±50 | 10/12 | 330 | Older than unit r2 or r3. | 330 | Late isotope stage 10. U-trend age for maximum. | [17]250-570 |
| Turlock Lake Formation | | | | | | | | | | |
| Upper unit (t2) | T2<br>T6<br>T11 | [11]103±6 | [18]615±31<br>[21]570±50<br>(USGS-T6) | [19]3,000-4,000<br>[22]730 | 16 | ---------- | | 600 | U-trend age for minimum. | [20]570-615 |
| Laguna Formation | | | | | | | | | | |
| China Hat Gravel Member (lch). | CH1<br>CH2<br>CH3 | [16]615±6<br>[24]730 | n.a. | [23]3,000-4,000 | ---------- | | | 3,000 | ---------- | 730-4,000 |

[1] $^{14}C$ age on wood in core 3 to 4 m below unit pmII and pmIII surfaces along the lower San Joaquin River.

[2] On upper member of the Modesto Formation (B.F. Atwater, unpub. data, 1983).

[3] $^{14}C$ age on charcoal of oxbow-lake deposit that appears to be cut by unit pmII and pmIII deposits of the lower San Joaquin River (B.F. Atwater, unpub. data, 1983).

[4] B.F. Atwater (unpub. data, 1983).

[5] On charcoal beneath unit m2 fan on the Kern River (Marchand and Allwardt, 1981).

[6] On wood in deposits of the lower San Joaquin River beneath unit m2 and m1 fans along the Tuolumne River (B.F. Atwater, unpub. data, 1983; Atwater and others, in press).

[7] J.N. Rosholt (unpub. data, 1984).

[8] E.G. Begg (oral commun., 1980) and Marchand and Allwardt (1981).

[9] Marchand and Allwardt (1981).

[10] U-series age on bone at top of unit m1 (E.G. Begg, oral commun., 1980; Marchand and Allwardt, 1981); Atwater and others (in press) estimate an age of 20 to 25 ka.

[11] Hansen and Begg (1970) and Marchand and Allwardt (1981).

[12] Upper uncertainty bound of 70 ka corresponds to both the end of isotope stage 7 and the limiting age of the informally designated West Lake silt of Atwater and others (in press).

[13] B.F. Atwater (unpub. data, 1983) and Atwater and others (in press).

[14] U-series age (Atwater and others, in press) cited by Marchand and Allwardt (1981) as within unit r2 deposit; correspondence with U-trend ages suggests that deposit is of unit r3.

[15] Upper uncertainty bound of 305 ka is U-trend maximum age on unit r2.

[16] Dalrymple (1980) and Marchand and Allwardt (1981).

[17] Upper uncertainty bound of 570 ka is U-trend minimum age on unit t2.

[18] K-Ar age on ash at base of unit t2 (Dalrymple, 1980; Marchand and Allwardt, 1981).

[19] Limiting age on Hemphillian fauna in stratigraphically lower unit (Marchand and Allwardt, 1981).

[20] Lower uncertainty bound of 570 ka is U-trend minimum age on unit t2.

[21] U-trend age that may indicate age of the surface and soil (J.N. Rosholt, unpub. data, 1984).

[22] Gilbert-Gauss boundary age on lower unit of the Turlock Lake Formation (Shackleton and Opdyke, 1976).

[23] Age of Hemphillian fauna found in the stratigraphically lower Mehrten Formation.

[24] Age corresponds to date of magnetic reversal in lower unit of the Turlock Lake Formation, assumed to be the Gilbert-Gauss boundary.

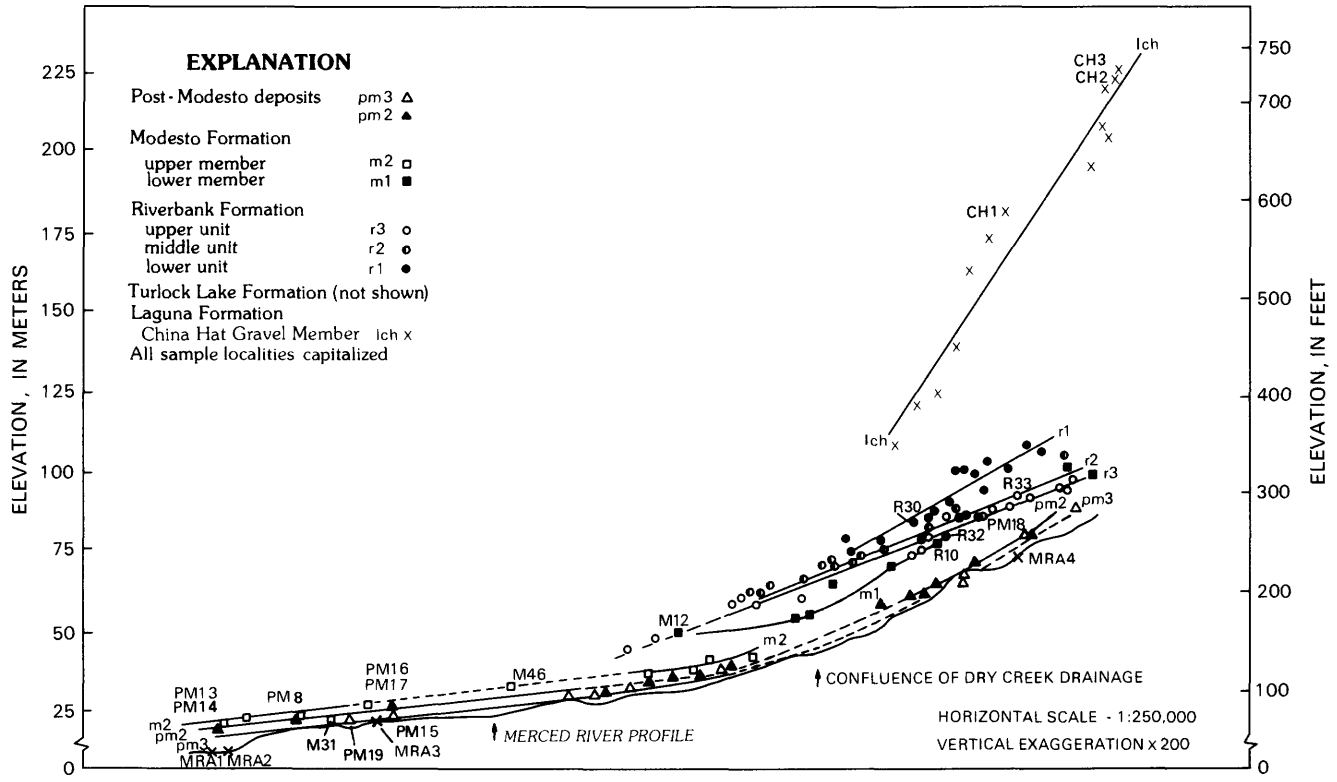


**Figure 3.** Profiles of Merced River terraces, showing sample localities (see supp. table 1).

615 ka (Janda, 1965, 1966; Dalrymple, 1980) on ash within the Turlock Lake Formation, and by a uranium-trend age of 570±50 ka for the upper unit of the Turlock Lake. Marchand (1977) and Marchand and Allwardt (1981) correlated the lower unit with oxygen-isotope stage 10 but suggested that this unit could also correlate with stage 12. A tentative age of 330 ka was used for this study (table 2) to generally coincide with the later part of marine oxygen-isotope stage 10 of Shackleton and Opdyke (1976).

## Turlock Lake Formation

At least two units compose the Turlock Lake Formation; they are separated by a well-developed buried soil at exposures near the town of Friant and in roadcuts near Turlock Lake (Marchand and Allwardt, 1981, p. 26-27). This study includes soil samples from only the upper unit of the Turlock Lake because there are no surface exposures of the lower unit. Janda (1965, 1966) found a pumiceous ash at the base of, and conformable with, the upper unit of the Turlock Lake. This ash, now called the Friant Pumice Member of the Turlock Lake Formation, provides a maximum age for the deposit and has a K-Ar age of 615±31 ka (Dalrymple, 1980). In addition, uranium-trend ages of about 570 and 610 ka (table 2), may indicate ages for about the upper 3 m of the deposit and thus for the surface and soil.

Sampling sites for soils of the upper unit of the Turlock Lake Formation are located along the Tuolumne River where the deposits and surfaces are well defined by mapping criteria. The surface of the upper unit of the Turlock Lake is dissected, and although samples were collected on relatively flat topographic highs, the soils could have been partly eroded. Janda (1965) proposed that dissection of the surface occurred during deposition of the Riverbank Formation, and so the soils of the Turlock Lake deposits would have developed for a few hundred thousand years before dissection and partial erosion occurred.

## China Hat Gravel Member of the Laguna Formation

The China Hat Gravel Member of the Laguna Formation, the oldest unit in the study area, occurs as a remnant of a late Tertiary gravel deposit of the Merced River near the town of Snelling (fig. 2). The gradient of the China Hat deposits along the Merced River is considerably steeper than those of younger alluvial units (fig. 3), and paleochannels in the China Hat Gravel Member have a more southerly trend than those in younger alluvial units (Marchand, 1977, p. 39-41).

A maximum age for the China Hat Gravel Member is provided by a vertebrate fauna of latest Hemphillian age (3,000-4,000 ka) from the underlying

Miocene and Pliocene Mehrten Formation (Marchand and Allwardt 1981, p. 19). Wahrhaftig and Birman (1965, p. 314, table 2) and Marchand and Allwardt (1981, p. 19) correlated the China Hat Gravel Member with the Pliocene Tuscan Formation in the Sacramento Valley, which includes the Nomlaki Tuff Member, dated at about 3,300 ka near its base. Marchand and Allwardt (1981, p. 19) also correlated the China Hat with gravel deposits in the Kings River, which contain basalt clasts about 3,800 ka old (Huber, 1981, p. 1194). Furthermore, Marchand and Allwardt (1981, p. 19) and Busacca (1982) discussed a magnetic reversal discovered by K.L. Verosub within the Laguna Formation in the Sacramento Valley and tentatively assigned it to the Gilbert Reversed/Gauss Normal Polarity Chrons boundary, at about 3,400 ka. For this study, an age of 3,000 ka was used for the surface; this age is constrained between about 730 ka (magnetic reversal within the younger North Merced Gravel) and 4,000 ka (Hemphillian fossil in the next oldest unit, the Mehten Formation) (table 2).

Soils found in the China Hat deposits were sampled on the flat, relatively uneroded tops of surface remnants. Mima-mound topography (Nikiforoff, 1941) is ubiquitous across the terrace surface, and soils were sampled at the tops of the mounds. Soil excavations revealed many filled animal burrows of different ages, as evidenced by varying degrees of redness, hardness, and clay-film development (see supp. table 1). Gopher activity probably played an important role in the formation of these mounds (Arkley and Brown, 1954). Concentric collapse features were also observed all along a depression (intermound area), suggesting collapse related to chemical loss or to ground-water dissolution (Nikiforoff, 1941).

As discussed above, there are considerable uncertainties in the dating of these surfaces. The uncertainties in both age estimates of the surfaces and in variation of the soils are shown schematically by horizontal and vertical error bars in figures 6, 7, 10, and 11.

### Provenance for Merced River deposits

Deposits along the Merced River were chosen for this study to limit the variation in mineralogy of the soil parent material. The Merced River drains about 600 $km^2$ of granitic terrane of the Sierra Nevada and about 150 $km^2$ of metamorphic and marine sedimentary rocks of the Sierra Nevada foothills.

Holocene alluvium along the Merced River has a larger component of mafic minerals than do older alluvial units, apparently in relation to a climatic control of erosion in the Merced River drainage basin. Janda (1966) discussed the relation of erosion rates in the Sierra Nevada and foothills to the origin of alluvium along the major Sierran streams. Under glacial conditions, most of the erosion and, thus, the sediment supply is from the glaciated headwaters of major Sierran streams. Under interglacial conditions and, possibly, during transitions into or out of glacial events, more erosion takes place in the Sierran foothills, which is underlain mainly by metavolcanic and metasedimentary rocks.

Janda's (1966) conclusions are borne out by the higher content of mafic minerals in Holocene deposits along the Merced River.[3] Some mineralogic and chemical trends of the soils developed in Merced River alluvium suggest that the Holocene deposits contain more metamorphic (foothill derived) debris in comparison with the older units. In general, metamorphic rocks of the foothills contain more pyroxene and less zircon than do granodiorites of the Sierra Nevada (Roger, 1966), and the pyroxene/zircon ratio of C horizons is much higher for Holocene (younger than 10 ka) than for older soils (fig. 4). Etching categories of some of the heavy minerals also indicate unusual characteristics of the Holocene soils. In older soils, increase in etching with age indicates systematic weathering of consecutively older units. Clinopyroxene and hornblende grains, however, are more etched in late Holocene than in early Holocene soils (fig. 5), a difference which may indicate that the late Holocene deposits have inherited etched grains from previously weathered sources. The Holocene soils also contain unusually large amounts of total Mg, exchangeable Mg and H, smectites, and oxalate-extractable and total Fe, and have high ratios of fine to total clay (see supplementary tables), which suggest reworking of previously weathered materials rich in ferromagnesian rocks of the foothills.

## EVALUATION OF SOIL DEVELOPMENT

### Site selection and sampling criteria

Sampling sites had to meet the following requirements to be included in this chronosequence study. Ideally, sites had not been cultivated, had 0- to 3-percent slopes, showed no active erosion, were on well-drained, sandy alluvium, and had a grassland vegetation. The requirement that excluded the largest area was cultivation. Most of the eastern San Joaquin Valley is intensely cultivated, typically including grading of surfaces, plowing of the upper half-meter of soil, and addition of large amounts of fertilizers, herbicides, and other soil amendments. All sampling sites in the study area were free from major grading, some sites had been farmed lightly, and all sites had been grazed by livestock at some time in the historical past.

[3] Although alluviation along major streams may have coincided with Holocene glaciations in response to climatic fluctuations (Marchand and Allwardt, 1981), alluvial deposits in the valley were probably derived primarily from the metamorphic rocks in the foothills. Several late Holocene moraines are still confined to the high alpine areas on the west slope of the Sierra Nevada (Curry, 1969; Yount and others, 1982), and preservation of these moraines indicates that the granitic debris was not captured by western drainages.

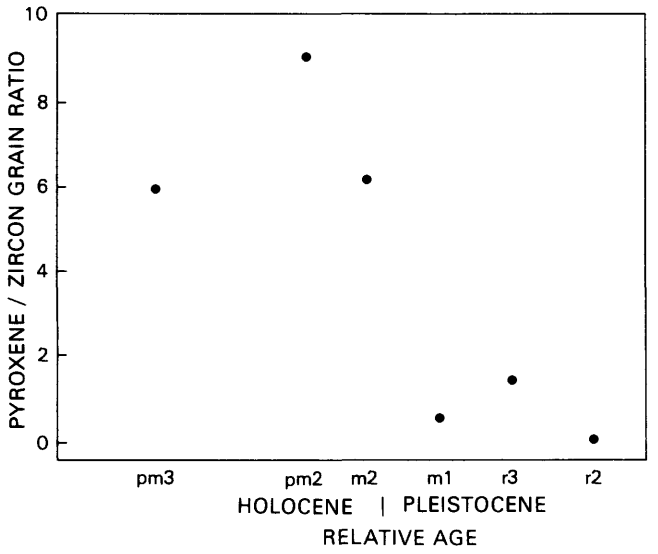


**Figure 4.** Ratio of pyroxene to zircon grains in the very fine sand fraction of C horizons of Merced soils. See table 2 for map units; data listed in supplementary table 4.

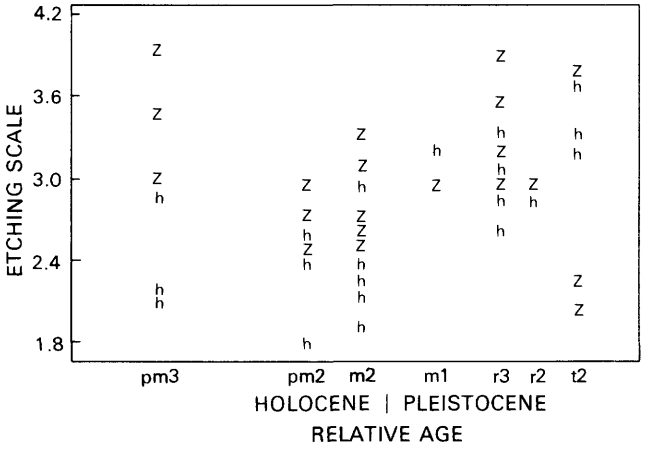


**Figure 5.** Etching scale of hornblende (h) and zircon (Z) grains from the very fine sand fraction of Merced soils. Etching scale after Gillam and others (1977).

Another requirement that excluded many potential sites was internal (vertical) drainage. Many soils in the Central Valley have hardpans cemented by carbonates, iron oxides, or silica that greatly affect the movement of soil water. Such hardpans may have formed as a result of initial stratification or drainage boundaries in the soil parent material (Marchand, 1976a; Harden and Marchand, 1977). Soils with hardpans were avoided in this study so as to compare only well-drained soils. All sites were sampled on topographic highs with slopes of 0 to 3 percent.

Further requirements of uniform vegetation and uniform parent-material texture were generally met, as outlined in figure 2 and generalized below for the study area. Sampling pits were excavated by backhoe or by hand, or sampled along a roadcut or bluff (in which case the site was dug at least a meter inward from the exposed vertical cut). Soils were sampled at least to the depth of the B3 (BC) horizons. Soils were described in the field (Soil Survey staff, 1962) and analyzed for several chemical, physical, and mineralogic properties; most of the analyses were described in detail by Singer and Janitsky (1986):

| Soil-forming factor | Description |
|---|---|
| Climate | Xeric moisture regime (mean annual precipitation, 30 cm), thermic temperature regime (mean annual temperature, 16 °C). |
| Vegetation | Perennial, annual grasses, scattered oaks (Quercus lobata). |
| Topography | Topographic highs, 0- to 3-percent slopes. |
| Parent material | Sand-loamy texture, granitic composition. |
| Age (ka) | 0.2-3,000 |

## Assumptions and methods

Some important limitations affect the interpretation of a soil chronosequence. Soil-forming factors other than time differ among the sampling sites, and so the differences in soils would be due not only to age but also to differences in other factors. If the variations in other factors is random within the chronosequence, then trends with increasing age are dominated by time rather than by other factors. For example, if precipitation at the sampling sites increased covariantly with age, then soil differences are due not only to age but also to the precipitation gradient. In the study area, precipitation increases slightly with the age of these soils, but this effect is thought to be minimal. Random differences in soil-forming factors (other than time) among the sampling sites might be an important source of soil variations, and accounting for these variations is likely to improve the age trends.

A similar complexity in a chronosequence is climatic change over time; older soils might have undergone more variations in climate, as well as drier or wetter climates, in comparison with younger soils. In the study area, soils older than those of the upper member of the Modesto Formation underwent at least one full glacial-to-interglacial cycle, and successively older soils underwent successively more cycles—an attribute of cumulative frequency and not necessarily one of differences in inherent precipitation. Because Holocene soils were developed only in Holocene, interglacial climates, important climate-related differences may exist between Holocene and pre-Holocene soils.

Reference to soil processes and pathways of soil development may be misleading if only chronosequence data are considered. For example, a soil property such as clay content may change systematically with age, but older soils may have had clay forming in place, whereas younger soils may have received clay from flood deposits. In addition, the systematicness of a plot of a soil property versus age does not necessarily reflect a continuous process. Because the deposits in this study were apparently generated during similar (late) phases in a climatic cycle, stepwise functions or some other pathway of soil development (such as the "soil-forming intervals" proposed by Morrison, 1967) would not be evident simply from age plots of soil properties. As Yaalon (1975) emphasized, the use of chronosequences to decipher pathways of soil genesis would be improved by smaller increments between the ages of deposits. The rates of soil or soil-property development are useful, but only as an empirical measure of cumulative processes. In figures 6, 7, and 9 through 12, the term "age" rather than "time" is used on the x-axis to emphasize this shortcoming.

Uncertainty in the numerical ages affects the correlation between soil properties and age; this uncertainty is large in most cases (a factor of 2 is typical). The uncertainty, expressed as a percentage, differs between age groups and generally is not centered about the best-estimate ages, and so the errors are not symmetrical. Several different graphical and numerical approaches are used to represent age uncertainties and their bearing on interpretation.

Laboratory-measurement error is small in comparison with the natural soil variation represented by replicate soils on a given terrace (Harden, 1982b; Singer and Janitzky, 1986). As a result, by analyzing replicate soils on given deposits, soil variation encompasses the smaller laboratory error.

### Trends of soil development with increasing age

Some soil properties develop rapidly or regularly within a given age interval, before or after which the properties decline or do not develop with age, or show irregular age trends (figs. 6, 7). Possible intermittent action of soil processes over long timespans results in a time dependence of soil-property development. Soil properties are discussed below according to the processes that may be time dependent, although such time dependence is hypothetical and limited by the numerous assumptions discussed above.

Clay content, rubification (figs. 6A, 6B), iron oxide content (fig. 7C) and the soil-development index (explained in detail for these soils by Harden, 1982a) increase throughout the 3,000-ka age span of these soils. These four properties increase most strikingly at first, then increase more slowly during later stages (older units) of soil development. Soil-property curves are bowl shaped if plotted against age on a log scale, and straighten when plotted as log (soil)-log (age) functions. Development of these properties is clearly nonlinear over such long timespans.

For young (as old as 10 ka) deposits of the Merced area, organic-matter content increases with soil age. Soils of this age range can be differentiated on the basis of their carbon content and by darkening and thickening of the A horizons, represented by melanization (fig. 6C). Although all soil characteristics vary somewhat, owing to stratification of the alluvium, strata in the upper meter are mixed by biotic (animals and plant roots) and mineralogic (swelling of grains) processes and weather fluctuations (freeze-thaw, shrink-swell). After about 10 ka, organic-carbon content and melanization generally decline irregularly with age, possibly in relation to a decline in soil fertility and in response to the climatic changes that are inherent in the trends of older soils.

After stabilization of the surface, soil structure forms (see supp. table 1), and peds become harder or firmer as binding agents develop, such as sesquioxides and organic matter. Buildup of binding agents is evident from the increase in hardness as measured by dry consistence of soils younger than about 100 ka (fig. 6D). Most of the structure and hardness in young (Holocene) soils develop in the A horizons, whereas in older (Pleistocene) soils, further changes occur mostly in the B horizons. After about 100 to 600 ka of soil development, consistence and structure apparently reach a maximum state of development, whereafter structure and consistence generally decline unsystematically. Commensurate with the development of consistence and structure in these soils, bulk density begins to increase within a few hundred years of surface stabilization, and then reaches a maximum after about 100 to 300 ka (see supp. table 2).

Properties related to clay formation[4] and translocation and to soil acidity develop most noticeably in soils older than about 100 ka. Although the total clay content increases in both young and old soils (fig. 6B), morphologic evidence for increase in clay content is unclear until sometime between about 10 and 100 ka, as indicated by increases in clay films (fig. 7B) and total texture. Soil acidity, indicated by pH lowering in figure 7D, develops mostly between about 600 and 3,000 ka.

Most physical and morphologic properties appear to be unaffected by mineralogic differences in the parent materials, as evidenced by smooth, systematic age curves through the Holocene to Pleistocene. Some soil parameters, however, particularly those measured by chemical analyses, appear to be highly sensitive to the mineralogic differences between deposits. Age trends of dithionite-extractable Fe (fig. 7C) demonstrate the difference between Holocene and pre-Holocene deposits. Most chemical analyses must be evaluated separately for these two age groups because the parent materials differ. Although the total-chemical analyses are discussed below only for Pliocene and Pleistocene age ranges, the same processes clearly must have occurred during the Holocene as well (there have been considerable

[4]Increase of kaolinite content over time suggests that this clay mineral is forming in these soils (see supp. table 4).

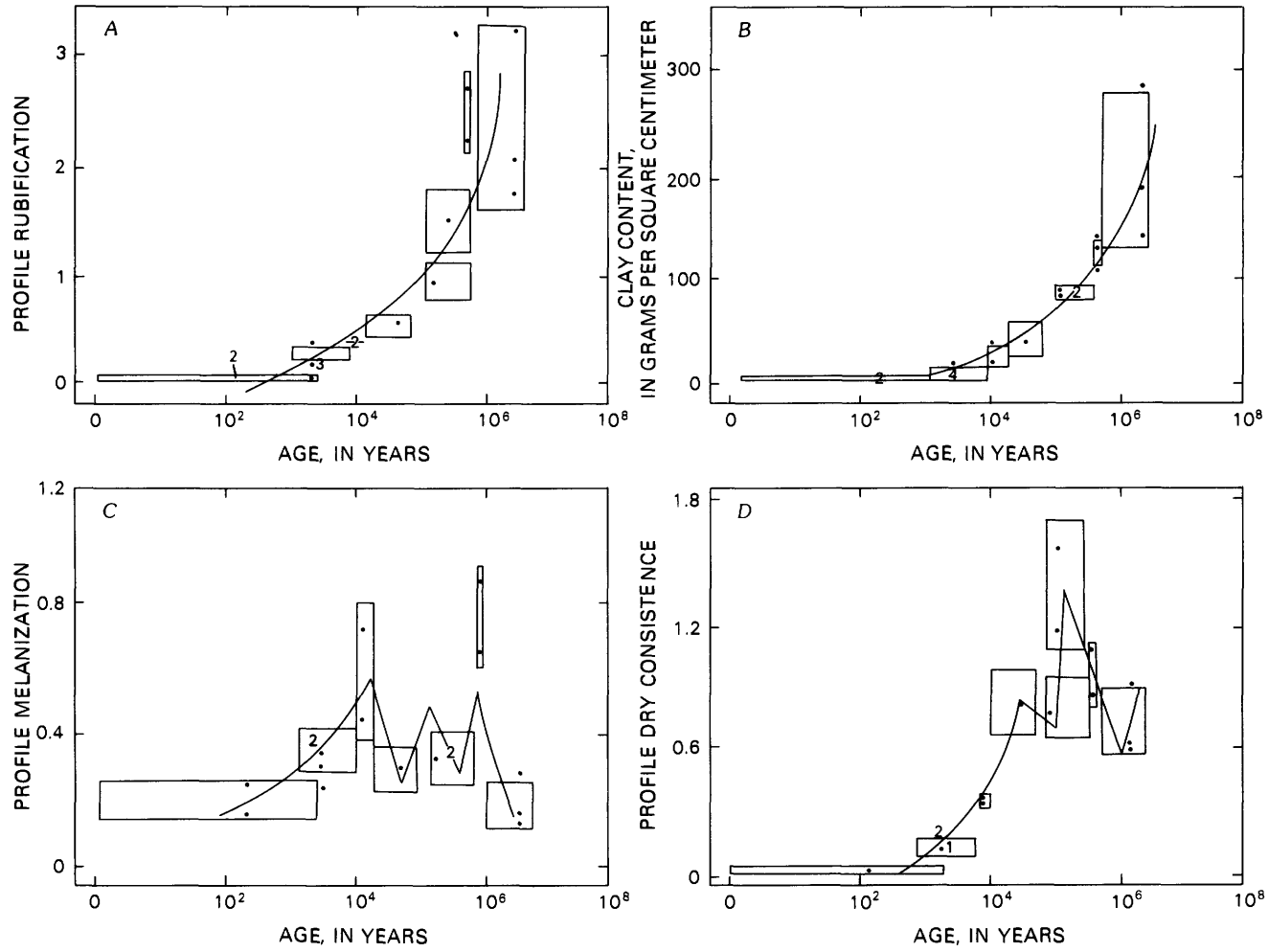


**Figure 6.** Examples of soil properties that develop over long timespans (A, B) and for initial timespans (C, D). A, Rubification. B, Clay content. C, Melanization. D, Dry consistence. Points and numbers indicate number of samples and best-estimate ages. Vertical dimension of boxes indicates one standard deviation for replicate soil profiles on same surface; horizontal dimension indicates total age uncertainty (table 2). Field properties in figures 6A, 6C, and 6D from Harden (1982a).

transformations in the youngest Pleistocene soil, which shows no evidence of reworked, preweathered parent material).

## Major- and trace-element chemistry

Two size fractions, 2 mm (whole soil) and silt plus clay (fine), were separated and analyzed for total amounts of major and trace elements. Major elemental oxides were determined by X-ray fluorescence (see supp. tables 5, 6), and trace elements were determined by instrumental neutron activation (see supp. tables 7, 8). The composition of the sand fraction was also determined by calculating the difference between the whole-soil and fine fractions. Samples chosen for analysis generally include the lowermost A1 horizon, the B horizon containing the most clay, and the lowermost C horizon. Trends in major-elemental composition of the A-horizon silt plus clay are used to demonstrate the methods used for data interpretation.

### Relative rates of element loss

The concentrations of major elements change profoundly over the 3,000-ka age span of these soils. Greater understanding of these changes requires that actual losses or gains of an element be distinguished from apparent changes caused by the opposite loss or gain of other constituents. Two methods were devised to determine the losses and gains of elements over time. The first method, referred to as the accumulation-series method, examines elemental ratios over time; the second method, referred to as the net-loss method, uses Merrill's (1906) loss equation, in which a stable constituent and a standard are defined for

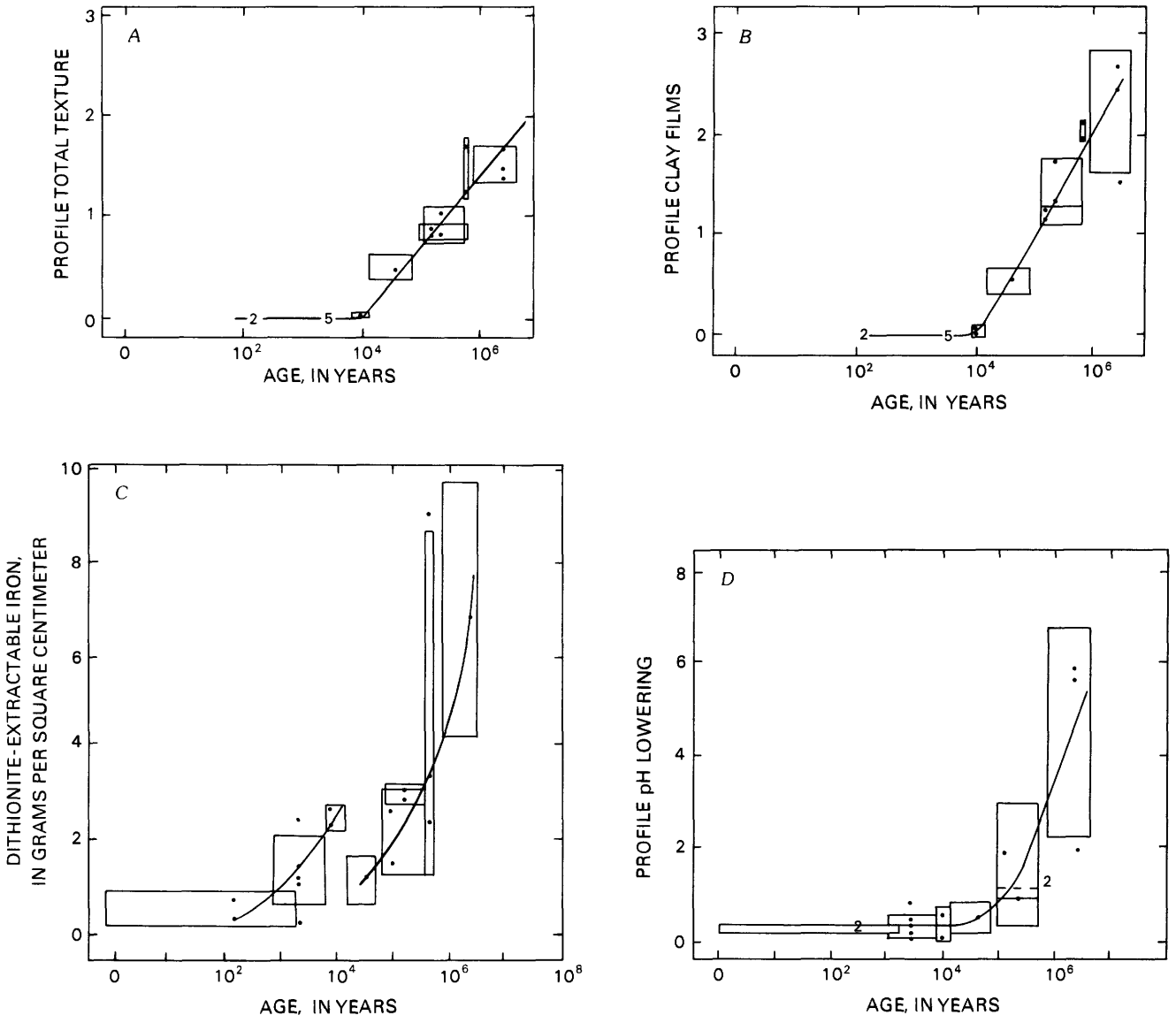


**Figure 7.** Examples of soil properties that show changes after 100 ka. A, Total texture. B, Clay films. C, Dithionite-extractable Fe. D, pH lowering. Vertical dimension of boxes indicates one standard deviation for replicate soils on deposit; horizontal dimension of box indicates total age uncertainty (table 2). Field properties in figures 7A and 7B from Harden (1982a).

calculating actual losses (positive values) or gains (negative loss values) of other constituents. Both methods allow for net loss or net gain of elements.

Methods for an accumulation series of elemental oxides

In the accumulation-series method (fig. 8), a ratio of two elements is tested for significant increases or decreases with age. The order of accumulation or depletion of elements is obtained by comparing the concentration of each element to that of every other element in a ratio and by tabulating the consecutive order of accumulation or depletion. The term "accumulation" is used here because it can mean net gain or only apparent gain by loss of other constituents. Net depletion or dilution by other elements can also cause relative accumulations. Rank correlation is used to test the age trends in which elemental ratios and age are both ranked from low to high categories. The (ranked) elemental ratio is then regressed against the (ranked) age. In this case, only the relative age

A

Spearman's rho coefficient for rank ratio versus rank age

NUMERATOR

| | Si | Al | Fe | Mg | Ca | Na | K | Ti | Zr |
|---|---|---|---|---|---|---|---|---|---|
| Si | --- | -0.369 | 0.033 | -0.567 | -0.758 | -0.680 | -0.649 | 0.313 | -0.805 |
| Al | .369 | --- | .651 | -.563 | -.767 | -.641 | .056 | .707 | .129 |
| Fe | -.033 | -.651 | --- | -.615 | -.770 | -.661 | -.565 | .217 | .078 |
| Mg | .567 | .563 | .615 | --- | -.662 | -.263 | .483 | .565 | .500 |
| Ca | .758 | .767 | .770 | .662 | --- | -.683 | -.773 | .771 | .675 |
| Na | .680 | .641 | .661 | .263 | -.683 | --- | .605 | .662 | .714 |
| K | .649 | -.056 | .565 | -.483 | -.773 | -.605 | --- | .670 | .609 |
| Tl | -.313 | -.707 | -.217 | -.565 | -.771 | -.662 | -.670 | --- | -.075 |
| Zr | .805 | -.129 | -.078 | -.500 | -.675 | -.714 | -.609 | .075 | --- |

B

NUMERATOR

| Accumulated relative to numerator | | Depleted relative to numerator |
|---|---|---|
| | Si | Mg,Ca,Na,K,Mn,Zr |
| Ti,Fe | Al | Mg,Ca,Na |
| | Fe | Al,Mg,Ca,Na,K,Mn |
| Fe,Al,Si | Mg | Ca,Ti,P (K,Zr) |
| Zr,Mn,P,Ti,K,Na,Mg,Fe,Al,Si | Ca | |
| Zr,P,Ti,K,Fe,Fe,Al,Si | Na | Ca |
| Zr,Ti,Fe,Si | K | Mg,Ca,Na |

C

Ti,Fe>Al>K>Mg,Na>Ca
Si>K

**Figure 8.** Example of method for deriving an accumulation series for relative rates of element loss or gain. A, Element ratios for A-horizon fine fraction, ranked and regressed against ranked age for Spearman's rho correlation. B, Element ratios listed as accumulated or depleted if significant at 5-percent-confidence level ($r \geq 0.66$). Numbers in parentheses, significant at 5- to 10-percent-confidence level. C, Series tabulated for relative rates of accumulation, with highest rates to left or most depleted to right.

must be known to determine the relative rates of element loss. The resulting correlation, or Spearman's rho coeffiecient (Tate and Clelland, 1957), is then a test for whether or not the elemental ratio changes significantly with relative age. Figure 8 illustrates this procedure. If an elemental ratio increases significantly with age, then the element in the numerator is said to accumulate relative to the element in denominator. A decreasing ratio indicates the reverse; if the ratio does not change significantly over time, the trend is not considered to be pedologically significant.[5]

[5]A constant ratio would infer that the elements are lost or gained at the same rate. Typically, however, when ratios do not change significantly with age, there is considerable scatter in the regression. Such scatter is likely to be caused by parent-material variation; therefore, statistical tests consider only significant changes with age.

For the silt-plus-clay fraction of the A horizons, Spearman's rho coefficients were determined for each (ranked) elemental ratio versus (ranked) age. For each element, the correlations of its ratio to the other elements are evaluated. If the ratio changes significantly (at the 5-percent-confidence level), then the relative loss or gain is tabulated (fig. 8B) by listing decreases with age to the right and increases to the left of the numerator (center column, fig. 8B). Elements listed to the right may be lost more rapidly or gained more slowly than a given element; elements listed to the left are either lost more slowly or gained more rapidly than the given element. The accumulation series of all elements is then tallied with accumulated or concentrated constituents to the left of other elements. For the A-horizon silt-plus-clay fraction, Fe, Ti, Si, and Al increase, and the alkaline-earth elements are depleted, relative to Zr (a stable constituent; fig. 8C).

## Methods for calculating loss percents of elemental oxides

Rates of element loss or gain can also be determined by using Merrill's (1906) loss equation, in which a stable or resistant species and an unweathered parent material are used as standards to monitor net changes in other constituents. For relative rates of element loss, the slopes of regression equations are used from correlating percent loss with age. Estimates of real percent loss can also be made, although many assumptions and limitations are used in these estimates.

Using the equation of Merrill (1906) for percent loss, and using Zr as the resistant species, Ca loss from the A horizons can be estimated as follows:

$$\text{Ca loss} = \frac{Ca_{pm}Zr_{A} - Ca_{A}Zr_{pm}}{Ca_{pm}Zr_{A}}$$

where pm signifies the parent material and A the A horizon.

For this study, Zr was used as the resistant species, and sample M12 was used as the parent material for all soils. Zr appears to be the most stable constituent, as indicated by its concentration in sand separates relative to the decreases in most other elements (see supp. tables 5-8). This stability is commensurate with the consistently low etching index of zircon grains in soils of various age (see supp. table 4). Barshad (1964), Wild (1961), Sudom and St. Arnaud (1971), and Busacca (1982) also found that Zr and zircon grains in soils are relatively resistant to loss and mobility. Given the resistance of Zr, element percent loss can be estimated by using Zr as a resistant species and by using a soil standard that represents the parent material. The C1 horizon of a soil from the lower member of the Modesto Formation (sample M12, from 20.1- to 23.1-cm depth) was chosen as the parent material for all soils because most soils were not sampled deep enough to reach relatively unweathered C horizons.

Use of a single parent material has the following advantages: (1) all data are normalized to a given standard; and (2) when element loss is plotted against age, the slopes of the curves do not change if the standard is changed. Thus, the estimated rates are good approximations that will change only when age uncertainties are considered. The disadvantages of using a single sample for the parent material are that (1) minor variations in parent material are not represented by the calculation; and (2) the intercepts, or estimates of loss percents, are not so valid because they depend on the chosen parent material. Mineralogic and chemical compositions of parent materials are assumed to be similar for Merced soils older than Holocene. Any variations among parent materials are most likely random and thus will increase scatter in the regression analysis. Holocene soils are not included because of compositional differences, and soils from the middle unit of the Riverbank Formation are omitted to ensure the correct order of ages (relative age).

Uncertainty of age estimates is a more complex problem for regressions of percent-loss calculations. Whereas relative age is established by the sequence of terraces, quantitative age can be listed only as a range (table 2). Most significantly, the uncertainty varies among the different deposits (as indicated by boxes in figs. 6 and 7). To determine the extent to which this uncertainty in age affects the correlation between chemical losses and age, the ages of units were allowed to vary within their constraints, and the resulting effects on regression were determined. If the slopes of the regressions maintain a similar order for all elements, then regression techniques can decipher relative rates of element loss by using best-estimate, assigned ages (table 2). Otherwise, relative rates of loss must rely on the accumulation-series method, using rank regression.

Ages of the different pre-Holocene units were varied for different regression analyses to test how age uncertainties affect the calculated rates of element loss. In table 3, these tests include various combinations of minimum and maximum ages, as well as the best-estimate age assignments listed in table 2. In general, the combinations chosen include those of maximum constraints on young ages with minimum constraints on old ages for finding maximum slopes, and the reverse (minimums for young and maximums for old) for minimum slopes. This technique is used in later sections of this report to estimate rates of soil development.

Regardless of the combination of possible ages used in regression (table 3), the order of slopes remains the same for percent loss. One exception is the order of Ca and Na loss, but these rates are so close that the differences are probably insignificant. For ordering the rates of loss, then, it is valid to use the relative order of slopes from regression of percent loss versus best-estimate age. Such regressions probably would be invalid if the relative age order were uncertain.

**Table 3.** Variation in rates of element loss from the A-horizon silt-plus-clay fraction, when age uncertainties are considered

[Ages used for trials: 1, best-estimate ages; 2 and 3, best-estimate ages with one young and one old constraint; 4 through 7, combined young, old, and best-estimate ages (see table 2). Rates vary by a factor of about 1.7. $\underline{S}$, standard deviation of predicted $\underline{y}$ values]

| | | | Age used for trial (ka) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trial---------- | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Map unit | | | | | | | | | | |
| m1 | | | 40 | 70 | 40 | 20 | 70 | 20 | 70 | |
| r3 | | | 130 | 130 | 130 | 130 | 130 | 103 | 250 | |
| r1 | | | 330 | 330 | 330 | 330 | 330 | 250 | 440 | |
| t2 | | | 600 | 600 | 600 | 600 | 600 | 570 | 615 | |
| CH | | | 3,000 | 3,000 | 1,000 | 4,000 | 4,000 | 4,000 | 1,000 | |
| Element | Regression | Units | | | | | | | | Range in rates (trial) |
| Al | Slope | percent/$\log_{10}$ yr | 0.213 | 0.249 | 0.223 | 0.170 | 0.171 | 0.278 | 0.267 | 0.170 (4) to 0.278 (6) |
| ($\underline{n}$=8) | $\underline{y}$-intercept | percent loss | -1.05 | -1.26 | -1.09 | -.804 | -.805 | -1.40 | -1.36 | |
| | $\underline{r}^2$ | .01 percent | .572 | .651 | .432 | .506 | .537 | .517 | .360 | |
| | $\underline{S}$ | percent loss | .11 | .10 | .13 | .12 | .12 | .12 | .14 | |
| Ca | Slope | percent/$\log_{10}$ yr | .412 | .458 | .460 | .343 | .340 | .537 | .588 | 0.340 (5) to 0.588 (7) |
| ($\underline{n}$=8) | $\underline{y}$-intercept | percent loss | -1.83 | -2.10 | -2.07 | -1.44 | -1.41 | -2.50 | -2.84 | |
| | $\underline{r}^2$ | .01 percent | .740 | .758 | .633 | .714 | .730 | .664 | .605 | |
| | $\underline{S}$ | percent loss | .15 | .15 | .18 | .16 | .15 | .17 | .19 | |
| Mg | Slope | percent/$\log_{10}$ yr | .319 | .354 | .358 | .266 | .264 | .418 | .458 | 0.264 (5) to 0.458 (7) |
| ($\underline{n}$=8) | $\underline{y}$-intercept | percent loss | -1.25 | -1.45 | -1.45 | -.949 | -.927 | -1.78 | -2.05 | |
| | $\underline{r}^2$ | .01 percent | .594 | .606 | .517 | .574 | .590 | .540 | .493 | |
| | $\underline{S}$ | percent loss | .16 | .16 | .18 | .17 | .16 | .173 | .18 | |
| Fe | Slope | percent/$\log_{10}$ yr | .124 | .140 | .136 | .101 | .099 | .165 | .173 | 0.099 (5) to 0.173 (7) |
| ($\underline{n}$=8) | $\underline{y}$-intercept | percent loss | -.452 | -.545 | -.526 | -.326 | -.312 | -.676 | -.738 | |
| | $\underline{r}^2$ | .01 percent | .621 | .656 | .537 | .582 | .582 | .585 | .490 | |
| | $\underline{S}$ | percent loss | .06 | .06 | .066 | .06 | .063 | .06 | .07 | |
| Na | Slope | percent/$\log_{10}$ yr | .405 | .459 | .436 | .333 | .333 | .521 | .548 | 0.333 (4, 5) to 0.548 (7) |
| ($\underline{n}$=8) | $\underline{y}$-intercept | percent loss | -.208 | -2.39 | -2.22 | -1.67 | -1.65 | -2.70 | -2.90 | |
| | $\underline{r}^2$ | .01 percent | .691 | .736 | .550 | .650 | .675 | .603 | .508 | |
| | $\underline{S}$ | percent loss | .167 | .15 | .20 | .18 | .172 | .19 | .21 | |

Regression lines and best-estimate ages were also used to order the rates of element loss in other size fractions of the A and B horizons (fig. 9; table 4).

### Resulting orders of rates of element loss

The accumulation-series and net-loss methods generally agree on the relative order of element loss. For example, for the A-horizon fine fraction, the order is Ti, Fe > Al > K > Mn > Na > Ca by the accumulation-series method and Si > Zr > K > Mn > Na > Ca by the net-loss method. The major difference in these two methods is that the net-loss method lists fewer elements, because it relies only on the significance of ratios with Zr versus time. In general, alkaline-earth elements are lost more rapidly than sesquioxides. Al is added more slowly to this fraction than Fe, as a result of either faster Fe dissolution of the sand fraction or more rapid incorporation into the fine fraction, in comparison with Al. The poor correlation of Zr ratios seen in the accumulation series (fig. 8A) suggests that although there are distinguishable differences in losses of Ti, Al, and Fe based on interrelations of these elements, Zr may not serve as a good index for monitoring their net loss. Indeed, Zr may not be truly stable, and so small losses or even gains of Zr into the silt or clay fraction would make the ratio correlation indeterminant. Relative to Al, there is a net gain of Ti and Fe. The increase in dithionite-extractable Fe over time (fig. 7C) verifies that Fe tends to be sustained in this fraction. Mabee (1978) found that magnetite grains incorporate Ti into the soils sampled in this study, an observation that explains the influx of Ti into this fraction relative to Al and, possibly, Fe.

The order of element loss varies among size fractions and horizons (table 4) in relation to processes of dissolution, translocation, and size fractionation. In the sand fraction of B horizons (fig. 9; table 4), the order of element loss is: Zr (most resistant) < Si < Al, K < Na < Ca. Cementation of fine particles into sand-size grains is not evident in these soils, and so the elements in the sand fraction are an index of the relative retention of elements by primary mineral grains, or, in other words, an index of dissolution. Mineral grains generally release Ca, Mg, and Na more readily than Si, Al, and K, and (or) minerals rich in Ca, Mg, and Na are more easily weathered than those rich in Si, Al, and K. There may be a net gain of Ti and, possibly, Fe into the sands via the magnetic grains (Mabee 1978), but there is no systematic change over time of either element relative to Zr.

In contrast to the order of element loss from the sand fraction, the silt-plus-clay fraction of B horizons gains Al, Ti, Fe, and Si (table 4). These elements may be weathering from sand grains and upper soil horizons and reprecipitating in the B-horizon clays. Clay mineralogy (see supp. table 4) indicates a regular increase of kaolinite over time. Although the mineralogy explains the influx of Al into the fine fraction, there is no strong evidence for desilication of the illite-dominated parent material. The influx of Ti can be explained by incorporation into both magnetite and octahedral layers of clays (Barshad, 1953), possibly in the abundant vermuculite clays (see supp. table 4).

The relative order of element loss from the less-than-2-mm fraction in B horizons is generally similar to that in the sand fraction, where Zr > Fe > Al > Na > Ca > Mg (percent-loss method, table 4). If, indeed, there are net losses of Fe and Al in the less-than-2-mm fraction, they are due mostly to dissolution of sand grains, because there are net gains of these elements in the silt-plus-clay fraction. The relative loss of Ca and Na is similar to that in the sand but different from that in the fine fraction (percent-loss method, table 4), possibly owing to incorporation of Na into secondary compounds or minerals. Silica is lost more readily from sand than is Al (accumulation-series method, table 4), but the reverse is true for the fine fraction. Thus, enrichment of Al in the whole soil is due to rates of Al and Si enrichment of clays rather than to rates of Al and Si release from sands.

Several other studies have estimated the relative rates of element loss, and despite differences in their methodologies, their results are nearly identical to those of this study. Comparing fresh to weathered rock or less-than-2-mm soil, Steidtmann (1908) concluded that Al is concentrated (gained more rapidly or lost more slowly) at higher rates than Fe, although Goldich (1938) found the reverse to be true. Both of these reports found that Si is intermediate in rate of loss between the sesquioxides (Fe and Al) and Na, Mg, and Ca. Because Si constitutes more than 60 percent of the elemental analyses, volumes of Si loss could be substantial. Although the losses of Na, Mg, and Ca were greater than those of other elements, their relative order varied among the studies and was related in part to the composition of the parent rock. Colman (1982) found similar rates of accumulation or loss in basalt and andesite, where Ti > Fe > K > Al > Si > Mg > Na > Ca.

This study generally confirms the conclusions of other workers, although the approach differs somewhat. The previous work compared one weathered sample to the parent material, whereas in this study the element-loss series is based on five different-age samples plus a parent material. The advantage of comparing several different-age samples is evident in figure 9. Using only the oldest sample for the less-than-2-mm fraction (fig. 9), Ca is apparently lost more readily than Na or Mg; but using the rates of loss for all pre-Holocene soils, Mg is actually lost most readily. Another advantage of this study over previous ones is in the separation of the size fractions. As discussed above, the less-than-2-mm soil fraction demonstrates that Fe and Al are lost relatively slowly; analysis of the sand and fine fractions shows that these low rates are due both to slow release of Fe and Al from the sand fraction and to slow release and reprecipitation of sesquioxides in the silt-plus-clay fraction. Although mechanisms in these two size fractions are probably interdependent, comparison of the rates in separate fractions is a step closer to understanding the causes of chemical differentiation in soils.

## Estimating rates of soil development

The number and age span of surfaces and soils and their associated ages invite calculations of soil-

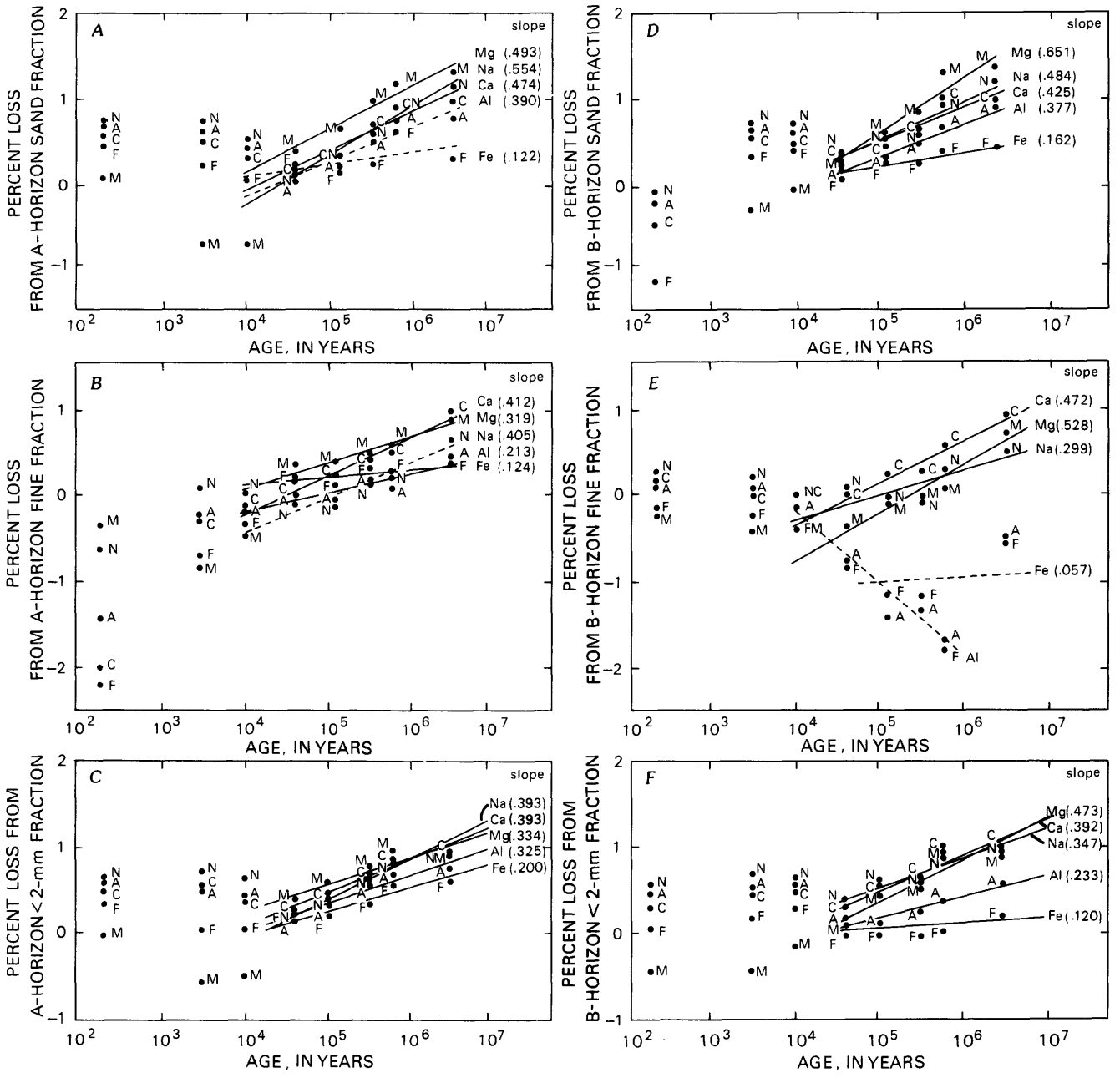


**Figure 9.** Percentage of element loss from A (A-C) and B (D-F) horizons for three size fractions versus best-estimate age. Using Merrill's (1906) loss equation (eq. 1), calculations used Zr for a stable index and sample M12-C1 for parent material. Linear regression was computed for all analyses, but values for each age group (table 2) are averaged to show sample point. Dashed lines indicate regressions with less than 95-percent confidence (trial 1, table 3). Holocene soils are plotted but not used in regression because of differences in parent material. Positive slope, net loss; negative slope, net gain.

development rates, in which a given soil property is plotted or regressed against age. In addition, analysis of multiple soil profiles on a given-age surface provides a measure of soil variation. There are important limitations to these techniques, however, many of which have been identified or rectified in previous sections of this report. Probably the greatest limitation to estimating soil-development rates from soil chronosequences is age uncertainties. As discussed in the preceding section, the effect of age uncertainties can be assessed by using different combinations of ages to calculate soil-development rates. Because some soil properties may change over wide or only narrow age ranges (for example, organic-carbon accumulation during the Holocene, or clay-film development during the Pliocene and Pleistocene),

**Table 4.** Order of rates of element loss from size separates

[Percent-loss method from Merrill's (1906) loss equation, using Zr as index and sample M12-C1 as parent material (see fig. 9 for regressions). Other elements were omitted because correlations with age were poor. Accumulation-series method as in figure 8]

| Fraction | A horizon | B horizon |
|---|---|---|
| | Percent-loss method | |
| Silt plus clay---- | Zr<Fe<Al<Mg<Na<Ca | Al<Fe≤Zr<Na<Ca<Mg |
| Sand---------- | Zr<Fe<Al<Ca<Mg<Na | Zr≤Fe<Al<Ca≤Na<Mg |
| Whole soil-------- | Zr<Fe<Al<Mg<Na,Ca | Zr≤Fe<Al<Na<Ca<Mg |
| | Accumulation-series method | |
| Silt plus clay---- | Ti,Fe<Al<K<Mg,Na<Ca | Ti,Fe,Al<Si<Zr<K<Na<Ca |
| Sand---------- | Ti,Zr<Si,Fe<Al<K<Ca | Ti<Fe,Si<Al,K<Na<Ca and Zr<Si |
| Whole soil-------- | Ti<Fe<Si<Al,K<Na,Ca | Ti,Fe<Al<Si<K<Na,Ca and Zr<K |

regressions of soil properties versus age are studied separately for the age spans 0-10, 0-3,000, 20-600, and 20-3,000 ka.

For soil properties that develop throughout the 3,000-ka age span of these surfaces, plots of soil property versus age are convex downward (fig. 10A), and of soil property versus the logarithm of age are bowl shaped (fig. 6B); the straightest curves are in log-log plots of soil property versus age (fig. 10A). Thus, linear regression must be applied only to log-log transformations for the wide (3,000 ka) age span. Seven trials of different age combinations suggest that rates using best-estimate ages are accurate within a factor of about 2 (fig. 10A; table 5). Minimum rates, obtained in trial 5 or 6, are obtained when minimum ages are used for young units and maximum ages for old units. Maximum rates (trial 2 or 3) correspond to a combination of maximum young and minimum old ages. Intermediate-age units in either of these cases may be assigned either best-guess or constraining ages.

Soil properties that develop primarily during the Holocene or Pleistocene age spans raise some important questions as to whether rates are linear or exponential. Properties that develop only during the Holocene or Pleistocene generally fit into linear curves, even when age uncertainies are accounted for. The seven combinations of ages have significant correlation coefficients for linear regressions of soil property versus age (figs. 10B, 10C; table 6). As in the trials for elemental analysis and the wide-range regressions (table 5), age uncertainties permit the rates to vary by a factor of about 2. If soil properties from the wide-range examples are plotted for only the Holocene or Pleistocene, the same properties appear to have linear rates, even though these rates are generally exponential over wider age spans. The exponential functions, then, might be approximated by linear segments along the curve (fig. 11). As would be

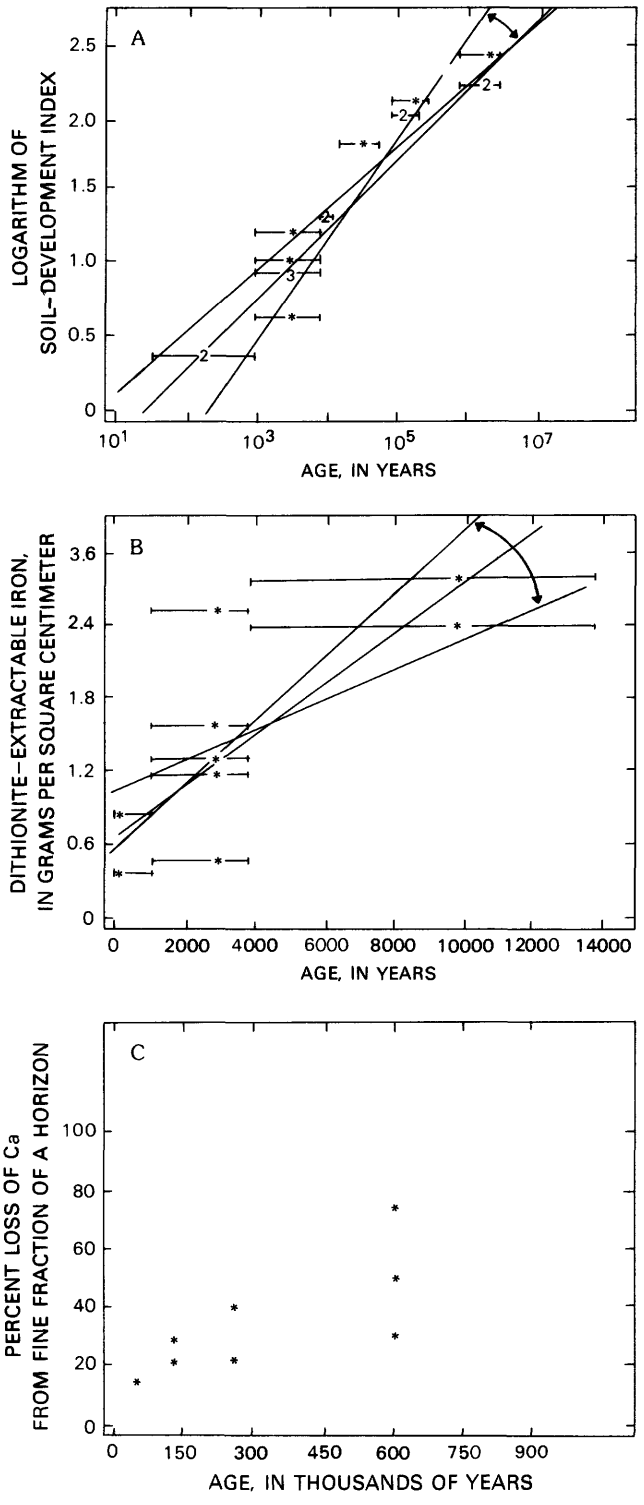


**Figure 10.** Rates of soil-property development for three timespans. A, Soil-development index. B, Dithionate-extractable Fe. C, Percent loss of Ca from A-horizon silt-plus-clay fraction. Points and numbers indicate samples at best-estimate age (table 1); error bars represent age uncertainty. Regression lines for constraining rates are from tables 5 through 7.

**Table 5.** Tests for constraining rates of soil development for Late Cenozoic deposits, when age uncertainties are considered

[Field properties from Harden (1982a). Rates vary by a factor of about 1.7. $\underline{S}$, standard deviation of predicted $\underline{y}$ values]

| | | | Age used for trial (ka) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trial---------- Map unit | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| pmIII | | | 0.20 | 1.00 | 1.00 | 1.00 | 0.05 | 0.05 | 0.20 | |
| pmII | | | 3.00 | 8.30 | 8.30 | 1.00 | 1.00 | 1.00 | 3.00 | |
| m2 | | | 10.00 | 14.00 | 14.00 | 14.00 | 8.30 | 8.30 | 10.00 | |
| m1 | | | 40.00 | 40.00 | 20.00 | 20.00 | 40.00 | 70.00 | 40.00 | |
| r3 | | | 130.00 | 130.00 | 103.00 | 103.00 | 130.00 | 250.00 | 130.00 | |
| r2 | | | 250.00 | 103.00 | 103.00 | 330.00 | 330.00 | 330.00 | 330.00 | |
| t2 | | | 600.00 | 570.00 | 570.00 | 615.00 | 615.00 | 615.00 | 615.00 | |
| CH | | | 3,000.00 | 1,000.00 | 1,000.00 | 4,000.00 | 4,000.00 | 4,000.00 | 4,000.00 | |
| Property | Regression | Units | | | | | | | | Range in rate (trial) |
| Soil development index (SDI). ($\underline{n}$=20) | Slope | log SDI/log yr | 0.495 | 0.680 | 0.674 | 0.555 | 0.415 | 0.412 | 0.479 | 0.412 (5) to 0.680 (2) |
| | $\underline{y}$-intercept | log SDI x cm/100 | -.731 | -1.64 | -1.59 | -1.12 | -.296 | -.299 | -.675 | |
| | $\underline{r}^2$ | .01 percent | .931 | .930 | .908 | .869 | .950 | .958 | .932 | |
| | $\underline{S}$ | log SDI x cm/100 | .173 | .19 | .21 | .25 | .16 | .14 | .18 | |
| Rubification (rub). ($\underline{n}$=18) | Slope | log rub/log yr | .107 | .146 | .146 | .120 | .089 | .089 | .104 | 0.089 (5, 6) to 0.146 (2, 3) |
| | $\underline{y}$-intercept | log rub x cm/100 | -.271 | -.465 | -.459 | -.358 | -.177 | -.176 | -.259 | |
| | $\underline{r}^2$ | .01 percent | .884 | .879 | .868 | .826 | .890 | .889 | .876 | |
| | $\underline{S}$ | log rub x cm/100 | .06 | .056 | .06 | .068 | .054 | .05 | .057 | |
| <2-μm clay ($\underline{n}$=20) | Slope | log g/cm$^2$/log yr | .454 | .620 | .617 | .513 | .381 | .377 | .440 | 0.377 (6) to 0.620 (2) |
| | $\underline{y}$-intercept | log g/cm$^2$ | -.556 | -1.37 | -1.34 | -.938 | -.158 | -.157 | -.507 | |
| | $\underline{r}^2$ | .01 percent | .937 | .916 | .902 | .884 | .950 | .954 | .933 | |
| | $\underline{S}$ | log g/cm$^2$ | .16 | .19 | .20 | .22 | .14 | .14 | .17 | |

expected from exponentially decreasing functions, Holocene rates are 10 times higher than Pleistocene rates of the same soil properties (table 7). Although the exact form of the curves may not prove to be correct when more data are available, the data clearly show that initial rates are highest at first and drop off drastically within 100 ka.

The age combinations in tables 5 through 7 generally constrain the rates of soil (or soil property) development. They demonstrate that best-estimate ages are intermediate between minimum and maximum possible rates, and that rates based on best-estimate ages are accurate to within a factor of about 2. Although the linear rates documented for the Holocene and Pleistocene may not be representative for long-term processes, the straight, nonlogarithmic units are easy to interpret and compare with those from other studies, and they are probably reasonable approximations of short-term rates.

## DISCUSSION

The systematic changes in the properties of Merced soils with age suggest that over intervals of thousands of years, some processes may act nearly continuously on soils, regardless of shorter term fluctuations and perturbations in soil-forming factors, such as paleoclimate or erosion. One question that should be addressed, however, is whether pre-Holocene soils formed as a result of modern soil-forming processes, or whether they are relict from past and different processes. If past processes were similar to modern ones, then "empirical" rates of soil-property development with age may be reasonable estimates of the actual rates. If past effects of paleoclimate and vegetation on soil development can be accounted for, then soil-chronosequence studies can provide an onsite, empirical laboratory for such fundamental questions as how soil properties and rates of soil development differ with climate and time, how mineral-dissolution rates compare with those determined by laboratory and theoretical studies, and how soils might respond to such perturbations as cultivation, erosion, deposition, or changes in climate.

The changes in major-element (total) chemistry over time are generally systematic for most of the size fractions and soil horizons. The changes over time in the A horizons suggest that the geomorphic surfaces are somewhat stable and do not receive significant amounts of eolian materials, or that such processes are time dependent. It may be that the surfaces are being eroded, but erosion rates would have to be slow for chemical trends of the A horizons to change systematically with age. For example, if all the surfaces had vast erosion rates, then soils probably would not form. If individual soils were more eroded than others, then age trends would not be expected, especially in the A horizons. If these soils are being eroded slowly but continually, then the actual rates of soil development would be far greater than those documented by the chronosequence. Decreasing rates of various soil properties over time (table 8) could reflect geomorphic stability rather than the kinetics of mineral dissolution or other soil processes. Recent $^{10}$Be analyses of the soils sampled in this study (M.J. Pavich, written commun., 1984) suggest significant erosion of these surfaces. One argument for a kinetic origin of the decreasing rates of soil development is

**Table 6.** Tests for constraining rates of soil development for Holocene deposits, when age uncertainties are considered

[Field properties from Harden (1982a). Trial 7 is generally not significant at the 5-percent-confidence level. Rates commonly vary by a factor of about 2.5. $\underline{S}$, standard deviation of predicted $\underline{y}$ values]

| | | | Age used for trials (ka) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trial---------- | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Map unit | | | | | | | | | | |
| pmIII | | | 0.20 | 0.05 | 0.05 | 0.05 | 1.00 | 1.00 | 0.20 | |
| pmII | | | 3.00 | 3.00 | 8.30 | 1.00 | 3.00 | 8.30 | 8.30 | |
| m2 | | | 10.00 | 14.00 | 14.00 | 14.00 | 8.30 | 8.30 | 8.30 | |
| Property | Regression | Units | | | | | | | | Range in rate (trial) |
| Organic-carbon content. | Slope | $g/cm^2/ka$ | 0.036 | 0.023 | 0.030 | 0.018 | 0.048 | 0.042 | 0.038 | 0.18 (4) to 0.48 (5) |
| | $\underline{y}$-intercept | $g/cm^2$ | .636 | .669 | .537 | .713 | .060 | .488 | .522 | |
| | $\underline{r}^2$ | .01 percent | .256 | .225 | .341 | .168 | .251 | .277 | .277 | |
| | $\underline{S}$ | mel x cm/ka | .22 | .228 | .21 | .24 | .22 | .22 | .22 | |
| Melanization (mel). ($\underline{n}$=10) | Slope | mel x cm/ka | 3.83 | 2.54 | 2.68 | 2.19 | 5.10 | 2.87 | 2.58 | 2.19 (4) to 5.10 (5) |
| | $\underline{y}$-intercept | mel x cm | 22.0 | 25.0 | 15.8 | 29.2 | 18.0 | 17.1 | 19.4 | |
| | $\underline{r}^2$ | .01 percent | .69 | .662 | .627 | .592 | .684 | .308 | .308 | |
| | $\underline{S}$ | mel x cm | 9.4 | 9.80 | 10.3 | 10.8 | 9.5 | 14.0 | 14.0 | |
| Dithionite-extractable Fe. ($\underline{n}$=9) | Slope | $g/cm^2/ka$ | .192 | .127 | .136 | .110 | .255 | .155 | .139 | 0.110 (4) to 0.255 (5) |
| | $\underline{y}$-intercept | $g/cm^2$ | .744 | .889 | .445 | 1.09 | .545 | .465 | .592 | |
| | $\underline{r}^2$ | .01 percent | .60 | .576 | .568 | .512 | .597 | .306 | .306 | |
| | $\underline{S}$ | $g/cm^2$ | .61 | .63 | .63 | .672 | .610 | .80 | .80 | |
| Dry consistence (dc). ($\underline{n}$=8) | Slope | dc x cm/ka | 3.27 | 2.14 | 2.53 | 1.85 | 4.34 | 2.46 | 2.21 | 1.85 (4) to 4.34 (5) |
| | $\underline{y}$-intercept | dc x cm | 4.31 | 7.15 | -3.32 | 11.1 | .987 | .544 | 2.56 | |
| | $\underline{r}^2$ | .01 percent | .18 | .900 | .805 | .855 | .916 | .268 | .268 | |
| | $\underline{S}$ | $g/cm^2$ | 3.78 | 4.18 | 5.8 | 5.2 | 3.8 | .11 | 11.3 | |
| Rubification (rub). ($\underline{n}$=10) | Slope | rub x cm/ka | 2.78 | 1.81 | 2.12 | 1.50 | 3.69 | 2.58 | 2.33 | 1.50 (4) to 3.69 (5) |
| | $\underline{y}$-intercept | rub x cm | 11.1 | 13.5 | 5.25 | 16.7 | 8.29 | 4.11 | 6.23 | |
| | $\underline{r}^2$ | .01 percent | .644 | .596 | .700 | .494 | .637 | .446 | .446 | |
| | $\underline{S}$ | $g/cm^2$ | 7.5 | 8.03 | 6.9 | 9.0 | 7.6 | 9.4 | 9.4 | |
| <2-μm clay ($\underline{n}$=10) | Slope | $g/cm^2/ka$ | 2.30 | 1.56 | 1.46 | 1.39 | 3.08 | 1.29 | 1.16 | 1.16 (7) to 3.08 (5) |
| | $\underline{y}$-intercept | $g/cm^2$ | 2.40 | 4.13 | -.047 | 6.57 | .056 | 2.52 | 3.57 | |
| | $\underline{r}^2$ | .01 percent | .730 | .733 | .46 | .705 | .732 | .182 | .182 | |
| | $\underline{S}$ | $g/cm^2$ | 5.11 | 5.08 | 6.6 | 5.3 | 5.1 | 8.9 | 8.9 | |
| Soil development index (SDI). ($\underline{n}$=10) | Slope | SDI x cm/ka | 1.69 | 1.12 | 1.18 | .966 | 2.25 | 1.25 | 1.12 | 0.966 (7) to 2.25 (5) |
| | $\underline{y}$-intercept | SDI x cm | .22 | 4.53 | .540 | 6.4 | 1.47 | 1.17 | 2.20 | |
| | $\underline{r}^2$ | .01 percent | .845 | .816 | .764 | .732 | .841 | .369 | .369 | |
| | $\underline{S}$ | SDI x cm | 2.6 | 2.87 | 3.3 | 3.5 | 2.7 | 5.32 | 5.3 | |

that studies on mineral weathering (Colman, 1982) typically document initially rapid rates, followed by slower rates.

The appropriateness of linear or nonlinear curve fitting is a difficult problem to overcome with these data. This study has shown that long-term exponential curves can be approximated by shorter term, linear segments (fig. 11); other chronosequence studies with narrow age spans may be approximated by linear rates for the same reason. In other words, such studies may actually demonstrate long-term nonlinear rates if older and (or) younger units were available for sampling.

Estimation of the ages of other deposits by using soil chronosequences is an important implication of this study, because so many soil properties change systematically with age. The age uncertainties of the chronosequence, however, are intrinsic to prediction of other ages. The clay content of Merced soils provides a good example for some methods and illustrates the problems with age prediction. When the clay content ($\underline{y}$-axis) is regressed against best-estimate age ($\underline{x}$-axis) about the regression line, then the standard error of estimate $\underline{S}$, given by

$$\underline{S} = \frac{\underline{y}-\underline{y}_{pred}}{\underline{n}-2}$$

(where $\underline{y}_{pred}$ is the predicted value of $\underline{y}$, and $\underline{n}$ is the number of samples), is about 30 percent (see table 5). In other words, there is about 30-percent scatter about the regression line related to soil variation. This result is commensurate with estimates of the amount of soil variation on a single-age surface, as represented by the standard deviation divided by the mean for replicate soils on a given terrace (Harden, 1982b). When the axes are switched, however, so that age is the dependent variable ($\underline{y}$-axis), then $\underline{S}$ more than doubles to about 70 percent (fig. 12). (Because the best-estimate ages are fixed without any uncertainties, this standard error cannot be related to inaccurate dating of the terraces.) The standard error, which is a rough estimate of how precise age estimates

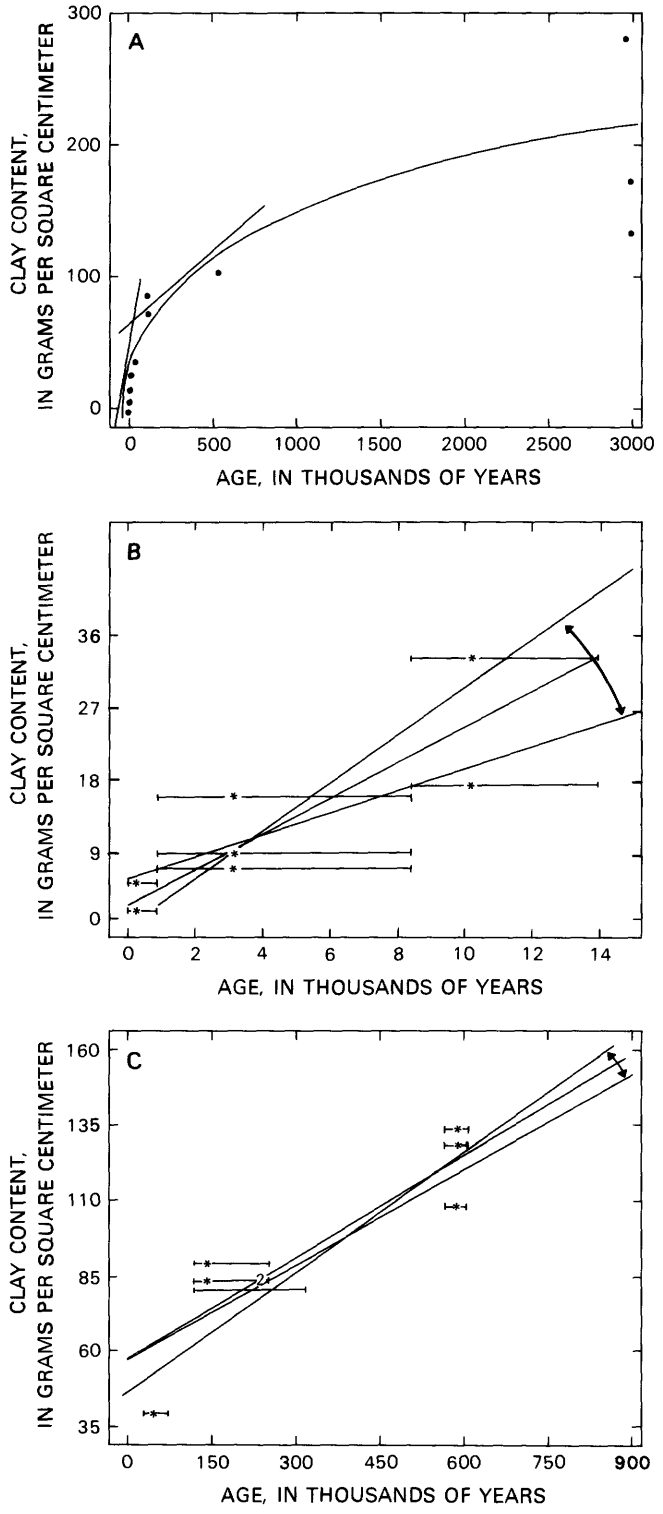


**Figure 11.** Exponential curve of clay content versus age, approximated by linear segments. A, Clay content versus log age for the timespan 3,000-0 ka. B, clay versus age for the timespan 10-0 ka. C, Clay versus age for the timespan 600-20 ka. Points and numbers indicate samples at best-estimate ages (table 2); error bars indicate constraining ages. Regression lines for rates are from tables 5 through 7.

by soils could be, suggests that a 100-ka-old deposit would be reported as being from about 40 to 160 ka old. More appropriate statistics are needed to consider the source of these errors. The standard error should increase when age errors are incorporated, but it might decrease when more appropriate statistics are used. Intuitively, because soil variation is typically about 30 percent, more appropriate statistics and sampling might improve the estimates to no better than about 30 percent for this clay function over the 3,000-ka age span.

Another aspect that should be considered for age prediction is the time dependence of different soil parameters. Although it is probably advantageous to use several soil properties for age estimates, a scheme must be devised for using properties that are limited to the Holocene or Pleistocene. One possibility is to use wide-range (0-3,000 ka) properties (table 5) for first-order estimates, and then to use Holocene and pre-Holocene parameters (tables 6, 7) for the appropriate soils. The more restricted age ranges, with their linear rates, might actually improve the precision of age estimates because then the standard errors are lower than in exponential functions.

## SUMMARY

The soil chronosequence near the Merced River demonstrates that many soil properties develop systematically over time and that a significant association exists between soil properties and geologic age. Morphologic properties that develop most regularly with age over wide (3,000 ka) or narrower (10 ka to a few tens of thousands of years) age ranges include clay films, total texture (texture and wet consistence), rubification (color hue and chroma), dry consistence, and the soil-development index (Harden, 1982a), which combines the morphologic properties. Elements determined by total-chemical analysis that change most systematically with age include Ca, Mg, Na, Fe, Al, and Ti, as expressed in loss percent relative to Zr, which is assumed to be stable. Physical properties most indicative of age include clay percent, bulk density, and thickness or depth to C horizons; extractive-chemical analyses include dithionite- and oxalate-extractable Fe. Although many mineralogic properties (percentages and degree of etching) do not change systematically with age or cannot be measured precisely enough, these analyses help to interpret the significance of other trends.

Several of the methods for data analysis described in this report can be applied to similar studies. From total-chemical analysis, an accumulation series was developed to determine relative rates of element loss. This series can be used for soil chronosequences that lack radiometric age control but whose relative ages are well defined. Merrill's (1906) loss calculation was adopted for calculating the percent loss of an element from a given size fraction. Zr appears to work well as a stable index element. The selection of a single sample for the parent material of all soils appears to be appropriate for pre-Holocene deposits.

**Table 7.** Tests for constraining rates of soil development for Pleistocene deposits, when age uncertainties are considered

[Field properties from Harden (1982a). Rates vary by a factor of about 1.3. $\underline{S}$, standard deviation of predicted $\underline{y}$ values]

| | | | Age used for trial (ka) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Trial---------- | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | |
| Map unit | | | | | | | | | | |
| m1 | | | 40.0 | 20.0 | 20.0 | 20.0 | 70.0 | 70.0 | 70.0 | |
| r3 | | | 130.0 | 130.0 | 250.0 | 103.0 | 130.0 | 103.0 | 250.0 | |
| r2 | | | 250.0 | 330.0 | 330.0 | 330.0 | 103.0 | 103.0 | 250.0 | |
| t2 | | | 600.0 | 615.0 | 615.0 | 615.0 | 570.0 | 570.0 | 600.0 | |
| Property | Regression | Units | | | | | | | | Range in rate (trial) |
| Total texture ($\underline{n}$=7) | Slope | total texture x cm/ka | 0.153 | 0.144 | 0.166 | 0.138 | 0.148 | 0.145 | 0.177 | 0.138 (4) to 0.177 (7) |
| | $\underline{y}$-intercept | total texture x cm | 51.5 | 50.5 | 38.1 | 53.4 | 59.8 | 61.7 | 37.7 | |
| | $\underline{r}^2$ | .01 percent | .806 | .774 | .822 | .754 | .748 | .744 | .830 | |
| | $\underline{S}$ | total texture x cm | 18.7 | 20.2 | 17.9 | 21.1 | 21.4 | 21.5 | 17.5 | |
| Clay films ($\underline{n}$=7) | Slope | clay films x cm/ka | 0.218 | 0.213 | 0.246 | .204 | .194 | .190 | .249 | 0.190 (6) to 0.249 (7) |
| | $\underline{y}$-intercept | clay films | 79.4 | 75.5 | 56.9 | 79.9 | 95.2 | 97.7 | 60.8 | |
| | $\underline{r}^2$ | .01 percent | .830 | .863 | .923 | .841 | .655 | .654 | .837 | |
| | $\underline{S}$ | clay films | 24.6 | 22.0 | 16.5 | 23.8 | 34.9 | 35.0 | 24.0 | |
| Rubification (rub). ($\underline{n}$=5) | Slope | rub x cm/ka | .339 | .329 | .347 | .322 | .323 | .319 | .369 | 0.319 (6) to 0.369 (7) |
| | $\underline{y}$-intercept | rub x cm | 49.4 | 46.8 | 32.1 | 50.9 | 65.9 | 68.8 | 28.8 | |
| | $\underline{r}^2$ | .01 percent | .942 | .955 | .926 | .953 | .825 | .832 | .900 | |
| | $\underline{S}$ | rub x cm | 25.6 | 22.4 | 28.9 | 23.0 | 44.4 | 43.5 | 33.6 | |
| Soil development index (SDI). ($\underline{n}$=7) | Slope | SDI x cm/ka | .212 | .198 | .225 | .190 | .207 | .203 | .244 | 0.190 (4) to 0.244 (7) |
| | $\underline{y}$-intercept | SDI x cm | 59.2 | 58.4 | 42.1 | 62.4 | 70.1 | 72.7 | 40.7 | |
| | $\underline{r}^2$ | .01 percent | .762 | .721 | .154 | .705 | .728 | .726 | .779 | |
| | $\underline{S}$ | SDI | 29.4 | 31.9 | 29.9 | 32.8 | 31.4 | 31.6 | 28.3 | |
| <2-μm clay ($\underline{n}$=8) | Slope | g/cm$^2$/ka | .112 | .108 | .130 | .103 | .105 | .102 | .134 | 0.102 (6) to 0.134 (7) |
| | $\underline{y}$-intercept | g/cm$^2$ | 57.8 | 65.5 | 44.8 | 59.0 | 64.5 | 66.2 | 46.1 | |
| | $\underline{r}^2$ | .01 percent | .183 | .774 | .901 | .743 | .712 | .694 | .870 | |
| | $\underline{S}$ | g/cm$^2$ | 15.1 | 15.4 | 10.2 | 16.4 | 17.4 | 17.9 | 11.4 | |
| Dithionite-extractable Fe. ($\underline{n}$=8) | Slope | g/cm$^2$/ka | .0061 | .0060 | .0067 | .0058 | .0057 | .0056 | .0069 | 0.0056 (6) to 0.0069 (7) |
| | $\underline{y}$-intercept | g/cm$^2$ | 1.40 | 1.31 | .866 | 1.42 | 1.79 | 1.85 | .924 | |
| | $\underline{r}^2$ | 0.1 percent | .352 | .353 | .353 | .349 | .311 | .314 | .343 | |
| | $\underline{S}$ | g/cm$^2$ | 2.1 | 2.13 | 2.13 | 2.13 | 2.19 | 2.19 | 2.14 | |

**Table 8.** Comparison of Holocene and Pleistocene rates of soil development from tables 6 and 7

[Field properties from Harden (1982a)]

| Property | Units | Holocene rate | Pleistocene rate |
|---|---|---|---|
| Dithionite-extractable Fe. | g/cm$^2$/ka | 0.110-0.255 | 0.0056-0.0069 |
| Rubification (rub)----- | rub x cm/ka | 1.5-3.69 | .319-0.369 |
| <1-μm clay---------- | g/cm$^2$/ka | 1.16-3.08 | .102-0.134 |
| Soil-development index (SDI). | SDI x cm/ka | .966-2.25 | .190-0.244 |

Long-term rates of soil development or some aspect of soil development, such as element loss or morphologic changes, can be estimated from these data. The variation between soils on the same age surface was represented by replication of soils on each terrace. Uncertainties in the ages of deposits can be considered by using minimum and maximum age constraints.

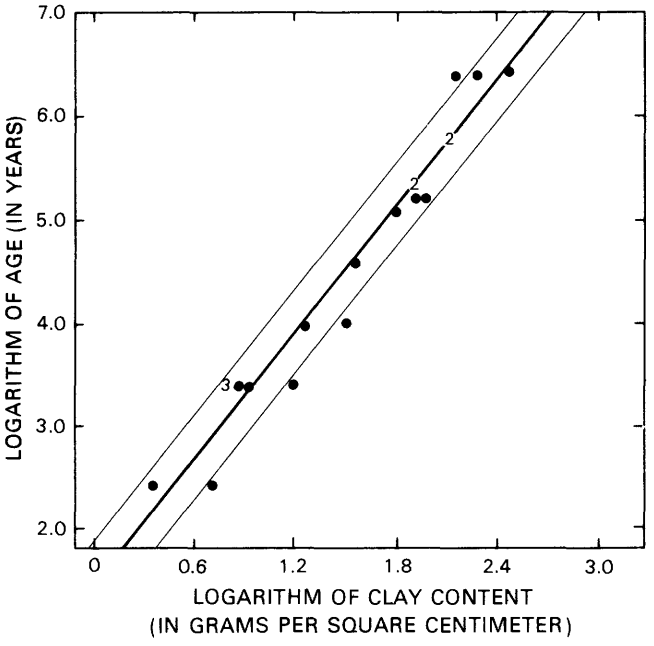


**Figure 12.** Example of estimating age from soil development. Points and numbers indicate number of samples. Heavy line, regression line; light lines, standard deviation of predicted $\underline{y}$ values about regression line.

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# SUPPLEMENTARY TABLES

**Supplementary Table 1.** Field descriptions

EXPLANATION

(see fig. 13 for sample locations)

SOIL STRUCTURE

| Grade | Size | Type |
|---|---|---|
| m, massive | vf, very fine (v thin) | gr, granular |
| sg, single grained | f, fine (thin) | pl, platey |
| 1, weak | m, medium, | pr, prismatic |
| 2, moderate | c, coarse (thick) | cpr, columnar |
| 3, strong | vc, very coarse (v thick) | abk, angular blocky |
| | | sbk, subangular blocky |

If two structures-listed as primary and secondary

SOIL TEXTURE

| | | |
|---|---|---|
| co, coarse | S, sand | SCL, sandy-clay loam |
| f, fine | LS, loamy sand | CL, clay loam |
| vf, very fine | SL, sandy loam | SiCL, silty-clay loam |
| | L, Loam | SC, sandy clay |
| | SiL, silt loam | C, clay |
| | Si, silt | SiC, silty clay |

SOIL CONSISTENCE

| Dry | Moist | Wet | |
|---|---|---|---|
| lo, loose | lo, loose | so, nonsticky | po, nonplastic |
| so, soft | vfr, very friable | ss, slightly sticky | ps, slightly plastic |
| sh, slightly hard | fr, friable | s, sticky | p, plastic |
| h, hard | fi, firm | vs, very sticky | vp, very plastic |
| vh, very hard | vf, very firm | | |
| eh, extremely hard | efi, extremely firm | | |

HORIZON BOUNDARIES

| Distinctness | Topography |
|---|---|
| va, very abrupt | s, smooth |
| a, abrupt | w, wavy |
| c, clear | i, irregular |
| g, gradual | b, broken |
| d, diffuse | |

ROOTS AND PORES

| Size | Abundance | Pore Shape |
|---|---|---|
| vf, very fine | 1 few | tub, tubular |
| f, fine | 2 common | ir, irregular |
| m, medium | 3 many | v, vesicular |
| co, coarse | | |

CLAY FILMS

| Frequency | Thickness | Morphology |
|---|---|---|
| $v_1$, very few | n, thin | pf, ped face coatings |
| 1, few | mk, moderately thick | br, bridging grains |
| 2, common | k, thick | po, pore linings |
| 3, many | | (w, occurs as waves or lamellae) |
| 4, continuous | | co, coats on clasts |

| Site | Geologic unit | Elev. (ft) | Present vegetation | Recent land use | Parent texture | Location (Mount Diablo base meridian) |
|---|---|---|---|---|---|---|
| **Modern river alluvium** | | | | | | |
| MRA1 | --- | 40 | ---------- | ---------- | ---------- | Ctr. SW1/4 sec. 2, T. 7 S., R. 9 E. |
| MRA2 | --- | 40 | ---------- | ---------- | ---------- | NW1/4NE1/4 sec. 2, T. 7 S., R. 9 E. |
| MRA3 | --- | 70 | ---------- | ---------- | ---------- | SE1/4SE1/4 sec. 34, T. 6 S., R. 10 E. |
| MRA4 | --- | 260 | ---------- | ---------- | ---------- | NE1/4NW1/4 sec. 10, T. 5 S., R. 14 E. |
| **Post-Modesto deposits** | | | | | | |
| PM15 | III | 80 | Annual grass---- | None---------- | SL | SE1/4SE1/4 sec. 34, T. 6 S., R. 10 E. |
| PM19 | III | 70 | do---------- | Heavy grazing--- | SL | NE1/4NE1/4 sec. 5, T. 6 S., R. 10 E. |
| PM8 | II | 70 | Annual grass, live oak. | None---------- | SiL/SL | NE1/4NW1/4 sec. 6, T. 7 S., R. 10 E. |
| PM13 | II | 65 | Annual grass, riparian. | do---------- | SiL/SL | NW1/4NW1/4 sec. 2, T. 7 S., R. 9 E. |
| PM14 | II | 65 | do---------- | do---------- | SiL/SL | NW1/4NW1/4 sec. 2, T. 7 S., R. 9 E. |
| PM16 | II | 85 | Annual grass---- | 2-5-yr melons--- | SL | E1/2 secs. 3, 34, T. 7 S., R. 10 E. |
| PM17 | II | 85 | do---------- | do---------- | SL | E1/2 secs. 3, 34, T. 7 S., R. 10 E. |
| PM18 | II | 265 | Annual grass, live oak. | Settlement------ | SL | Ctr. SW1/4 sec. 3, T. 5 S., R. 14 E. |
| **Modesto Formation** | | | | | | |
| M31 | Upper member------- | 70 | Annual grass---- | None---------- | SiL/SL | NE1/4NW1/4 sec. 5, T. 7 S., R. 14 E. |
| M46 | do---------- | 105 | Irrigated pasture. | Pre-1965 crops. | SL | Ctr. N1/2 sec. 28, T. 6 S., R. 11 E. |
| M12 | Lower member------- | 160 | Annual grass---- | None---------- | SL | NE1/4SE1/4 sec. 9, T. 6 S., R. 12 E. |
| **Riverbank Formation** | | | | | | |
| R9 | Upper unit--------- | 295 | Irrigated pasture. | Pasture--------- | SL | SW1/4SE1/4 sec. 10, T. 5 S., R. 14 E. |
| R33 | do---------- | 295 | Annual grass--- | do---------- | SL | NW1/4NW1/4 sec. 15, T. 5 S., R. 14 E. |
| R2 | Middle unit-------- | 260 | do---------- | None---------- | SL | SE1/4NE1/4 sec. 11, T. 5 S., R. 13 E. |
| R10 | do---------- | 260 | do---------- | do---------- | SL | SE1/4NE1/4 sec. 11, T. 5 S., R. 13 E. |
| R32 | do---------- | 260 | do---------- | do---------- | SL | Ctr. N1/2 sec. 12, T. 5 S., R. 13 E. |
| R30 | Lower--------- | 275 | do---------- | do---------- | SL | NE1/4NE1/4 sec. 11, T. 5 S., R. 13 E. |
| **Turlock Lake Formation** | | | | | | |
| T2 | Upper unit--------- | 425 | Annual grass---- | None---------- | SL | SE1/4NE1/4 sec. 31, T. 3 S., R. 14 E. |
| T6 | do---------- | 305 | do---------- | do---------- | SL | SW1/4SW1/4 sec. 31, T. 3 S., R. 13 E. |
| T11 | do---------- | 355 | do---------- | Turkey farm----- | SL | NE1/4NE1/4 sec. 11, T. 4 S., R. 13 E. |
| **Laguna Formation** | | | | | | |
| CH1 | China Hat Gravel Member. | 590 | Annual grass---- | Pasture--------- | SL/grS | NE1/4NW1/4 sec. 2, T. 6 S., R. 14 E. |
| CH2 | do---------- | 720 | do---------- | do---------- | SiL/grS | SE1/4SW1/4 sec. 30, T. 5 S., R. 15 E. |
| CH3 | do---------- | 730 | do---------- | do---------- | SiL/grS | NW1/4SE1/4 sec. 30, T. 5 S., R. 15 E. |

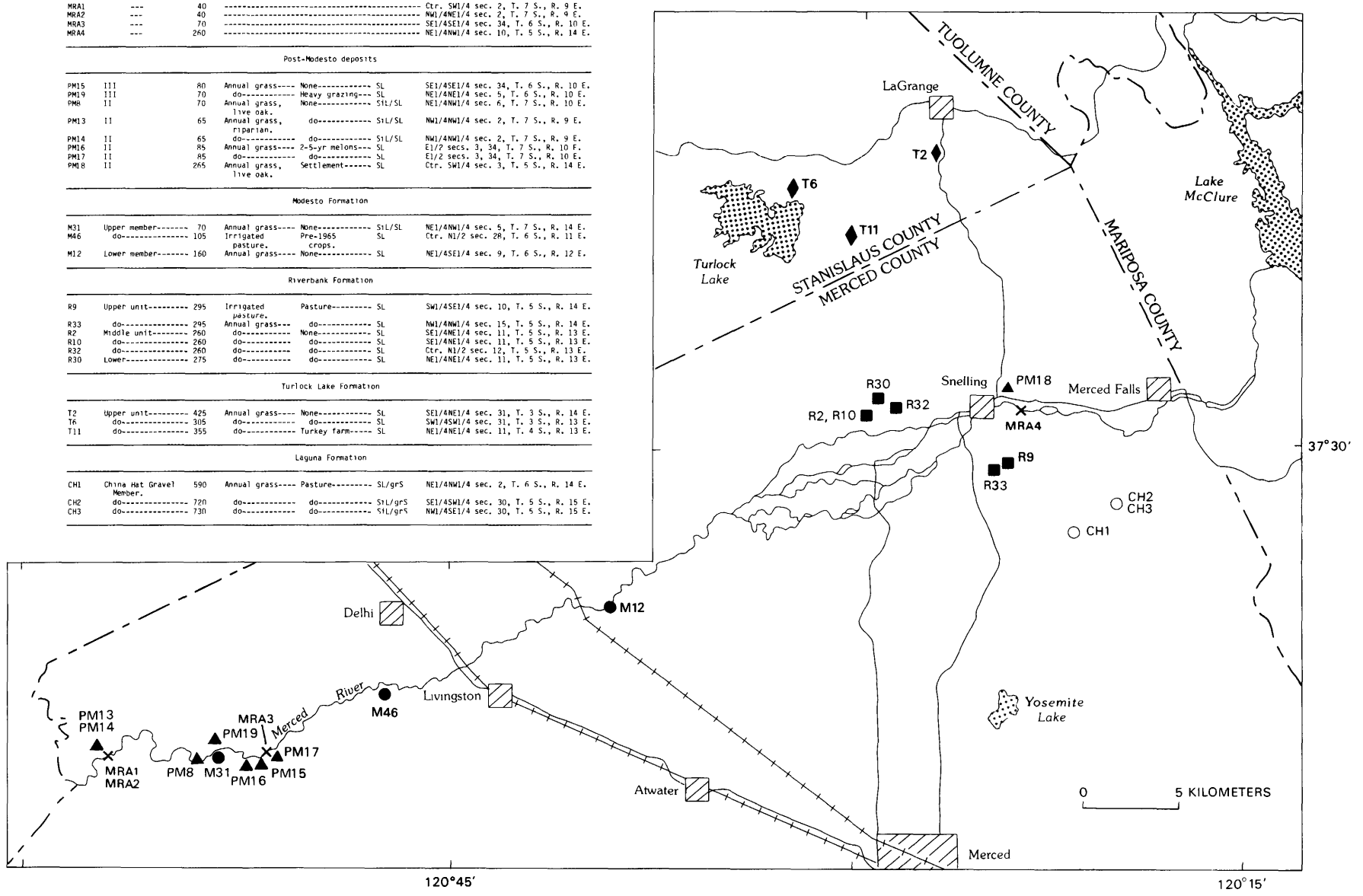



**Figure 13.** Study area in central California, showing locations of sampling sites.

## Supplementary Table 1. Field descriptions—Continued

[Analyst: J.W. Harden U.S. Geological Survey]

| No. | Sample | Horizon | Basal depth (cm) | Lower boundary | Moist color | Dry color | Texture | Structure | Consistence | | | Roots | Pores | Clay films | pH | Assumed Parent Material | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Dry | Moist | Wet | | | | | Texture | Wet consistence |
| **Modern River Alluvium** | | | | | | | | | | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Post-Modesto Deposits, .2 Ka** | | | | | | | | | | | | | | | | | |
| 5 | PM15 | A | 0-4 | a,w | 10YR3/3 | 10YR5/3 | S | 1 m gr | lo | lo | so,po | 3vf | -- | 0 | 5.84 | S | so,po |
| 6 | | IIClox | 4-19 | a,w | 10YR4/4 | 10YR5/4 | LS | m | sh | fr | so,po | 2vf,2f | 1ftub | 0 | 5.69 | LS | so,po |
| 7 | | IIIC2ox | 19-42 | --,w | 10YR4/3 | 10YR5/3 | S | sg | lo | lo | so,po | 2vf,1m | -- | 0 | 5.56 | S | so,po |
| 8 | | IVC3ox | 42-47 | a,i | 10YR3/3.5 | 10YR6/4, 10YR5/6 | LS | sg | lo | vfr | so,po | 2m | -- | 0 | 5.55 | LS | so,po |
| 9 | | VC4n | 47-51 | a,w | 10YR4/2 | 10YR6.5/2 | coS | sg | lo | lo | so,po | -- | -- | 0 | 5.72 | coS | so,po |
| 10 | | VICn | 51- | -- | 10YR4/3.5 | 10YR6/3 | S | sg | lo | lo | so,po | 1f | -- | 0 | 5.82 | S | so.po |
| 11 | PM19 | A11 | 0-7 | c,w | 10YR2/2 | 10YR6/3 | SL | 1 m gr | sh | vfr | so,po | 3vf,3f | 1fir | 0 | 5.56 | SL | so,po |
| 12 | | IIA12 | 7-12 | g,w | 10YR3/2 | 10YR6/3 | fSL | m,1 m sbk | -- | fr | so,po | 2f | 2f, 1mtub | 0 | 6.25 | fSL | so,po |
| 13 | | IIIC1ox | 12-23 | g,w | 10YR3/3 | 10YR6/3 | LS | m | -- | vfr | so,po | 2f | 1ftub | 0 | 6.32 | LS | so,po |
| 14 | | IVC2ox | 23-43 | a,w | 10YR3/3 | 10YR5/3 | L | m, 1 m sbk | -- | fr | ss,oo | 1m,1f, 1cs | 2f, 1mtub | 0 | 6.91 | L | ss,po |
| 15 | | VC3ox | 43-49 | a,w | 10YR3/3 | 10YR6/3 | LS | sg | -- | lo | so,po | 1f | -- | 0 | 6.79 | LS | so,po |
| 16 | | VIC4ox | 49-55 | a,w | 10YR3/2 | 10YR6/3 | vfSL | m | -- | fr | so,po | 1f | 2ftub | 0 | 6.98 | vfSL | so,po |
| 17 | | VIIC5ox | 55-66 | a,w | 10YR3/2 | 10YR6.5/3 | S | sg | -- | lo | so,po | -- | -- | 0 | 6.54 | S | so,po |
| 18 | | VIIIC6 | 66-80+ | -- | 10YR3/2 | 10YR6/3 | SiL | m | -- | fr | ss,po | 2vcs | 2ftub | 0 | -- | SiL | ss,po |
| **Post-Modesto Deposits, 3 Ka** | | | | | | | | | | | | | | | | | |
| | PM8 | Ao | 4-0 | c,s | -- | -- | -- | 2 gr | -- | -- | -- | 3f,3m | -- | 0 | -- | -- | -- |
| 19 | | A1 | 0-28 | g,w | 10YR3/3 | 10YR5/4 | SiL | 1 m sbk | so | fr | ss,po | 3f,3m | 1ftub | 0 | 6.33 | SiL | ss,po |
| 20 | | IIC1 | 28-51 | c,w | 10YR3/3 | 10YR5/3 | vfSL | 1 co sbk | sh | fr | so,po | 1f | 1mtub | 0 | 7.20 | vfSL | so,po |
| 21 | | IIIC2 | 51-62 | g,s | 10YR4/3 | 10YR6/3 | LS | m | sh | vfr | so,po | -- | -- | 0 | 7.33 | LS | so,po |
| 22 | | IVC3 | 62-76 | -- | -- | -- | fS | sg | -- | lo | so,po | -- | -- | 0 | 7.48 | fS | so,po |
| 23 | PM13 | A11 | 0-5 | a,s | 10YR3/2 | 10YR5/4 | SiL | 2 f gr | so | vfr | ss,po | -- | 2m, 2fir | 0 | 6.30 | SiL | ss,po |
| 24 | | A12 | 5-35 | c,w | 10YR3/3 | 10YR4/3 | L | m, m sbk, f gr | so | vfr | ss,po | 2f | 2f, 1mtub | 0 | 7.71 | L | ss,po |
| 25 | | IIC1ox | 35-86 | g,w | 10YR4/3 | 10YR5/3 | SL | m, m sbk | -- | vfr | so,po | 1m, 1co | 2vf tub | 0 | 7.85 | LS | so,po |
| 26 | | IIIC2ox | 86-112 | -- | 10YR4/3 | 10YR5/4 | LS | m, m sbk | -- | vfr | so,po | 1f | 1vf tub | 0 | 7.35 | LS | so,po |
| 27 | | IVC3ox | 112-136 | -- | 10YR4/3 | 10YR5/3 | LS | sg | -- | lo | so,po | -- | -- | 0 | -- | LS | so,po |
| 28 | | VC4ox | 136-160+ | -- | 10YR4/4, 3/6 | 10YR5/4 | SiL | m | -- | lo | ss,po | -- | -- | 0 | -- | SiL | ss,po |
| 29 | | | | | | | | | | | | | | | | | |
| 30 | PM14 | A11 | 0-3 | a,s | 10YR3/3 | 10YR5/3 | L | 2 m gr | -- | vfr | ss,po | 3f | 3fir | 0 | 6.42 | L | ss,po |
| 31 | | IIA12 | 3-33 | c,w | 10YR3/3 | 10YR4/3 | SiL | m, m sbk | -- | vfr | ss,po | 2m,2f | 2ftub | 0 | 7.83 | SiL | ss,po |
| 32 | | IIIC1ox | 33-99 | g,w | 10YR4/3 | 10YR5/3 | SL | m, m sbk | -- | vfr | so,po | 2vf | 1f tub | 0 | 7.83 | SL | so,po |
| 33 | | IVC2ox | 99-130 | c,w | 10YR4/3 | 10YR5/3 | LS | m, 1 m sbk | -- | vfr | so,po | 1co, 1vc | 1vf tub | 0 | 6.88 | LS | so,po |
| 34 | | VC3ox | 130-175 | c,w | 10YR3/3 | 10YR5/4 | SL | m | -- | vfr | so,po | -- | -- | 0 | 6.54 | SL | so,po |
| 35 | | VIC4ox | 175-200 | c,w | 10YR3/3 | 10YR5/3 | LS | m | -- | vfr | so,po | -- | -- | 0 | 6.66 | LS | so,po |
| 36 | | VIIC5n | 200-230+ | -- | 10YR5/2 | 10YR7/2 | S | sg | -- | lo | so,po | -- | -- | 0 | 6.92 | S | so,po |
| 37 | PM16 | A | 0-2 | a,w | 10YR3/4 | 10YR4/3 | SL | 1 m gr | sh | fr | so,po | 3vf | 1mir | 0 | 6.50 | SL | so,po |
| 38 | | C1ox | 2-25 | g,w | 10YR3/4 | 10YR5/4 | fSL | m, 2 m sbk | sh | fr | so,po | 2vf | 2vf tub | 0 | 6.48 | fSL | so,po |
| 39 | | IIC2ox | 25-35 | g,w | 10YR3/3 | 10YR5/3 | fSL | m, 2 m sbk | sh | fr | ss,po | 2vf | 2vf tub | 0 | 6.86 | fSL | ss,po |
| 40 | | IIIC3ox | 35-65 | g,w | 10YR4/4 | 10YR5/4 | LS | m, 1 m sbk | so | vfr | so,po | 1f | 1vf, 1ftub | 0 | 7.29 | LS | so,po |
| 41 | | IVC4ox | 65-90 | g,w | 10YR4/3 | 10YR6/2 | S | sg | -- | vfr | so,po | 1f | -- | 0 | 7.22 | S | so,po |
| 42 | | VC5ox | 90-116+ | g,w | 10YR4/4 | 10YR5/4 | LS | m | -- | vfr | so,po | 1f | -- | 0 | 7.42 | LS | so,po |
| 43 | | VC6n | 216-236 | -- | 10YR3/4 | 10YR5/4 | -- | sg | -- | -- | -- | -- | -- | 0 | -- | -- | -- |
| 44 | PM17 | A | 0-6 | a,w | 10YR3.5/4 | 10YR5/4 | LS | 1 co gr | sh | fr | so,po | 3f | 1ftub | 0 | 6.61 | LS | so,po |
| 45 | | IIC1ox | 6-45 | g,w | 10YR3/4 | 10YR5/3 | fSL | m, 1 m sbk | sh | fr | so,po | 2f | 1ftub | 0 | 6.99 | fSL | so,po |
| 46 | | IIC2ox | 45-63 | g,w | 10YR3/4 | 10YR5/3 | vfSL | m, 1 m sbk | sh | fr | so,po | 2f | 2ftub | 0 | 7.18 | vfSL | so,po |
| 47 | | IIC3ox | 63-74 | g,w | 10YR4/4 | 10YR5/4 | vfSL | m, 1 m sbk | sh | fr | ss,po | 2vf | 2ftub | 0 | 8.03 | vfSL | ss,po |
| 48 | | IIIC4n | 74-120+ | -- | 10YR4/3 | 10YR5/3 | LS | sg | -- | -- | -- | -- | -- | 0 | 7.83 | LS | -- |
| 49 | PM18 | A | 0-6 | g,w | 10YR3/2 | 10YR4/2 | SL | 2 m gr | sh | fr | so,po | 3f | 2fir | 0 | 7.26 | LS | so,po |
| 50 | | IIC1ox | 6-65 | d,w | 10YR3/4 | 10YR5/4 | LS | m, 1 m sbk | sh | fr | so,po | 2m,2f | 1ftub | 0 | 6.00 | LS | so,po |
| 51 | | IIC2ox | 65-115 | g,w | 10YR4/4 | 10YR5/4 | LS | m, 1 m sbk | so | vfr | so,po | 3m,2co | 1mtub | 0 | 5.75 | LS | so,po |
| 52 | | IIIC3ox | 115-164 | g,w | 10YR4/4 | 10YR5/4 | S | sg | -- | lo | so,po | 1m,1co | -- | 0 | 5.98 | S | so,po |
| 53 | | IVC4ox | 164-175+ | -- | 10YR4/4 | 10YR6/3 | slgrS | sg | -- | lo | so,po | -- | -- | 0 | 6.20 | slgrS | so,po |

**Supplementary Table 1.** Field descriptions—Continued

| No. | Sample | Horizon | Basal depth (cm) | Lower boundary | Moist color | Dry color | Texture | Structure | Consistence: Dry | Consistence: Moist | Consistence: Wet | Roots | Pores | Clay films | pH | Assumed parent Material: Texture | Assumed parent Material: Wet consistence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Modesto Formation, upper member, 10 Ka** | | | | | | | | | | | | | | | | | |
| 54 | M31 | A11 | 0-20 | c,s | 10YR3/2 | 10YR5/4 | SL | 2 m gr | so | vfr | ss,po | 2f | 1ftub | 0 | 7.62 | SL | ss,po |
| 55 | | A12 | 20-63 | g,w | 10YR3/3 | 10YR6/4 | fSL | m | so | fr | so,po | 2m,1f | 2mtub | 0 | 9.64 | fSL | so,po |
| 56 | | AC | 63-150 | g,w | 10YR3/3 | 10YR6/4 | fSL | m | sh | -- | so,po | -- | 3m, 3ftub | 0 | 10.0 | fSL | so,po |
| 57 | | IIC1 | 150-200 | c,w | 10YR3/3 | 10YR5/4 | fSL | m | h | -- | so,po | -- | 2mtub | 0 | 10.0 | fSL | so,po |
| 58 | | IIIC2 | 200-254 | a,s | -- | -- | LS | sg | lo | lo | so,po | -- | -- | 0 | 9.64 | LS | so,po |
| 59 | M46 | A11p | 0-5 | c,w | 10YR4/2 | 10YR6/3, 5/3 | fSL | 2 m+co gr | so | vfr | so,po | 3m,2f, 2vf | 2fir | 0 | 6.29 | fSL | so,po |
| 60 | | A12p | 5-14 | c,w | 10YR4/2, 4/6 | 10YR5/3 | fSL | 1 m pl | sh | fr | ss,po | 2m, 1f | 2f, 2vftub | 0 | 6.76 | fSL | so,po |
| 61 | | IIA13p | 14-32 | c,s | 10YR3/3 | 10YR5/3 | fSL | m, 2 m sbk | sh | fi | so,po | 2m, 2f | 3f, 2vftub | 0 | 6.77 | fSL | so,po |
| 62 | | IIIAC | 32--66 | g,w | 10YR4/3 | 10YR5/3 | fSL | m, 2 co sbk | h | fi | so,po | 1m, 1f | 1m, 2ftub | 2npo, $v_1$npo | 7.01 | fSL | so,po |
| 63 | | IVCox | 66-250 | c,s | 10YR4/3 | 10YR5/4 | fSL | sg | so | fr | so,po | 1f, 1vf | -- | 0 | 7.04 | fSL | so,po |
| | | IIBb | 250+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | -- | -- | -- |
| **Modesto Formation, lower member, 40 Ka** | | | | | | | | | | | | | | | | | |
| 64 | M12 | A11 | 0-15 | c,w | 10YR3/3 | 10YR5/3 | fSL | 1 m sbk | so | lo | so,po | -- | -- | 0 | -- | fSL | so,po |
| 65 | | A12 | 15-81 | c,w | 10YR3/2 | 10YR6/3 | LS | 1 m sbk | h | fr | so,po | -- | 3mtub | 0 | 6.45 | LS | so,po |
| 66 | | IIB21t | 81-102 | g,w | 10YR4/3 | 10YR5/4 | LS | 2 m sbk | h | fr | s,ps | -- | 3mtub | 1npo, 1nbr | 6.87 | LS | so,po |
| 67 | | IIIB22t | 102-170 | c,w | 10YR5/6 | 10YR5/6 | SL+ | 2 m sbk | vh | fi | s,ps | -- | 2m, 1ftub | 2mkpo, 2mkbr, $v_1$npf | 6.67 | LS | so,po |
| 68 | | IVB3 | 170-201 | g,w | 10YR5/4 | 10YR6/6 | LS | 2 m sbk | h | fr | ss,ps | -- | -- | 1npo, 1nbr | 6.98 | LS | so,po |
| 69 | | VC1 | 201-231 | d,w | 10YR4/4 | 10YR6/4 | S | 1 m sbk | so | lo | ss,po | -- | -- | 0 | 7.34 | S | so,po |
| 70 | | VIC2 | 230-413+ | -- | 10YR6/2 | 10YR7/2 | S | sg | so | lo | so,po | -- | -- | 0 | -- | S | so,po |
| **Riverbank Formation, upper member, 130 Ka** | | | | | | | | | | | | | | | | | |
| 71 | R9 | A11p | 0-30 | g,s | 10YR3/3 | -- | SL | -- | -- | fr | so,po | 2m | 2mtub | 0 | 5.83 | SL | so,po |
| 72 | | A12p | 30-60 | g,w | 10-7.5YR, 4/3 | -- | SL | 1 f sbk | -- | fr | so,po | 2m | 2mtub | 0 | 5.77 | SL | so,po |
| 73 | | B1 | 60-105 | c,w | 10YR4/3 | -- | SL+ | 1 m sbk | -- | -- | ss,ps | -- | -- | 1npo, 1nbr | 5.77 | SL | so,po |
| 74 | | IIB21 | 105-180 | c,w | 7.5YR5/4 | -- | SCL | 1 m sbk | -- | -- | s,p | -- | -- | 2mkpo, 2mkbr | 6.13 | SL | so,po |
| 75 | | IIB22 | 180-235 | g,w | 7.5YR6/4 | -- | SL | sg | -- | -- | so,po | -- | -- | 1npo, 1nbr | 6.05 | SL | so,po |
| 76 | | IIB3 | 235-350 | c,s | 7.5YR4/4 | -- | SL+ | sg | -- | -- | ss,ps | -- | -- | 2mkpo, 2mkbr | 6.15 | SL | so,po |
| 77 | | IVC | 350-400+ | -- | 7.5YR5.5/6 | -- | LS | sg | -- | -- | so,po | -- | -- | 0 | 6.13 | LS | so,po |
| 78 | R33 | A11 | 0-4 | c,s | -- | -- | SL | 2 co gr | sh | fr | so,po | 2f | 2f,2mtub | 0 | 6.26 | SL | so,po |
| 79 | | IIA12 | 4-19 | c,w | -- | -- | SL | 2 co sbk | sh | fr | so,po | 2f, 2m | 2co,2f, 2vftub | 0 | 6.29 | SL | so,po |
| 80 | | IIIA3 | 19-39 | g,w | -- | -- | SL | 2 vco sbk | h | fr | so,po | 1f | 3vf,3f, 1mtub | $v_1$npo | 6.12 | SL | so,po |
| 81 | | IIIB21t | 39-62 | g,w | -- | -- | coSCL- | 2 co sbk | vh | fi | ss,ps | 1f | 2f,2m, 2vftub | 3nbr, 1mkbr | 5.94 | SL | so,po |
| 82 | | IIIB22t | 62-83 | g,w | -- | -- | SCL | 1 fi pr | vh | fi | ss,ps | -- | 2f,1m tub | 3nbr, 2mkbr, 1npo | 6.21 | SL | so,po |
| 83 | | IIIB23t | 83-122 | g,w | -- | -- | coSCL | 1 fi pr | vh | vfi | s,p | -- | 2f,2m tub | 4nbr, 2kbrw | -- | SL | so,po |
| 84 | | IIIB31 | 122-151 | g,w | -- | -- | coSCL- | 2 vco sbk | vh | fi | ss,ps | -- | 2f,2m tub | 4nbr, 2mkbr, 1kbrw | -- | SL | so,po |
| 85 | | IIIB32 | 151-210 | c,w | -- | -- | vgrSL | m,vco sbk | -- | fi | ss,ps | -- | 3f,2m tub | 3nbr, 2mkbrw | -- | SL | so,po |
| 86 | | IVB33 | 210-260 | c,w | -- | -- | vgrSL | sg | -- | vfr | ss,ps | -- | 3f,2m tub | 2n-mk coats | -- | LS | so,po |
| 87 | | VCox | 260-300+ | -- | -- | -- | S | sg | -- | | so,po | -- | -- | 0 | -- | S | so,po |
| **Riverbank Formation, middle member, 250 Ka** | | | | | | | | | | | | | | | | | |
| 88 | R2 | Ap | 0-25 | c,s | 10YR3/3 | -- | SL | 2 f sbk | -- | -- | ss,po | -- | -- | 0 | -- | -- | -- |
| 89 | | B21 | 25-81 | c,w | 7.5YR4/4, 10YR3/3 | -- | SCL | 3 co sbk | -- | -- | ss,ps | -- | -- | 0 | -- | -- | -- |
| 90 | | B22t | 81-185 | c,w | 7.5YR4/4 | -- | SCL+ | 3 vco cpr | -- | -- | s,ps | -- | -- | 0 | -- | -- | -- |
| 91 | | B3 | 185-386 | g,w | 10YR4/4 | -- | SCL | 2 co sbk | -- | -- | ss,po | -- | -- | 0 | -- | -- | -- |
| 92 | | C1 | 386-500 | g,w | 10YR5/4, 4/4 | -- | SL | m | -- | -- | so,po | -- | -- | 0 | -- | -- | -- |
| 93 | | C2n | 500+ | -- | 10YR5/3 | -- | S | sg | -- | -- | so,po | -- | -- | 0 | -- | -- | -- |

**Supplementary Table 1.** Field descriptions—Continued

| No. | Sample | Horizon | Basal depth (cm) | Lower boundary | Moist color | Dry color | Texture | Structure | Consistence: Dry | Consistence: Moist | Consistence: Wet | Roots | Pores | Clay films | pH | Assumed Parent Material: Texture | Assumed Parent Material: Wet consistence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Riverbank Formation, middle member, 250 Ka** | | | | | | | | | | | | | | | | | |
| 94 | R10 | A | 0-46 | c,s | 10YR3/3 | 10YR6/3 | SL | 2 co sbk | sh | -- | so,po | 1m | 3m,2co tub | 0 | 6.20 | SL | so,po |
| 95 | | IIB1 | 46-70 | c,w | 7.5YR4/4 | 10YR6/4 | SL+ | 2 co pr | vh | -- | ss,ps | 1m | 2m,1co tub | 3nbr | 6.83 | SL | so,po |
| 96 | | IIB21t | 70-140 | g,i | 7.5YR4/6, 5YR4/4 | 7.5YR6/6 | SL+ | 3 v co sbk | eh | -- | s,p | -- | 1co,3m tub | 3mkbr, 3mkpo | 7.17 | SL | so,po |
| 97 | | IIB22t | 140-210 | g,i | 7.5YR4/6, 5YR4/4 | 7.5YR6/6 | SL | 3 v co sbk | eh | -- | s,p | -- | 3m,1co tub | 3mkbr, 1kpo, 2mkpf | 7.47 | SL | so,po |
| 98 | | IIIB3t | 210-386 | g,w | 7.5YR4/4 | 10YR6/6, 7.5YR4/4 | SL | 3 v co sbk | eh | -- | ss,po | -- | -- | 2mkbr, 2mkpo | 7.47 | SL | so,po |
| 99 | | IIICox | 386-500 | g,w | 10YR4/4 | 10YR5/4 | SL | sg | vh | -- | so,po | -- | -- | 2mkbr, 2mkpo | -- | SL | so,po |
| 100 | R32 | A11 | 0-26 | g,w | 10YR3/2 | 10YR6/3 | SL | m, 1 f sbk | sh | fr | so,ps | 1f, 1vf | 3fir,1vf tub | 0 | 6.41 | SL | so,po |
| 101 | | A12 | 26-50 | c,w | 10YR3/3 | 10YR6/3 | SL | m, 2 m sbk | sh | fr | ss,po | 1f, 1vf | 2m,2f, 3vftub | 0 | 6.28 | SL | so,po |
| 102 | | A3 | 50-70 | c,w | 7.5YR3/4 | 10YR6/3, 7.5YR5/4 | SL | m, 2 f sbk | h | fr | ss,po | 1f | 1m,2f, 3vftub | 0 | 6.26 | SL | so,po |
| 103 | | B21t | 70-105 | g,w | 7.5YR4/4 | 7.5YR5/4 | SL+ | 1 m sbk | h | fi | s,ps | -- | 3vf,2f tub | 1nbr | 6.18 | SL | so,po |
| 104 | | B22t | 105-150 | g,w | 7.5YR4/5 | 7.5YR5/4 | SCL | 1 co sbk | vh | fi | s,ps | -- | 2vf,1f tub | 4nbr, 1kpf, 3mkbrw | 6.56 | SL | so,po |
| 105 | | B31t | 150-220 | d,w | 7.5YR4/4 | 7.5YR5/4 | SL+ | m,1 co sbk | h | fi | s,ps | -- | 1f,1vf tub | 3nbr, 1mkbrw | -- | SL | so,po |
| 106 | | IIB32 | 220-354 | g,w | -- | -- | SL | sg | -- | vfr | ss,po | -- | 2vftub | 1nbrw, 1mkbrw | -- | SL | so,po |
| 107 | | IIICox | 354-360+ | -- | 10YR5/4 | -- | S+ | sg | -- | lo | so,po | -- | -- | v$_1$nbr | -- | S | so,po |
| **Riverbank Formation, lower member, 330 Ka** | | | | | | | | | | | | | | | | | |
| 108 | R30 | Ap | 49-65 | a,w | 7.5YR4/4 | 10YR6/3 | SL | m | sh | vfr | so,po | -- | 3vf,2fir | 0 | 6.45 | SL | so,po |
| 109 | | B1 | 65-78 | c,w | 5YR4/4 | 7.5YR5/6 | SL+ | m,1 co abk | h | fi | ss,ps | -- | 1vfir | 2nbr | 6.00 | SL | so,po |
| 110 | | B21t | 78-127 | g,w | 5YR4/6 | 5YR5/6 | SCL | 2 co sbk | vh | fi | s,ps | -- | 2fir | 3nbr, 2npf | 5.75 | SL | so,po |
| 111 | | IIB22t | 127-179 | g,w | 5YR5/6, 4/4 | 5YR5/6 | SCL | 2 co abk | vh | fi | s,p | -- | 2fir | 1kpf, 4mkbr | 5.90 | SL | so,po |
| 112 | | IIIB3t | 179-197 | g,w | 5YR5/6, 4/4 | 7.5YR7/6 | SL | m | -- | fr | ss,po | -- | 2fir | 3nbr, 1kbr | 6.45 | SL | so,po |
| 113 | | IIIClox | 197-220 | c,w | 7.5YR4/4 | 7.5YR6/6 | SL+ | m | sh | vfr | so,po | -- | -- | 2nbr, 1mkbrw | 6.95 | SL | so,po |
| | | IIBb | 220+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 0 | -- | -- | -- |
| **Turlock Lake Formation, 600 Ka** | | | | | | | | | | | | | | | | | |
| 114 | T2 | A | 0-31 | g | 5YR3/4 | -- | coSL | m sbk | -- | vfi | -- | -- | -- | 0 | 6.58 | SL | -- |
| 115 | | B21 | 31-173 | i | 2.5YR3/6 | -- | CL | co abk | -- | vfi | -- | -- | -- | 0 | 5.82 | SL | -- |
| 116 | | IIB22 | 173-386 | i | 7.5YR5/6, 2.5YR3/6 | -- | SL | m-co abk | -- | vfi | -- | -- | -- | 0 | 6.52 | SL | -- |
| 117 | | IIIC | 386-417 | -- | 2.5YR5/8, 5YR5/6 | -- | S | 1 m sbk | -- | -- | -- | -- | -- | 0 | 6.48 | S | -- |
| 118 | T6 | A11 | 0-20 | g,w | 10YR3/4 | 10YR4/4 | LS | -- | -- | fr | so,po | 3f | 3mir | 0 | 6.50 | LS | so,po |
| 119 | | A12 | 20-40 | a,i | 10YR3/4 | 10YR5/3 | LS | -- | sh | fr | so,po | 2f | 3m,3co tub | 0 | 6.00 | LS | so,po |
| 120 | | IIB21t | 40-90 | g,w | 5YR3/6 | 5YR4/8 | LS | 2 med pr | h | fi | s,ps | -- | 2 m | 3mkpo, 3mkbr, 2mkpf | 7.00 | LS | so,po |
| 121 | | IIB22t | 90-190 | g,w | 2.5YR3/6 | 2.5YR3/4, 3/6 | SCL | -- | h | vfi | vs,p | -- | 2cotub | 2kpf, 3mkpo, 3mkbr | 6.20 | LS | so,po |
| 122 | | IIIB+C | 190-370 | g,w | 2.5-5YR, 3/4 and 30% 10YR5/4 | 2.5YR3/6, 4/6 10YR6/4 | coSL | sg | sh | fi | ss,po | -- | 2co,1f tub | 2mkpo, 2mkbr | 6.60 | coSL | so,po |
| 123 | T11 | A11p | 0-5 | -- | 10YR3/2 | 10YR5/2 | SL | -- | sh | fr | so,po | -- | -- | 0 | 6.82 | SL | so,po |
| 124 | | IIA12p | 5-11 | a | 10YR3/3 | 10YR5/3 | SL | -- | h | fr | so,po | -- | 2f,2vfir | 0 | 6.95 | SL | so,po |
| 125 | | IIA+B | 11-20 | g | 5YR4/4, 7.5YR4/4 | 7.5YR5/4, 10YR6/3 | SCL | -- | h | fi | ss,ps | -- | -- | 0 | 6.85 | SL | so,po |
| 126 | | IIB1t | 20-33 | g | 2.5YR3/6 | 5YR4/6 | SCL | 2 co abk | h | fi | s,p | -- | 2f,vf tub | 4nbr | 6.70 | SL | so,po |
| 127 | | IIB2t | 33-80 | g | 2.5YR4/4, 3/6 | 5YR5/6, 4/6 | SCL | 2 m sbk | vh | vfi | vs,pv | -- | 3vfir | 4mkbr, 3mkpo, 3kpow | 6.60 | SL | so,po |
| 128 | | IIIB31t | 80-191 | g | 2.5YR4/4 | 5YR5/6 | SCL | m | -- | fi | s,p | -- | 3vf,3f ir | 4mkbr, 3mkpf | 6.90 | SL | so po |
| 129 | | IVB32t | 191-256 | g | 5YR4/4, 2.5YR4/4 | 5YR6/6 | SL+ | m | -- | fr | s,p | -- | 2fir | 2mkpf, 4nbr | 7.10 | SL | so,po |
| 130 | | VB+C | 256-292 | g | 5YR4/4, 5YR5/6 | 5YR6/6 | SL- | m | -- | vfr | ss,ps | -- | 2fir | 3nbr | 6.95 | SL | so,po |
| 131 | | VClox | 292-375 | g | 5YR4/6 | 7.5YR6/6 | SL- | m | -- | vfr | ss,ps | -- | 1ftub | 3nbr | 7.00 | LS | so,po |
| 132 | | VIC2ox | 375+ | -- | 7.5YR4/6 | -- | LS | sg | -- | -- | so,po | -- | -- | 0 | 7.15 | LS | so,po |

**Supplementary Table 1.** Field descriptions--Continued

| No. | Sample | Horizon | Basal depth (cm) | Lower boundary | Moist color | Dry color | Texture | Structure | Consistence | | | Roots | Pores | Clay films | pH | Assumed Parent Material | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Dry | Moist | Wet | | | | | Texture | Wet consistence |
| | | | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | | | |
| 133 | CH1 | O1 | 1-0 | a,s | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 134 | | A1 | 0-12 | g,w | 10YR5/4, 7.5YR4/4 | 7.5YR6/6, | slgr L | 1 f sbk | sh | -- | ss,ps | 2f, 2m | 2m,2co tub | 0 | 4.84 | L | ss,ps |
| 135 | | AB | 12-53 | a,w | 7.5YR4/4, kroto. 2.5YR4/4 | 7.5YR6/6, kroto. 2.5YR4/4 | slgr SiL | 1 f sbk | sh | -- | ss,ps | 2f, 2m | 2m, 2co tub | 2npo, 2nbr | 4.93 | L | ss,ps |
| 136 | | IIB21t | 53-140 | g,w | 2.5YR3/6, 4/6 | 5YR4/8, 2.5YR3/6, 4/8, skins10R 3/6, 4/8 | grC | 2 m sbk | exh | -- | vs,pv | 1m | 2mtub | 3kpo, 3kbr, 3kpf | 4.55 | L | ss,ps |
| 137 | | IIB22t | 140-234 | g,i | 10YR4/7, cr.coats 2.5YR4/8, skins | 2.5YR4/8, skins 10R4/8, 10R3/6 | grC | 2 m sbk | exh | -- | vs,ps | -- | 2mtub | 4kpo, 4kbr, 4kpf | 4.40 | L | so,po |
| 138 | | IIB31t | 234-310 | g,i | 10R3/6, 10R4/8, 5Y-5GY4/1 | 2.5YR4/8, gr.stains 10R4/8 | grco C | 1 m sbk | -- | -- | vs,pv | -- | 1mtub | 2mkbr, 2mkpo, 2mkco | 4.00 | L | so,po |
| 139 | | IIB32t | 310-350+ | -- | 10R3/6, 4/8 | 2.5YR3/6, 5YR6/8, stains 10R4/8,gley 10YR8/2 | grco C- | 1 m sbk | -- | -- | vs,pv | -- | -- | 1mkbr, 1mkco | 4.06 | L | so,po |
| 140 | CH2 | A1 | 0-8 | c,w | 7.5YR4/4 | 10YR6/4 | slgr L | 2 f sbk | h | fr | ss,po | 2f, 2vf | 2co,3f tub | 0 | 4.71 | L | ss,po |
| 141 | | A3 | 8-30 | g,w | 7.5YR4/6 | 10YR6/4 | slgr L | 2 f sbk | h | fr | s,po | 2f | 3m,3f, 2vftub | 2n-mkpo | 4.55 | L | ss,po |
| 142 | | A+B | 30-50 | a,s | 5YR4/4 | 7.5YR6/4 | slgr CL | 1 f sbk | h | fr | s,ps | 1f | 2m,3f tub | 2mkpo-br, 2npo-br | 4.17 | L | ss,po |
| 143 | | IIB21t | 50-110 | g,w | 2.5YR4/6, 2.5YR4/6 | 5YR5/6 | grC | m | vh | fi | vs,p | -- | 2f,3vf tub | 2mkbr, 3mkpo | 4.36 | L | ss,po |
| 144 | | IIB22 | 110-170 | c,w | 2.5YR4/6, some10YR 8/8 | 2.5YR4/6 | grC | m | eh | fi | vs,pv | -- | 1vftub | 4kbr, 4kco | 4.20 | LS | ss,po |
| 145 | | IIB23 | 170-200 | g,w | 2.5YR3/6, 2.5YR4/6 | 2.5YR4/6, 2.5YR4/8, 5Y8/2 | grCL | m | eh | fi | vs,pv | -- | 1vftub | 4kbr, 4kco | 4.12 | LS | ss,po |
| 146 | | IIB24 | 200-290 | g,w | 2.5YR4/8, 10R4/6 | 10R4/6, 2.5YR4/8 | grC | m | eh | fi | vs,pv | -- | 1vftub | 4kbr, 4kco | 4.14 | LS | ss,po |
| 147 | | IIB3 | 290-350 | -- | -- | -- | grC | m | eh | fi | vs,pv | -- | -- | 4kbr, 4kco | 4.14 | LS | ss,po |
| | | 8+C or Cox | 750-1000 | d | 7.5YR6/6, clay 2.5YR4/6 | 10YR7/6 | grLS | sg | lo | lo | ss,po | -- 4kco | -- | 1nbr, | -- | LS | so,po |
| | CH3 | Ao | 1.5-0 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 148 | | A1 | 0-9 | c,w | 7.5YR4/4 | 7.5YR6/4 | slgr L | 2 m sbk | h | fr | ss,po | 3f, 1m | 3f,1m tub | 0 | 5.84 | L | ss,po |
| 149 | | A3 | 9-35 | g,w | 7.5YR3/4 | 7.5YR6/4 | slgr L | 2 m sbk | sh | fr | ss,po | 3f | 3f,2m, 2vftub | 0 | 5.44 | L | ss,po |
| 150 | | A+B | 35-68 | a,w | 5YR4/4 | 5YR6/4 | slgr L+ | 1 m sbk | h | fr | ss,ps | 3f | 2f,3m, 2vftub | 2mkpo | 5.01 | L | ss,po |
| 151 | | IIB2t | 68-105 | g,w | 2.5YR4/6 | 5YR5/6 | grC | m | h | fr | so,po | 2f, 2vf | 2f,3m, 2vftub | 3mk-kpo, 3mkco | 4.62 | L | so,po |
| 152 | | IIIB22t | 105-153 | g,w | 10R3/6, 2.5YR5/8 | 2.5YR4/8 | grC | m | h | fr | s,ps | 2f | 3f,3vf tub | 4kbr, 4kco | 4.48 | SL | so,po |
| 153 | | IVB23 | 153-173 | c,w | 2.5YR4/8, 5Y6/1 | 2.5YR4/8 | grC | m | vh | fi | vs,pv | -- | 3vftub | 4kbr, 4kco | 4.06 | SL | so,po |
| 154 | | VB24 | 173-260 | g,w | 10R4/8, 7.5YR6/6 | 10YR4/6, 7.5YR4/6 | slgr L | m | eh | fi | vs,pv | -- | -- | 4kbr, 4kco | 4.33 | SL | so,po |
| 155 | | VIB31 | 260-340 | g,w | 10R3/6 | 10R3/6 | grSCL | m | -- | fr | s,ps | -- | -- | 3mkbr | 4.20 | SL | so,po |
| 156 | | VI32 | 340-750+ | -- | 10R3/6 | 10R3/6 | grCL | m | -- | -- | -- | -- | -- | 3mkbr | 4.10 | SL | so,po |

**Supplementary Table 2.** Physical properties

[Analysts: A.J. Busacca, Peter Janitsky, and R. Meixner, University of California, Davis]

| No. | Sample | Horizon | Basal depth (cm) | >2-mm | Percentage of <2-mm fraction: Total sand | vco sand | co sand | m sand | fi+vfi sand | Silt | <2-μ clay | <1-μ clay | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | **Modern River Alluvium** | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | **Post-Modesto deposits, .2 Ka** | | | | | | | | |
| 5 | PM15 | A1 | 4 | 0 | 87.1 | 0.1 | 11.1 | 21.8 | 54.1 | 10.0 | 2.9 | 2.3 | -- |
| 6 | PM15 | 2C1ox | 19 | 0 | 80.5 | 0.4 | 2.6 | 7.4 | 70.3 | 15.4 | 4.1 | 3.4 | 1.43 |
| 7 | PM15 | 3C2ox | 42 | 0 | 92.4 | 0.1 | 5.2 | 18.2 | 68.9 | 4.9 | 2.7 | 2.5 | -- |
| 8 | PM15 | 4C3ox | 47 | 0 | 87.3 | 0.0 | 3.0 | 7.7 | 76.5 | 9.1 | 3.6 | 2.3 | 1.41 |
| 9 | PM15 | 5C4ox | 51 | 0 | 95.4 | 0.2 | 19.4 | 41.7 | 34.1 | 3.2 | 1.4 | 1.0 | -- |
| 10 | PM15 | 6C5ox | 51+ | 0 | 90.0 | 0.0 | 2.1 | 11.7 | 76.1 | 6.7 | 3.3 | 2.4 | 1.37 |
| 11 | PM19 | A11 | 7 | 0 | 71.1 | 0.1 | 2.5 | 12.4 | 56.1 | 27.0 | 6.9 | 5.1 | 1.29 |
| 12 | PM19 | 2A12 | 12 | 0 | 68.6 | 0.1 | 2.3 | 11.9 | 54.3 | 71.3 | 7.0 | 5.4 | 1.47 |
| 13 | PM19 | 3C1ox | 23 | 0 | 75.5 | 0.2 | 2.6 | 13.1 | 59.6 | 19.3 | 5.2 | 4.2 | 1.32 |
| 14 | PM19 | 4C2ox | 43 | 0 | 46.3 | 0.3 | 1.9 | 4.8 | 39.3 | 43.9 | 9.8 | 7.2 | 1.42 |
| 15 | PM19 | 5C35C3ox | 49 | 0 | 85.9 | 0.0 | 0.1 | 1.6 | 84.1 | 11.4 | 2.7 | 2.4 | 1.40 |
| 16 | PM19 | 6C4n | 55 | 0 | 63.4 | 0.6 | 9.7 | 14.1 | 39.0 | 31.0 | 5.6 | 4.6 | 1.39 |
| 17 | PM19 | 7C5n | 66 | 0 | 89.9 | 0.2 | 17.9 | 45.4 | 26.4 | 7.7 | 2.4 | 1.8 | -- |
| 18 | PM19 | 8C6n | 80+ | 0 | 30.4 | 0.0 | 0.4 | 1.7 | 28.3 | 59.9 | 9.7 | 6.7 | 1.36 |
| | | | | | **Post-Modesto deposits, 3 Ka** | | | | | | | | |
| 19 | PM8 | A1 | 32 | 0 | 36.4 | 0.2 | 2.6 | 2.6 | 33.7 | 52.8 | 13.5 | 10.0 | 1.24 |
| 20 | PM8 | 2C1 | 55 | 0 | 55.4 | 0.0 | 0.2 | 1.2 | 50.4 | 41.1 | 5.9 | 3.8 | 1.21 |
| 21 | PM8 | 3C2 | 66 | 0 | 81.5 | 0.1 | 1.8 | 14.6 | 65.0 | 12.5 | 4.2 | 3.0 | 1.30 |
| 22 | PM8 | 4C3 | 76+ | 0 | 92.9 | 0.0 | 3.7 | 27.4 | 61.4 | 3.8 | 2.7 | 1.2 | -- |
| 23 | PM13 | A11 | 5 | 0 | 38.5 | 0.0 | 0.0 | 0.9 | 37.0 | 49.9 | 12.1 | 9.5 | 1.17 |
| 24 | PM13 | A12 | 35 | 0 | 44.8 | 0.1 | 2.0 | 3.8 | 39.0 | 37.8 | 10.2 | 7.2 | 1.27 |
| 25 | PM13 | 2C1ox | 86 | 0 | 72.9 | 0.1 | 2.3 | 6.2 | 64.2 | 23.2 | 3.9 | 2.2 | 1.39 |
| 26 | PM13 | 3C2ox | 112 | 0 | 81.7 | 0.0 | 0.6 | 4.4 | 76.6 | 15.6 | 2.8 | 2.0 | 1.31 |
| 27 | PM13 | 4C3ox | 136 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | 0 | 50.1 | 0.0 | 0.9 | 1.8 | 47.4 | 39.1 | 10.8 | 7.2 | -- |
| 31 | PM14 | 2A12 | 33 | 0 | 39.1 | 0.1 | 1.3 | 2.3 | 35.4 | 49.7 | 11.2 | 7.8 | 1.28 |
| 32 | PM14 | 3C1ox | 99 | 0 | 71.1 | 0.0 | 4.2 | 7.3 | 59.2 | 23.4 | 5.5 | 3.9 | 1.39 |
| 33 | PM14 | 4C2ox | 130 | 0 | 80.3 | 0.1 | 2.3 | 5.7 | 72.2 | 15.4 | 4.3 | 3.0 | 1.41 |
| 34 | PM14 | 5C3ox | 175 | 0 | 71.7 | 0.4 | 3.2 | 2.9 | 65.3 | 22.6 | 5.7 | 3.9 | 1.40 |
| 35 | PM14 | 6C4ox | 200 | 0 | 85.7 | 0.4 | 6.0 | 9.0 | 70.3 | 10.6 | 3.7 | 2.8 | 1.38 |
| 36 | PM14 | 7C5n | 230+ | 0 | 96.5 | 4.5 | 58.6 | 24.3 | 9.1 | 2.8 | 0.7 | 0.6 | -- |
| 37 | PM16 | A | 2 | 0 | 73.7 | 0.1 | 0.2 | 4.7 | 68.3 | 19.9 | 6.4 | 4.8 | -- |
| 38 | PM16 | C1ox | 25 | 0 | 74.9 | 0.0 | 0.3 | 3.7 | 70.9 | 18.9 | 6.2 | 4.5 | 1.38 |
| 39 | PM16 | 2C2ox | 35 | 0 | 75.1 | 0.0 | 0.2 | 3.7 | 71.1 | 19.5 | 5.4 | 4.6 | 1.40 |
| 40 | PM16 | 3C3ox | 65 | 0 | 83.3 | 0.0 | 0.5 | 6.6 | 76.1 | 12.4 | 4.3 | 3.8 | 1.35 |
| 41 | PM16 | 4C4ox | 90 | 0 | 92.5 | 0.0 | 1.7 | 21.8 | 69.1 | 5.6 | 1.9 | 1.8 | -- |
| 42 | PM16 | 5C5ox | 116 | 0 | 82.9 | 0.0 | 0.2 | 4.3 | 78.5 | 13.9 | 3.2 | 2.3 | 1.37 |
| 43 | PM16 | 5C6n | 236 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | 0 | 74.6 | 0.2 | 2.3 | 7.0 | 65.0 | 22.5 | 2.9 | 1.2 | -- |
| 45 | PM17 | 2C1ox | 45 | 0 | 74.1 | 0.1 | 1.7 | 6.6 | 65.8 | 21.0 | 5.0 | 3.9 | 1.34 |
| 46 | PM17 | 2C2ox | 63 | 0 | 73.0 | 0.0 | 0.4 | 1.3 | 71.3 | 21.3 | 5.7 | 4.4 | 1.24 |
| 47 | PM17 | 2C3ox | 74 | 0 | 64.2 | 0.0 | 0.1 | 1.5 | 62.5 | 28.9 | 6.9 | 4.8 | 1.22 |
| 48 | PM17 | 3C4n | 120+ | 0 | 85.9 | 0.0 | 0.3 | 6.0 | 79.6 | 10.9 | 3.2 | 2.6 | 1.34 |
| 49 | PM18 | A | 6 | 0 | 70.1 | 0.5 | 5.1 | 13.7 | 50.9 | 21.3 | 8.6 | 6.8 | -- |
| 50 | PM18 | 2C1ox | 65 | 0 | 77.7 | 1.0 | 6.5 | 13.4 | 57.0 | 18.2 | 4.1 | 2.9 | 1.53 |
| 51 | PM18 | 2C2ox | 115 | 0 | 83.0 | 1.3 | 8.5 | 18.5 | 54.5 | 13.3 | 3.7 | 2.6 | 1.53 |
| 52 | PM18 | 3C3ox | 164 | 0 | 90.4 | 1.1 | 11.4 | 28.1 | 49.8 | 7.0 | 2.6 | 2.3 | 1.52 |
| 53 | PM18 | 4C4ox | 175+ | 10 | 88.7 | 0.7 | 9.6 | 31.1 | 47.3 | 9.0 | 2.3 | 1.7 | -- |

**Supplementary Table 2.** Physical properties—Continued

| No. | Sample | Horizon | Basal depth (cm) | >2-mm | Percentage of <2-mm fraction: Total sand | vco sand | co sand | m sand | fi+vfi sand | Silt | <2-μ clay | <1-μ clay | Bulk density (g/cm³) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | |
| 54 | M31 | A11 | 20 | 0.0 | 53.6 | 0.0 | 0.7 | 4.0 | 48.5 | 36.8 | 8.8 | 6.1 | 1.26 |
| 55 | M31 | A12 | 63 | 0.0 | 61.5 | 0.1 | 0.6 | 4.1 | 54.8 | 31.9 | 4.8 | 2.2 | 1.28 |
| 56 | M31 | AC | 150 | 0.0 | 67.7 | -- | -- | -- | -- | 28.1 | 4.2 | 1.7 | 1.43 |
| 57 | M31 | 2C1 | 200 | 0.0 | 62.2 | 0.0 | 0.4 | 2.5 | 55.7 | 27.7 | 6.5 | 4.1 | 1.52 |
| 58 | M31 | 3C2 | 254 | 0.0 | 83.0 | 0.0 | 1.3 | 10.1 | 68.7 | 11.6 | 3.6 | 2.1 | 1.42 |
| 59 | M46 | A11p | 5 | 0 | 68.6 | 0.8 | 9.7 | 13.4 | 44.7 | 25.8 | 5.6 | 4.4 | -- |
| 60 | M46 | A12p | 14 | 0 | 63.7 | 0.9 | 10.9 | 13.5 | 38.3 | 30.0 | 6.9 | 4.7 | 1.61 |
| 61 | M46 | 2A13p | 32 | 0 | 65.3 | 0.7 | 10.4 | 13.9 | 40.4 | 28.9 | 5.8 | 4.6 | 1.66 |
| 62 | M46 | 3AC | 66 | 0 | 58.2 | 0.5 | 7.0 | 12.4 | 38.7 | 33.6 | 8.2 | 6.0 | 1.65 |
| 63 | M46 | 4Cox | 250 | 0 | 60.1 | 0.1 | 4.5 | 12.8 | 42.7 | 31.2 | 8.7 | 6.4 | 1.62 |
| | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | | |
| 64 | M12 | A11 | 15 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 0 | 80.5 | 2.3 | 24.4 | 17.2 | 36.6 | 13.5 | 6.0 | 3.3 | 1.68 |
| 66 | M12 | 2B21t | 102 | 0 | 87.4 | 1.1 | 21.3 | 15.7 | 34.9 | 1.4 | 11.2 | 7.6 | 1.68 |
| 67 | M12 | 3B22t | 170 | 0 | 78.9 | 2.7 | 22.7 | 15.5 | 31.3 | 4.0 | 16.8 | 15.8 | 1.89 |
| 68 | M12 | 4B3 | 201 | 0 | 85.9 | 2.6 | 27.0 | 17.6 | 33.5 | 7.8 | 6.3 | 4.2 | 1.85 |
| 69 | M12 | 5C1 | 231 | 0 | 90.6 | 3.9 | 39.2 | 19.0 | 27.0 | 6.1 | 3.3 | 1.6 | -- |
| 70 | M12 | 6C2 | 413+ | 0 | 97.0 | -- | -- | -- | -- | 2.2 | 0.8 | 0.4 | -- |
| | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | |
| 71 | R9 | A11p | 30 | 0 | 73.2 | 2.8 | 24.5 | 16.0 | 17.6 | 19.6 | 7.2 | 4.5 | 1.75 |
| 72 | R9 | A12p | 60 | 0 | 71.4 | 2.4 | 24.0 | 16.4 | 26.7 | 21.3 | 7.3 | 4.3 | 1.75 |
| 73 | R9 | B1 | 105 | 0 | 68.0 | 2.2 | 22.5 | 16.4 | 26.7 | 19.4 | 12.6 | 10.0 | 1.84 |
| 74 | R9 | 2B21 | 180 | 0 | 64.0 | 1.8 | 18.8 | 15.9 | 26.9 | 15.2 | 20.8 | 18.2 | 1.93 |
| 75 | R9 | 2B22 | 235 | 0 | 73.5 | 4.3 | 29.8 | 17.4 | 20.7 | 12.8 | 13.7 | 11.8 | 1.84 |
| 76 | R9 | 3B3 | 350 | 0 | 72.8 | 6.4 | 36.4 | 17.7 | 15.6 | 14.2 | 13.0 | 11.6 | 1.88 |
| 77 | R9 | 4C | 400+ | 20 | 87.9 | 16.5 | 32.6 | 18.6 | 19.6 | 5.8 | 6.8 | 6.2 | 1.42 |
| 78 | R33 | A11 | 4 | 0 | 70.3 | 4.4 | 24.3 | 14.6 | 51.7 | 23.2 | 6.5 | 4.4 | 1.57 |
| 79 | R33 | 2A12 | 19 | 0 | 58.2 | 3.4 | 18.5 | 11.8 | -- | 36.1 | 5.7 | 3.5 | 1.73 |
| 80 | R33 | 3A3 | 39 | 0 | 67.8 | 4.6 | 22.5 | 13.7 | -- | 23.0 | 9.2 | 6.8 | 1.77 |
| 81 | R33 | 3B21t | 62 | 0 | 60.4 | 3.1 | 19.1 | 12.3 | -- | 21.9 | 17.7 | 14.8 | 2.03 |
| 82 | R33 | 3B22t | 83 | 0 | 57.0 | 2.9 | 17.7 | 11.8 | -- | 18.0 | 25.0 | 21.9 | 2.04 |
| 83 | R33 | 3B23t | 122 | 0 | 59.2 | 2.7 | 18.0 | 12.6 | -- | 15.6 | 25.2 | 22.4 | 2.01 |
| 84 | R33 | 3B31 | 151 | 0 | 69.8 | 3.5 | 22.7 | 16.3 | -- | 12.3 | 17.9 | 16.0 | 1.89 |
| 85 | R33 | 3B32 | 210 | -- | 71.9 | 4.3 | 24.1 | 16.0 | -- | 15.6 | 12.5 | 11.0 | 1.97 |
| 86 | R33 | 4B33 | 260 | -- | 79.4 | 19.5 | 31.5 | 13.1 | -- | 7.5 | 13.1 | 12.6 | 1.94 |
| 87 | R33 | 5Cox | 300+ | 0 | 90.7 | 8.9 | 40.7 | 20.7 | -- | 2.1 | 7.2 | 6.6 | -- |
| | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | |
| 88 | R2 | Ap | 25 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | 1.43 |
| 89 | R2 | B21 | 81 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | 1.57 |
| 90 | R2 | B22t | 185 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | 2.01 |
| 91 | R2 | B3 | 386 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | 1.86 |
| 92 | R2 | C1 | 500 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | 1.72 |
| 93 | R2 | C2 | 500+ | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | 0 | 73.4 | 3.8 | 24.1 | 14.4 | 32.3 | 19.3 | 7.3 | 5.2 | 1.80 |
| 95 | R10 | 2B1 | 70 | 0 | 68.1 | 5.7 | 30.4 | 12.4 | 22.9 | 18.8 | 13.1 | 11.5 | 1.86 |
| 96 | R10 | 2B21t | 140 | 0 | 68.4 | 5.6 | 30.0 | 12.9 | 22.5 | 18.0 | 13.6 | 11.1 | 1.92 |
| 97 | R10 | 2B22t | 210 | 0 | 72.9 | 6.1 | 33.3 | 13.7 | 22.9 | 14.9 | 12.2 | 10.2 | 1.93 |
| 98 | R10 | 3B3t | 386 | 0 | 77.6 | 10.2 | 39.8 | 7.9 | 19.4 | 9.8 | 11.6 | 9.8 | 1.85 |
| 99 | R10 | 3Cox | 500 | 0 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 0 | 72.4 | 2.6 | 19.0 | 16.1 | 34.7 | 20.6 | 7.0 | 4.4 | 1.67 |
| 101 | R32 | A12 | 50 | 0 | 73.0 | 2.4 | 19.7 | 16.0 | 35.0 | 19.2 | 7.8 | 5.2 | 1.63 |
| 102 | R32 | A3 | 70 | 0 | 69.4 | 2.2 | 18.2 | 15.2 | 43.8 | 19.9 | 10.7 | 7.6 | 1.86 |
| 103 | R32 | B21t | 105 | 0 | 64.7 | 2.1 | 16.7 | 14.5 | 31.3 | 19.2 | 16.1 | 13.2 | 2.05 |
| 104 | R32 | B22t | 150 | 0 | 63.7 | 1.8 | 17.0 | 14.8 | 30.2 | 16.7 | 19.6 | 16.7 | 2.06 |
| 105 | R32 | B31t | 220 | 0 | 69.1 | 1.7 | 17.9 | 16.4 | 33.1 | 13.7 | 17.2 | 14.7 | 1.96 |
| 106 | R32 | 2B32 | 354 | 0 | 76.7 | 2.1 | 24.1 | 20.4 | 30.1 | 8.5 | 14.8 | 14.5 | 1.82 |
| 107 | R32 | 3Cox | 360+ | 0 | 88.0 | 7.9 | 42.8 | 17.7 | 19.6 | 4.2 | 8.0 | 7.6 | -- |

**Supplementary Table 2.** Physical properties—Continued

| No. | Sample | Horizon | Basal depth (cm) | >2-mm | Percentage of <2-mm fraction | | | | | | | | Bulk density ($g/cm^3$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total sand | vco sand | co sand | m sand | fi+vfi sand | Silt | <2-μ clay | <1-μ clay | |
| **Riverbank Formation, lower member, 330 Ka** | | | | | | | | | | | | | |
| 108 | R30 | Ap | 65 | 0 | 75.0 | 2.0 | 21.4 | 18.7 | 32.9 | 19.0 | 8.0 | 6.6 | 1.71 |
| 109 | R30 | B10 | 78 | 0 | 66.7 | 1.4 | 19.9 | 16.0 | 29.4 | 14.2 | 19.1 | 17.0 | 1.97 |
| 110 | R30 | B21t | 127 | 0 | 63.5 | 1.4 | 17.7 | 15.2 | 29.2 | 11.1 | 25.4 | 24.6 | 1.95 |
| 111 | R30 | 2B22t | 179 | 0 | 69.8 | 5.7 | 29.8 | 15.2 | 19.1 | 5.0 | 25.2 | 25.1 | 1.93 |
| 112 | R30 | 3B3t | 197 | 0 | 78.2 | 5.9 | 37.6 | 18.5 | 16.2 | 3.3 | 18.5 | 18.4 | 1.85 |
| 113 | R30 | 3C1ox | 220 | 0 | 77.5 | 4.6 | 34.1 | 19.9 | 18.9 | 2.5 | 20.0 | 18.8 | -- |
| **Turlock Lake Formation, 600 Ka** | | | | | | | | | | | | | |
| 114 | T2 | A | 31 | 0 | 67.9 | 4.1 | 21.4 | 13.4 | 25.9 | 26.6 | 5.5 | 2.4 | -- |
| 115 | T2 | B21 | 173 | 0 | 44.1 | 2.8 | 15.3 | 8.7 | 16.1 | 18.2 | 37.7 | 35.0 | -- |
| 116 | T2 | 2B22 | 386 | 0 | 70.6 | 4.0 | 14.1 | 6.7 | 42.1 | 17.0 | 12.4 | 11.1 | 1.90 |
| 117 | T2 | 3C | 417 | 0 | 89.3 | 20.2 | 42.3 | 10.5 | 14.2 | 4.5 | 6.2 | 5.6 | -- |
| 118 | T6 | A11 | 20 | 0 | 85.6 | 19.1 | 31.7 | 17.5 | 17.3 | 10.1 | 4.3 | 3.4 | -- |
| 119 | T6 | A12 | 40 | 0 | 83.3 | 15.2 | 29.2 | 18.1 | 20.8 | 11.5 | 5.3 | 4.3 | -- |
| 120 | T6 | 2B21t | 90 | 0 | 83.3 | 29.6 | 37.6 | 10.9 | 5.2 | 7.4 | 9.3 | 7.2 | -- |
| 121 | T6 | 2B22t | 190 | 0 | 68.1 | 19.8 | 33.1 | 8.8 | 6.4 | 4.8 | 27.1 | 27.1 | -- |
| 122 | T6 | 3B+C | 370 | 0 | 79.9 | 12.3 | 43.6 | 16.0 | 8.0 | 7.9 | 12.2 | 2.2 | -- |
| 123 | T11 | A11p | 5 | 0 | 79.1 | 6.6 | 26.4 | 18.6 | 27.5 | 14.1 | 5.4 | 3.5 | 1.49 |
| 124 | T11 | 2A12p | 11 | 0 | 74.4 | 10.2 | 25.0 | 14.5 | 24.7 | 16.4 | 7.1 | 4.4 | 1.85 |
| 125 | T11 | 2A+B | 20 | 0 | 63.1 | 8.0 | 19.7 | 13.2 | 22.2 | 15.1 | 20.9 | 17.3 | 1.91 |
| 126 | T11 | 2B1t | 33 | 0 | 58.0 | 6.9 | 19.1 | 11.3 | 20.7 | 12.0 | 28.9 | 24.5 | 1.88 |
| 127 | T11 | 2B2t | 80 | 0 | 64.3 | 7.4 | 21.8 | 13.8 | 21.3 | 8.6 | 26.0 | 23.8 | 1.95 |
| 128 | T11 | 3B31t | 191 | 0 | 76.0 | 13.2 | 22.3 | 17.8 | 22.7 | 3.0 | 20.0 | 18.3 | 1.81 |
| 129 | T11 | 4B32t | 256 | 0 | 79.2 | 5.6 | 19.1 | 24.8 | 29.7 | 2.5 | 18.3 | 18.0 | 1.81 |
| 130 | T11 | 5B+C | 292 | 0 | 84.5 | 10.5 | 38.9 | 19.7 | 15.4 | 1.0 | 13.9 | 12.6 | 1.76 |
| 131 | T11 | 5C1ox | 375 | 0 | 84.2 | 9.2 | 33.6 | 21.9 | 19.5 | 0.8 | 14.2 | 13.5 | -- |
| 132 | T11 | 6C2ox | 375+ | 0 | 86.4 | 15.7 | 41.7 | 18.3 | 10.7 | 1.7 | 11.8 | 11.2 | -- |
| **China Hat gravel member of Laguna Formation, 3,000 Ka** | | | | | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 20 | 37.7 | 9.8 | 7.4 | 3.3 | 17.4 | 46.0 | 16.5 | 13.6 | 1.64 |
| 134 | CH1 | 2AB | 53 | 20 | 34.1 | 5.2 | 6.3 | 3.5 | 19.1 | 43.3 | 22.7 | 19.0 | 1.60 |
| 135 | CH1 | 2B21t | 88 | 30 | 24.9 | 4.5 | 3.5 | 2.0 | 14.5 | 31.8 | 43.3 | 39.7 | 1.49 |
| 136 | CH1 | 2B22t | 140 | 20 | 24.9 | 4.5 | 3.5 | 2.0 | 14.5 | 20.4 | 55.8 | 52.8 | 1.65 |
| 137 | CH1 | 2B31 | 234 | -- | 30.7 | 9.2 | 6.0 | 3.2 | 14.8 | 26.4 | 42.9 | 36.7 | 1.84 |
| 138 | CH1 | 2B32 | 310 | -- | 24.2 | 6.0 | 4.3 | 2.6 | 11.6 | 20.6 | 55.2 | 49.7 | 1.92 |
| 139 | CH1 | 3B33 | 350 | -- | 41.0 | 12.6 | 15.4 | 3.0 | 7.6 | 18.4 | 40.6 | 34.3 | 1.54 |
| 140 | CH2 | A1 | 8 | 20 | 48.9 | 6.2 | 8.1 | 4.3 | 30.3 | 38.8 | 12.5 | 8.6 | 1.68 |
| 141 | CH2 | A3 | 30 | 10 | 40.3 | 5.6 | 6.6 | 3.8 | 24.3 | 35.6 | 24.0 | 20.0 | -- |
| 142 | CH2 | 2A+B | 50 | 10 | 35.6 | 3.1 | 6.0 | 3.7 | 22.8 | 33.7 | 30.7 | 26.7 | 1.67 |
| 143 | CH2 | 2B21t | 110 | 30 | 25.6 | 3.4 | 4.2 | 2.4 | 15.7 | 21.5 | 52.9 | 49.8 | 1.66 |
| 144 | CH2 | 2B22 | 170 | 20 | 34.2 | 6.2 | 8.7 | 3.9 | 15.3 | 18.6 | 46.9 | 43.3 | 1.74 |
| 145 | CH2 | 2B23 | 200 | 10 | 37.8 | 5.9 | 10.2 | 4.6 | 17.0 | 23.0 | 39.2 | 35.1 | 1.82 |
| 146 | CH2 | 3B24 | 290 | 20 | 29.3 | 6.5 | 10.3 | 3.0 | 9.4 | 24.8 | 45.9 | 40.9 | 1.75 |
| 147 | CH2 | 3B3 | 350 | 30 | 30.9 | 7.0 | 10.2 | 3.8 | 9.8 | 24.3 | 44.8 | 40.0 | -- |
| 148 | CH3 | A1 | 9 | 20 | 44.0 | 6.2 | 7.8 | 5.1 | 24.8 | 41.7 | 14.3 | 10.4 | 1.53 |
| 149 | CH3 | A3 | 35 | 10 | 41.9 | 4.5 | 7.5 | 5.1 | 24.9 | 38.0 | 20.0 | 15.7 | 1.67 |
| 150 | CH3 | A+B | 68 | 10 | 39.1 | 3.5 | 7.5 | 4.8 | 23.3 | 35.6 | 25.2 | 20.1 | 1.72 |
| 151 | CH3 | B2t | 105 | 50 | 26.4 | 3.0 | 4.5 | 3.1 | 15.8 | 26.2 | 47.5 | 43.0 | 1.67 |
| 152 | CH3 | B22t | 153 | 40 | 21.4 | 2.8 | 4.6 | 3.0 | 10.9 | 16.1 | 62.6 | 60.2 | 1.73 |
| 153 | CH3 | 2B23 | 173 | 20 | 30.3 | 1.9 | 5.0 | 10.0 | 13.2 | 12.0 | 57.7 | 54.7 | 1.84 |
| 154 | CH3 | 3B24 | 260 | 10 | 47.5 | 10.5 | 15.6 | 6.1 | 15.2 | 29.0 | 23.5 | 20.5 | 1.81 |
| 155 | CH3 | 4B31 | 340 | 30 | 60.8 | 5.9 | 18.0 | 16.8 | 20.2 | 10.1 | 29.1 | 24.6 | 1.75 |
| 156 | CH3 | 5B32 | 750+ | 30 | 29.9 | 7.2 | 9.2 | 3.7 | 9.8 | 30.5 | 39.6 | 32.5 | 1.82 |
| 157 | CH4 | 2B31 | 750 | -- | 50.5 | 8.0 | 25.4 | 5.6 | 11.6 | 23.0 | 26.5 | 21.3 | 1.71 |
| 158 | CH4 | 4C1ox | 1000 | -- | 63.1 | 2.9 | 25.0 | 17.3 | 17.9 | 18.0 | 18.9 | 14.8 | 1.61 |

**Supplementary Table 3, Part 1.** Extractive chemical analyses

[CEC, cation-exchange capacity; m, with magnetic minerals; w, without magnetic minerals. Analysts: A. L. Walker, U.S. Geological Survey, and A.J. Busacca, Peter Janitsky, and R. Meixner, University of California, Davis]

| No. | Sample | Horizon | Basal depth (cm) | Percentage of <2-mm | | mg/100 g soil | | | | | | pH | pH | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total N | Organic C | Exchange Na | Exchange K | Exchange Ca | Exchange Mg | Exchange N | CEC | 1:1$H_2O$ | 1:1KCl | Saturated |
| | | | | | | Modern River Alluvium | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | | |
| 5 | PM15 | A1 | 4 | 0.0371 | 0.54 | 0.39 | 0.23 | 3.84 | 2.93 | 1.29 | 4.83 | 5.84 | 5.25 | -- |
| 6 | PM15 | 2C1ox | 19 | 0.0428 | 0.44 | 0.41 | 0.14 | 4.04 | 3.23 | 1.69 | 6.66 | 5.69 | 4.68 | -- |
| 7 | PM15 | 3C2ox | 42 | 0.0255 | 0.14 | 0.41 | 0.09 | 3.13 | 1.92 | 1.33 | 3.25 | 5.56 | 4.37 | -- |
| 8 | PM15 | 4C3ox | 47 | 0.0226 | 0.20 | 0.42 | 0.11 | 4.54 | 2.63 | 1.08 | 5.99 | 5.55 | 4.75 | -- |
| 9 | PM15 | 5C4ox | 51 | 0.0097 | 0.08 | 0.39 | 0.05 | 2.83 | 1.82 | 0.64 | 1.66 | 5.72 | 5.01 | -- |
| 10 | PM15 | 6C5ox | 51+ | 0.0205 | 0.14 | 0.41 | 0.07 | 4.34 | 3.03 | 1.04 | 4.91 | 5.82 | 5.03 | -- |
| 11 | PM19 | A11 | 7 | 0.2790 | 3.81 | -- | -- | -- | -- | 4.99 | -- | 5.56 | 5.12 | -- |
| 12 | PM19 | 2A12 | 12 | 0.1443 | 1.62 | -- | -- | -- | -- | 2.57 | -- | 6.25 | 5.85 | -- |
| 13 | PM19 | 3C1ox | 23 | 0.0983 | 1.10 | -- | -- | -- | -- | 1.85 | -- | 6.32 | 5.87 | -- |
| 14 | PM19 | 4C2ox | 43 | 0.0635 | 0.60 | -- | -- | -- | -- | 1.53 | -- | 6.91 | 6.30 | -- |
| 15 | PM19 | 5C3ox | 49 | 0.0185 | 0.52 | -- | -- | -- | -- | 0.72 | -- | 6.79 | 6.33 | -- |
| 16 | PM19 | 6C4n | 55 | 0.0322 | 0.31 | -- | -- | -- | -- | 1.33 | -- | 6.98 | 6.36 | -- |
| 17 | PM19 | 7C5n | 66 | 0.0121 | 0.08 | -- | -- | -- | -- | 0.64 | -- | 6.54 | 6.22 | -- |
| 18 | PM19 | 8C6n | 80+ | -- | -- | -- | -- | -- | -- | 1.41 | -- | -- | -- | -- |
| | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | | |
| 19 | PM8 | A1 | 32 | 0.199 | 2.26 | 0.18 | 1.76 | 15.30 | 2.53 | 4.66 | 22.73 | 6.33 | 5.72 | -- |
| 20 | PM8 | 2C1 | 55 | 0.049 | 0.66 | 0.13 | 0.17 | 11.01 | 2.52 | 1.25 | 13.82 | 7.20 | 6.36 | -- |
| 21 | PM8 | 3C2 | 66 | 0.038 | 0.41 | 0.22 | 0.22 | 5.25 | 3.13 | 0.76 | 7.08 | 7.33 | 7.13 | -- |
| 22 | PM8 | 4C3 | 76+ | 0.018 | 0.13 | 0.04 | 0.15 | 3.84 | 1.61 | 0.84 | 3.66 | 7.48 | 6.72 | -- |
| 23 | PM13 | A11 | 5 | 0.2609 | 3.26 | -- | -- | -- | -- | 4.10 | -- | 6.30 | 5.89 | -- |
| 24 | PM13 | A12 | 35 | 0.0877 | 0.99 | -- | -- | -- | -- | 1.04 | -- | 7.71 | 6.93 | -- |
| 25 | PM13 | 2C1ox | 86 | 0.0278 | 0.32 | -- | -- | -- | -- | 0.84 | -- | 7.85 | 6.67 | -- |
| 26 | PM13 | 3C2ox | 112 | 0.0187 | 0.30 | -- | -- | -- | -- | 1.45 | -- | 7.35 | 5.90 | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | 0.2429 | 2.91 | -- | -- | -- | -- | 2.65 | -- | 6.42 | 5.99 | -- |
| 31 | PM14 | 2A12 | 33 | 0.0942 | 1.21 | -- | -- | -- | -- | 0.32 | -- | 7.83 | 7.12 | -- |
| 32 | PM14 | 3C1ox | 99 | 0.0301 | 1.00 | -- | -- | -- | -- | 0.48 | -- | 7.83 | 6.62 | -- |
| 33 | PM14 | 4C2ox | 130 | 0.0153 | 0.30 | -- | -- | -- | -- | 1.21 | -- | 6.88 | 5.42 | -- |
| 34 | PM14 | 5C3ox | 175 | 0.0242 | 0.25 | -- | -- | -- | -- | 1.45 | -- | 6.54 | 5.11 | -- |
| 35 | PM14 | 6C4ox | 200 | 0.0146 | 0.11 | -- | -- | -- | -- | 1.13 | -- | 6.66 | 5.32 | -- |
| 36 | PM14 | 7C5n | 239+ | 0.0077 | 0.04 | -- | -- | -- | -- | 0.24 | -- | 6.92 | 5.52 | -- |
| 37 | PM16 | A | 2 | 0.2215 | 2.64 | 0.49 | 0.88 | 8.79 | 2.94 | 2.29 | 12.57 | 6.50 | 6.00 | -- |
| 38 | PM16 | C1ox | 25 | 0.0670 | 0.58 | 0.53 | 0.63 | 6.26 | 3.13 | 1.53 | 9.07 | 6.48 | 5.68 | -- |
| 39 | PM16 | 2C2ox | 35 | 0.0404 | 0.48 | 0.53 | 0.14 | 7.58 | 3.03 | 0.96 | 9.41 | 6.86 | 6.33 | -- |
| 40 | PM16 | 3C3ox | 65 | 0.0273 | 0.34 | 0.53 | 0.14 | 6.46 | 3.12 | 0.48 | 7.57 | 7.29 | 6.70 | -- |
| 41 | PM16 | 4C4ox | 90 | 0.0124 | 0.12 | 0.49 | 0.07 | 4.14 | 2.83 | 0.32 | 3.50 | 7.29 | 6.89 | -- |
| 42 | PM16 | 5C5ox | 116 | 0.0169 | 0.16 | 0.23 | 0.07 | 6.06 | 5.56 | 1.45 | 5.83 | 7.22 | 6.95 | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | 0.79 | 0.07 | 6.87 | 6.26 | 0.64 | 8.91 | 7.42 | -- | -- |
| 44 | PM17 | A | 6 | 0.2098 | 2.14 | -- | -- | -- | -- | 2.05 | -- | 6.61 | 6.25 | -- |
| 45 | PM17 | 2C2ox | 45 | 0.0594 | 0.62 | -- | -- | -- | -- | 1.04 | -- | 6.99 | 6.32 | -- |
| 46 | PM17 | 2C2ox | 63 | 0.0378 | 0.44 | -- | -- | -- | -- | 0.36 | -- | 7.18 | 6.65 | -- |
| 47 | PM17 | 2C3ox | 74 | 0.0439 | 0.50 | -- | -- | -- | -- | 0.36 | -- | 8.03 | 7.42 | -- |
| 48 | PM17 | 3C4n | 120+ | 0.0175 | 0.18 | -- | -- | -- | -- | 0.16 | -- | 7.83 | 7.36 | -- |
| 49 | PM18 | A | 6 | 0.3966 | 3.69 | -- | -- | -- | -- | 2.21 | -- | 7.26 | 6.92 | -- |
| 50 | PM18 | 2C1ox | 65 | 0.0358 | 0.37 | -- | -- | -- | -- | 1.29 | -- | 5.69 | 5.54 | -- |
| 51 | PM18 | 2C2ox | 115 | 0.0245 | 0.25 | -- | -- | -- | -- | 1.57 | -- | 5.75 | 4.64 | -- |
| 52 | PM18 | 3C3ox | 164 | 0.0260 | 0.10 | -- | -- | -- | -- | 1.04 | -- | 5.98 | 4.77 | -- |
| 53 | PM18 | 4C4ox | 175+ | 0.0145 | 0.12 | -- | -- | -- | -- | 0.84 | -- | 6.18 | 5.10 | -- |

**Supplementary Table 3, Part 1.** Extractive chemical analyses—Continued

| No. | Sample | Horizon | Basal depth (cm) | Percentage of <2-mm | | mg/100 g soil | | | | | | pH | pH | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total N | Organic C | Exchange Na | Exchange K | Exchange Ca | Exchange Mg | Exchange N | CEC | 1:1$H_2O$ | 1:1KCl | Saturated |
| **Modesto Formation, upper member, 10 Ka** | | | | | | | | | | | | | | |
| 54 | M31 | A11 | 20 | 0.101 | 1.23 | 0.32 | 1.83 | 11.82 | 1.81 | 1.37 | 15.23 | 7.62 | 6.83 | -- |
| 55 | M31 | A12 | 63 | 0.041 | 0.45 | 7.42 | 1.13 | 5.45 | 1.32 | 0.04 | 9.32 | 9.64 | 7.88 | -- |
| 56 | M31 | AC | 150 | 0.022 | 0.21 | 8.38 | 0.97 | 2.42 | 0.51 | 0.00 | 6.83 | 10.00 | 8.78 | -- |
| 57 | M31 | 2C1 | 200 | 0.018 | 0.13 | 8.68 | 0.22 | 1.62 | 0.80 | 0.68 | 7.24 | 10.01 | 8.36 | -- |
| 58 | M31 | 3C2 | 254 | 0.011 | 0.06 | 2.99 | 0.10 | 1.92 | 1.11 | 0.80 | 3.58 | 9.64 | 7.45 | -- |
| 59 | M46 | A11p | 5 | 0.1881 | 2.24 | 0.53 | 0.76 | 7.37 | 2.22 | 2.01 | 10.57 | 6.29 | 5.87 | -- |
| 60 | M46 | A12p | 14 | 0.0959 | 1.00 | 0.44 | 0.53 | 5.86 | 1.31 | 1.37 | 8.74 | 6.76 | 6.06 | -- |
| 61 | M46 | 2A13p | 32 | 0.0544 | 0.52 | 0.25 | 0.48 | 4.65 | 1.11 | 1.00 | 6.65 | 6.80 | 6.23 | -- |
| 62 | M46 | 3AC | 66 | 0.0331 | 0.26 | 0.26 | 0.54 | 4.95 | 1.41 | 0.92 | 7.33 | 7.01 | 6.23 | -- |
| 63 | M46 | 4Cox | 250 | 0.0206 | 0.11 | 0.26 | 0.28 | 6.16 | 1.52 | 0.76 | 8.41 | 7.04 | 5.80 | -- |
| **Modesto Formation, lower member, 40 Ka** | | | | | | | | | | | | | | |
| 64 | M12 | A11 | 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 0.025 | 0.23 | 0.13 | 0.24 | 3.43 | 0.11 | 1.42 | 2.91 | 6.45 | 5.59 | -- |
| 66 | M12 | 2B21t | 102 | 0.019 | 0.16 | 0.28 | 0.13 | 3.74 | 1.21 | 2.11 | 4.33 | 6.87 | 5.48 | -- |
| 67 | M12 | 3B22t | 170 | 0.020 | 0.10 | 0.19 | 0.10 | 6.67 | 2.12 | 2.35 | 7.99 | 6.67 | 5.32 | -- |
| 68 | M12 | 4B3 | 201 | 0.012 | 0.40 | 0.14 | 0.08 | 4.95 | 2.37 | 1.26 | 5.83 | 6.98 | 5.40 | -- |
| 69 | M12 | 5C1 | 231 | 0.006 | 0.40 | 0.65 | 0.06 | 3.74 | 1.21 | 1.22 | 3.91 | 7.34 | 5.22 | -- |
| 70 | M12 | 6C2 | 413+ | -- | 0.02 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| **Riverbank Formation, upper member, 130 Ka** | | | | | | | | | | | | | | |
| 71 | R9 | A11p | 30 | 0.044 | 0.36 | 0.13 | 0.22 | 2.73 | 0.40 | 2.73 | 3.83 | 5.83 | 4.87 | -- |
| 72 | R9 | A12p | 60 | 0.040 | 0.29 | 0.09 | 0.11 | 3.23 | 0.00 | 2.45 | 4.24 | 5.77 | 4.88 | -- |
| 73 | R9 | B1 | 105 | -- | 0.15 | 0.11 | 0.08 | 3.84 | 0.26 | 2.49 | 4.66 | 5.77 | 4.70 | -- |
| 74 | R9 | 2B21 | 180 | -- | 0.08 | 0.04 | 0.09 | 4.44 | 1.82 | 4.66 | 6.83 | 6.13 | 4.56 | -- |
| 75 | R9 | 2B22 | 235 | -- | 0.04 | 0.09 | 0.09 | 4.34 | 1.11 | 4.58 | 4.49 | 6.05 | 4.38 | -- |
| 76 | R9 | 3B3 | 350 | -- | 0.03 | 0.13 | 0.10 | 5.35 | 1.72 | 2.10 | 7.08 | 6.15 | 4.44 | -- |
| 77 | R9 | 4C | 400+ | -- | 0.03 | 0.13 | 0.08 | 5.25 | 1.01 | 1.87 | 6.08 | 6.13 | 4.28 | -- |
| 78 | R33 | A11 | 4 | 0.1261 | 1.53 | -- | -- | -- | -- | 1.85 | -- | 6.26 | 5.69 | -- |
| 79 | R33 | 2A12 | 19 | 0.0492 | 0.47 | -- | -- | -- | -- | 1.33 | -- | 6.11 | 5.54 | -- |
| 80 | R33 | 3A3 | 39 | 0.0248 | 0.16 | -- | -- | -- | -- | 1.29 | -- | 5.56 | 5.11 | -- |
| 81 | R33 | 3B21t | 62 | 0.0229 | 0.06 | -- | -- | -- | -- | 1.61 | -- | 5.94 | 4.60 | -- |
| 82 | R33 | 3B22t | 83 | 0.0240 | 0.06 | -- | -- | -- | -- | 1.61 | -- | 6.21 | 4.86 | -- |
| 83 | R33 | 3B23t | 122 | -- | -- | -- | -- | -- | -- | 2.81 | -- | -- | -- | -- |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | 1.22 | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | 1.10 | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | 1.08 | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | -- | -- | -- | -- | -- | -- | 0.64 | -- | -- | -- | -- |
| **Riverbank Formation, middle member, 250 Ka** | | | | | | | | | | | | | | |
| 88 | R2 | Ap | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 90 | R2 | B22t | 185 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 93 | R2 | C2n | 500+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | 0.023 | 0.16 | 0.13 | 0.22 | 3.53 | 0.01 | 1.74 | 3.00 | 6.20 | 5.12 | -- |
| 95 | R10 | 2B1 | 70 | -- | 0.07 | 0.06 | 0.23 | 3.43 | 0.81 | 1.71 | 4.33 | 6.82 | 5.08 | -- |
| 96 | R10 | 2B21t | 140 | -- | 0.03 | 0.19 | 0.10 | 4.65 | 2.11 | 2.47 | 6.49 | 7.17 | 4.98 | -- |
| 97 | R10 | 2B22t | 210 | -- | 0.03 | 0.15 | 0.08 | 3.64 | 2.72 | 1.46 | 5.91 | 7.47 | 4.98 | -- |
| 98 | R10 | 3B3t | 386 | -- | 0.03 | 0.19 | 0.08 | 4.75 | 1.82 | 1.10 | 5.58 | 7.47 | 5.32 | -- |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 0.0351 | 0.31 | 0.17 | 0.32 | 3.54 | 0.50 | 1.29 | 4.83 | 6.41 | 5.57 | -- |
| 101 | R32 | A12 | 50 | 0.0278 | 0.15 | 0.26 | 0.23 | 3.03 | 0.61 | 1.00 | 3.83 | 6.28 | 5.41 | -- |
| 102 | R32 | A3 | 70 | 0.0195 | 0.10 | 0.25 | 0.22 | 3.23 | 0.71 | 1.13 | 3.91 | 6.26 | 4.99 | -- |
| 103 | R32 | B21t | 105 | 0.0200 | 0.08 | 0.22 | 0.24 | 3.33 | 1.32 | 1.53 | 4.74 | 6.18 | 4.77 | -- |
| 104 | R32 | B22t | 150 | 0.0180 | 0.04 | 0.25 | 0.23 | 4.54 | 1.01 | 1.93 | 6.08 | 6.56 | 4.85 | -- |
| 105 | R32 | B31t | 220 | -- | -- | 0.25 | 0.20 | 3.94 | 1.41 | 1.21 | 4.99 | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | 0.31 | 0.22 | 4.34 | 1.52 | 0.48 | 5.49 | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | -- | -- | 0.36 | 0.14 | 3.84 | 1.51 | 0.48 | 3.66 | -- | -- | -- |
| **Riverbank Formation, lower member, 330 Ka** | | | | | | | | | | | | | | |
| 108 | R30 | Ap | 65 | 0.019 | 0.18 | 0.09 | 0.18 | 2.52 | 0.00 | 1.10 | 2.75 | 6.45 | 4.73 | 6.6 |
| 109 | R30 | B10 | 78 | -- | -- | 0.15 | 0.23 | 4.34 | 0.61 | 2.23 | 6.49 | 6.00 | 4.49 | 6.1 |
| 110 | R30 | B21t | 127 | -- | -- | 0.19 | 0.18 | 4.95 | 1.92 | 2.47 | 8.24 | 5.75 | 4.21 | 5.8 |
| 111 | R30 | 2B22t | 179 | -- | -- | 0.63 | 0.26 | 8.69 | 2.72 | 2.63 | 12.90 | 5.90 | 4.11 | 6.0 |
| 112 | R30 | 3B3t | 197 | -- | -- | 0.28 | 0.14 | 9.90 | 2.93 | 1.58 | 12.90 | 6.45 | 4.62 | 6.8 |
| 113 | R30 | 3C1ox | 220 | -- | -- | 0.19 | 0.16 | 9.09 | 2.42 | 1.46 | 11.41 | 6.95 | 4.90 | 7.0 |

**Supplementary Table 3, Part 1.** Extractive chemical analyses—Continued

| No. | Sample | Horizon | Basal depth (cm) | Percentage of <2-mm | | mg/100 g soil | | | | | | pH | pH | pH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total N | Organic C | Exchange Na | Exchange K | Exchange Ca | Exchange Mg | Exchange N | CEC | 1:1$H_2O$ | 1:1KCl | Saturated |
| | | | | | | Turlock Lake Formation, 600 Ka | | | | | | | | |
| 114 | T2 | A | 31 | 0.037 | 0.38 | 0.08 | 0.27 | 2.73 | 0.50 | 1.87 | 3.50 | 6.58 | 5.20 | -- |
| 115 | T2 | B21 | 173 | -- | 0.17 | 0.11 | 0.26 | 4.65 | 1.81 | 4.16 | 8.91 | 5.82 | 4.30 | -- |
| 116 | T2 | B22 | 386 | -- | 0.05 | 0.26 | 0.11 | 5.96 | 2.12 | 1.74 | 8.41 | 6.52 | 4.65 | -- |
| 117 | T2 | 3C | 417 | -- | 0.04 | 0.06 | 0.07 | 3.28 | 0.20 | 0.86 | 3.17 | 6.48 | 4.46 | -- |
| 118 | T6 | A11 | 20 | 0.0364 | -- | 0.27 | 0.28 | 3.33 | 0.00 | -- | 3.08 | 6.50 | -- | -- |
| 119 | T6 | A12 | 40 | 0.0214 | -- | 0.25 | 0.31 | 3.33 | 0.21 | -- | 2.66 | 6.00 | -- | -- |
| 120 | T6 | 2B21t | 90 | 0.0091 | -- | 0.29 | 0.42 | 8.69 | 1.71 | -- | 8.99 | 7.00 | -- | -- |
| 121 | T6 | 2B22t | 190 | -- | -- | 0.26 | 0.35 | 8.08 | 1.62 | -- | 10.41 | 6.20 | -- | -- |
| 122 | T6 | 3B+C | 370 | -- | -- | 0.36 | 0.17 | 5.05 | 1.41 | -- | 7.41 | 6.60 | -- | -- |
| 123 | T11 | A11p | 5 | -- | -- | 0.09 | 0.81 | 8.58 | 0.41 | 1.95 | 11.07 | 6.82 | 6.44 | 6.9 |
| 124 | T11 | 2A12p | 11 | 0.032 | 0.64 | 0.04 | 0.34 | 3.94 | 0.00 | 1.18 | 4.00 | 6.95 | 5.99 | 7.1 |
| 125 | T11 | 2A+B | 20 | -- | -- | 0.06 | 0.34 | 4.65 | 0.60 | 1.91 | 6.66 | 6.85 | 5.51 | 6.8 |
| 126 | T11 | 2B1t | 33 | -- | -- | 0.17 | 0.27 | 5.35 | 2.22 | 2.87 | 9.65 | 6.70 | 4.96 | 6.5 |
| 127 | T11 | 2B2t | 80 | -- | -- | 0.18 | 0.11 | 5.66 | 2.12 | 2.59 | 9.57 | 6.60 | 4.61 | 6.4 |
| 128 | T11 | B31t | 191 | -- | -- | 0.21 | 0.12 | 7.27 | 2.51 | 1.58 | 8.99 | 6.90 | 5.21 | 6.6 |
| 129 | T11 | 4B32t | 256 | -- | -- | 0.23 | 0.12 | 5.81 | 1.41 | 1.50 | 7.41 | 7.10 | 5.03 | 6.5 |
| 130 | T11 | 5B+C | 292 | -- | -- | 0.21 | 0.13 | 5.05 | 0.51 | 1.38 | 7.16 | 6.95 | 4.90 | 6.4 |
| 131 | T11 | 5C1ox | 375 | -- | -- | 0.19 | 0.14 | 5.35 | 1.21 | 1.26 | 6.91 | 7.00 | 4.88 | 6.5 |
| 132 | T11 | 6IC2ox | 375+ | -- | -- | 0.19 | 0.19 | 5.86 | 1.31 | 1.22 | 6.91 | 7.15 | 4.96 | 6.5 |
| | | | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | |
| 133 | CH1 | A1 | 12 | 0.053 | 0.34 | 0.11 | 0.26 | 1.92 | 0.60 | 4.80 | 6.58 | 4.84 | 3.66 | -- |
| 134 | CH1 | 2AB | 53 | 0.046 | 0.28 | 0.11 | 0.27 | 2.52 | 0.36 | 5.16 | 7.08 | 4.93 | 3.56 | -- |
| 135 | CH1 | 2B21t | 88 | -- | 0.12 | 0.19 | 0.22 | 2.83 | 0.30 | 9.15 | 11.57 | 4.55 | 3.19 | -- |
| 135 | CH1 | 2B22t | 140 | -- | 0.26 | 0.15 | 0.06 | 4.44 | 0.21 | 8.98 | 12.15 | 4.40 | 3.05 | -- |
| 137 | CH1 | 2B31 | 234 | -- | 0.21 | 0.24 | 0.05 | 5.65 | 0.71 | 6.81 | 11.90 | 4.00 | 2.84 | -- |
| 138 | CH1 | 2B32 | 310 | -- | 0.22 | 0.39 | 0.10 | 6.56 | 2.73 | 7.66 | 15.73 | 3.96 | 2.77 | -- |
| 139 | CH1 | 3IB33 | 350 | -- | 0.21 | 0.37 | 0.09 | 5.85 | 2.94 | 6.61 | 15.32 | 4.06 | 2.94 | -- |
| 140 | CH2 | A1 | 8 | -- | 0.80 | 1.06 | 0.33 | 2.83 | 0.71 | 5.79 | 7.76 | 4.71 | -- | -- |
| 141 | CH2 | A3 | 30 | -- | 0.29 | 1.50 | 0.32 | 1.62 | 0.45 | 7.52 | 7.82 | 4.55 | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | 0.23 | 1.62 | 0.26 | 1.48 | 0.36 | 8.20 | 8.66 | 4.17 | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | 0.12 | 1.42 | 0.24 | 2.91 | 0.71 | 11.26 | 11.87 | 4.36 | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | 0.08 | 1.34 | 0.20 | 4.12 | 1.41 | 11.78 | 12.32 | 4.20 | -- | -- |
| 145 | CH2 | 2B23 | 200 | -- | 0.06 | 0.83 | 0.10 | 5.02 | 2.08 | 11.42 | 14.23 | 4.12 | -- | -- |
| 146 | CH2 | 3B24 | 290 | -- | 0.05 | 0.98 | 0.17 | 7.60 | 3.10 | 12.63 | 16.76 | 4.14 | -- | -- |
| 147 | CH2 | 3IIB3 | 350+ | -- | 0.04 | 1.34 | 0.19 | 6.28 | 3.71 | 12.71 | 18.28 | 4.14 | -- | -- |
| 148 | CH3 | A1 | 9 | -- | 2.01 | 0.88 | 0.50 | 10.21 | 1.13 | 4.83 | 11.19 | 5.84 | -- | -- |
| 149 | CH3 | A3 | 35 | -- | 0.34 | 1.62 | 0.43 | 4.25 | 1.03 | 4.50 | 7.87 | 5.44 | -- | -- |
| 150 | CH3 | A+B | 68 | -- | 0.26 | 0.67 | 0.40 | 3.19 | 0.81 | 5.71 | 8.04 | 5.01 | -- | -- |
| 151 | CH3 | B2t | 105 | -- | 0.11 | 0.70 | 0.31 | 4.28 | 0.96 | 9.49 | 11.25 | 4.62 | -- | -- |
| 152 | CH3 | B22t | 153 | -- | 0.11 | 1.52 | 0.27 | 5.38 | 1.32 | 10.06 | 12.15 | 4.48 | -- | -- |
| 153 | CH3 | 2B23 | 173 | -- | 0.09 | 1.24 | 0.24 | 6.11 | 2.45 | 10.86 | 14.74 | 4.06 | -- | -- |
| 154 | CH3 | 3IIB24 | 260 | -- | 0.03 | 1.06 | 0.17 | 6.87 | 3.64 | 11.02 | 15.30 | 4.33 | -- | -- |
| 155 | CH3 | 4VB31 | 340 | -- | 0.03 | 0.88 | 0.15 | 6.07 | 3.74 | 11.26 | 15.86 | 4.20 | -- | -- |
| 156 | CH3 | 5B32 | 750+ | -- | 0.03 | 1.26 | 0.24 | 6.92 | 4.81 | 12.63 | 21.09 | 4.10 | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | 0.02 | 1.16 | 0.18 | 2.96 | 3.25 | 6.52 | 10.57 | 3.92 | -- | -- |
| 158 | CH4 | 4C1ox | 1000 | -- | 0.02 | 1.68 | 0.31 | 3.78 | 4.60 | 3.38 | 10.29 | 4.41 | -- | -- |

## **Supplementary Table 3, Part 2.** Extractive chemical analyses

[CEC, cation-exchange capacity; m, with magnetic minerals; w, without magnetic minerals. Analysts: A. L. Walker, U.S. Geological Survey, and A. J. Busacca, Peter Janitsky, and R. Meixner, University of California, Davis]

| No. | Sample | Horizon | Basal depth (cm) | percentage of <2-mm | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $Fe_d$(m) | $Fe_d$(w) | $Al_d$(w) | mags | $Fe_o$ | $Al_o$ |
| **Modern River Alluvium** | | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- |
| **Post-Modesto Deposits, .2 Ka** | | | | | | | | | |
| 5 | PM15 | A1 | 4 | 1.18 | 0.52 | 0.05 | 0.72 | 0.22 | 0.04 |
| 6 | PM15 | 2C1ox | 19 | 0.65 | 0.59 | 0.06 | 0.99 | 0.22 | 0.04 |
| 7 | PM15 | 3C2ox | 42 | 0.98 | 0.53 | 0.03 | 0.58 | 0.19 | 0.04 |
| 8 | PM15 | 4C3ox | 47 | 1.19 | 0.71 | 0.08 | 0.34 | 0.24 | 0.04 |
| 9 | PM15 | 5C4ox | 51 | 1.09 | 0.41 | 0.05 | 1.03 | 0.13 | 0.03 |
| 10 | PM15 | 6C5ox | 51+ | 0.68 | 0.65 | 0.05 | 0.39 | 0.20 | 0.03 |
| 11 | PM19 | A11 | 7 | 1.15 | 0.70 | 0.08 | 0.21 | 0.23 | 0.05 |
| 12 | PM19 | 2A12 | 12 | 0.81 | 0.76 | 0.08 | 0.43 | 0.24 | 0.05 |
| 13 | PM19 | 3C1ox | 23 | 1.25 | 0.73 | 0.06 | 0.23 | 0.24 | 0.05 |
| 14 | PM19 | 4C2ox | 43 | 1.10 | 1.07 | 0.11 | 0.25 | 0.34 | 0.07 |
| 15 | PM19 | 5C3ox | 49 | 0.95 | 0.67 | 0.07 | 0.27 | 0.22 | 0.04 |
| 16 | PM19 | 6C4n | 55 | 1.22 | 0.82 | 0.09 | 0.07 | 0.25 | 0.06 |
| 17 | PM19 | 7C5n | 66 | 1.20 | 1.22 | 0.12 | 0.19 | 0.42 | 0.09 |
| 18 | PM19 | 8C6n | 80+ | -- | 0.56 | 0.06 | -- | 0.18 | 0.04 |
| **Post-Modesto Deposits, 3 Ka** | | | | | | | | | |
| 19 | PM8 | A1 | 32 | 1.13 | -- | -- | -- | -- | -- |
| 20 | PM8 | 2C1 | 55 | 0.97 | -- | -- | -- | -- | -- |
| 21 | PM8 | 3C2 | 66 | 0.68 | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 0.53 | -- | -- | -- | -- | -- |
| 23 | PM13 | A11 | 5 | 1.14 | 1.09 | 0.12 | 0.09 | 0.25 | 0.06 |
| 24 | PM13 | A12 | 35 | 1.18 | 1.03 | 0.11 | 0.03 | 0.26 | 0.06 |
| 25 | PM13 | 2C1ox | 86 | 0.99 | 0.78 | 0.07 | 0.16 | 0.28 | 0.05 |
| 26 | PM13 | 3C2ox | 112 | 0.83 | 0.83 | 0.05 | 0.07 | 0.31 | 0.05 |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | 0.94 | 0.11 | 0.02 | 0.31 | 0.06 |
| 31 | PM14 | 2A12 | 33 | 0.93 | 1.12 | 0.12 | 0.05 | 0.32 | 0.08 |
| 32 | PM14 | 3C1ox | 99 | 0.71 | 0.78 | 0.08 | 0.24 | 0.28 | 0.05 |
| 33 | PM14 | 4C2ox | 130 | 0.96 | 0.79 | 0.07 | 0.13 | 0.29 | 0.04 |
| 34 | PM14 | 5C3ox | 175 | 1.03 | 0.87 | 0.09 | 0.03 | 0.36 | 0.05 |
| 35 | PM14 | 6C4ox | 200 | 0.56 | 0.60 | 0.06 | 0.15 | 0.24 | 0.04 |
| 36 | PM14 | 7C5n | 239+ | 0.08 | 0.26 | 0.05 | 0.20 | 0.09 | 0.03 |
| 37 | PM16 | A | 2 | 1.15 | 0.76 | 0.07 | 0.19 | 0.18 | 0.04 |
| 38 | PM16 | C1ox | 25 | 1.30 | 0.85 | 0.07 | 0.18 | 0.23 | 0.05 |
| 39 | PM16 | 2C2ox | 35 | 1.37 | 0.84 | 0.09 | 0.18 | 0.24 | 0.05 |
| 40 | PM16 | 3C3ox | 65 | 1.19 | 0.73 | 0.05 | 0.27 | 0.19 | 0.04 |
| 41 | PM16 | 4C4ox | 90 | 0.99 | 0.56 | 0.04 | 0.40 | 0.15 | 0.04 |
| 42 | PM16 | 5C5ox | 116 | 1.06 | 0.73 | 0.07 | 0.37 | 0.19 | 0.04 |
| 43 | PM16 | 5C6n | 236 | 1.00 | 0.86 | 0.08 | -- | 0.20 | 0.05 |
| 44 | PM17 | A | 6 | 0.80 | 0.70 | 0.06 | 0.34 | 0.18 | 0.04 |
| 45 | PM17 | 2C2ox | 45 | 1.20 | 0.80 | 0.07 | 0.27 | 0.20 | 0.04 |
| 46 | PM17 | 2C2ox | 63 | 1.47 | 0.88 | 0.08 | 0.18 | 0.22 | 0.05 |
| 47 | PM17 | 2C3ox | 74 | 1.47 | 0.94 | 0.08 | 0.16 | 0.23 | 0.04 |
| 48 | PM17 | 3C4n | 120+ | 1.31 | 0.66 | 0.08 | 0.49 | 0.19 | 0.05 |
| 49 | PM18 | A | 6 | 0.91 | 0.79 | 0.09 | 0.31 | 0.26 | 0.06 |
| 50 | PM18 | 2C1ox | 65 | 0.97 | 0.85 | 0.09 | 0.37 | 0.16 | 0.06 |
| 51 | PM18 | 2C2ox | 115 | 1.33 | 0.78 | 0.09 | 0.21 | 0.16 | 0.05 |
| 52 | PM18 | 3C3ox | 164 | 1.06 | 0.68 | 0.08 | 0.28 | 0.14 | 0.05 |
| 53 | PM18 | 4C4ox | 175+ | 0.73 | 0.65 | 0.08 | 0.32 | 0.13 | 0.04 |
| **Modesto Formation, upper member, 10 Ka** | | | | | | | | | |
| 54 | M31 | A11 | 20 | 0.92 | 0.96 | 0.10 | -- | 0.27 | 0.07 |
| 55 | M31 | A12 | 63 | 0.81 | 0.87 | 0.09 | -- | 0.20 | 0.07 |
| 56 | M31 | AC | 150 | 0.76 | 0.81 | 0.08 | -- | 0.20 | 0.07 |
| 57 | M31 | 2C1 | 200 | 0.78 | 0.82 | 0.10 | -- | 0.18 | 0.07 |
| 58 | M31 | 3C2 | 254 | 0.46 | 0.56 | 0.07 | -- | 0.15 | 0.04 |
| 59 | M46 | A11p | 5 | 0.78 | 0.44 | 0.06 | 0.46 | 0.10 | 0.03 |
| 60 | M46 | A12p | 14 | 0.53 | 0.51 | 0.06 | 0.74 | 0.12 | 0.03 |
| 61 | M46 | 2A13p | 32 | 0.96 | 0.54 | 0.06 | 0.52 | 0.10 | 0.03 |
| 62 | M46 | 3AC | 66 | 0.67 | 0.60 | 0.07 | 0.69 | 0.11 | 0.03 |
| 63 | M46 | 4Cox | 250 | 0.70 | 0.60 | 0.07 | 0.60 | 0.07 | 0.04 |

**Supplementary Table 3, Part 2.** Extractive chemical analyses--Continued

| No. | Sample | Horizon | Basal depth (cm) | percentage of <2-mm | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $Fe_d(m)$ | $Fe_d(w)$ | $Al_d(w)$ | mags | $Fe_o$ | $Al_o$ |
| | | | Modesto Formation, lower member, 40 Ka | | | | | | |
| 64 | M12 | A11 | 15 | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 0.34 | 0.27 | 0.03 | -- | 0.06 | 0.04 |
| 66 | M12 | 2B21t | 102 | 0.44 | 0.34 | 0.05 | -- | 0.06 | 0.04 |
| 67 | M12 | 3B22t | 170 | 0.49 | 0.45 | 0.06 | -- | 0.06 | 0.06 |
| 68 | M12 | 4B3 | 201 | 0.40 | 0.33 | 0.08 | -- | 0.03 | 0.05 |
| 69 | M12 | 5C1 | 231 | 0.42 | -- | -- | -- | -- | -- |
| 70 | M12 | 6C2 | 413+ | -- | 0.24 | 0.05 | 3.77 | 0.03 | 0.04 |
| | | | Riverbank Formation, upper member, 130 Ka | | | | | | |
| 71 | R9 | A11p | 30 | 0.48 | 0.40 | 0.05 | -- | 0.13 | 0.04 |
| 72 | R9 | A12p | 60 | 0.50 | 0.38 | 0.06 | -- | 0.09 | 0.04 |
| 73 | R9 | B1 | 105 | 0.59 | 0.49 | 0.08 | -- | 0.10 | 0.04 |
| 74 | R9 | 2B21 | 180 | 0.70 | 0.57 | 0.09 | -- | 0.09 | 0.07 |
| 75 | R9 | 2B22 | 235 | 0.46 | 0.36 | 0.06 | -- | 0.03 | 0.04 |
| 76 | R9 | 3B3 | 350 | 0.48 | 0.45 | 0.08 | -- | 0.03 | 0.05 |
| 77 | R9 | 4C | 400+ | 0.42 | 0.34 | 0.06 | -- | 0.05 | 0.05 |
| 78 | R33 | A11 | 4 | 0.46 | 0.37 | 0.05 | 0.92 | 0.06 | 0.04 |
| 79 | R33 | 2A12 | 19 | 1.07 | 0.40 | 0.05 | 0.04 | 0.07 | 0.04 |
| 80 | R33 | 3A3 | 39 | 0.87 | 0.49 | 0.05 | 0.47 | 0.09 | 0.04 |
| 81 | R33 | 3B21t | 62 | 1.32 | 0.62 | 0.08 | 0.10 | 0.12 | 0.06 |
| 82 | R33 | 3B22t | 83 | 1.38 | 0.71 | 0.10 | 0.14 | 0.13 | 0.06 |
| 83 | R33 | 3B23t | 122 | -- | 0.65 | 0.09 | -- | 0.10 | 0.06 |
| 84 | R33 | 3B31 | 151 | 1.19 | 0.47 | 0.08 | 0.22 | 0.07 | 0.05 |
| 85 | R33 | 3B32 | 210 | 1.05 | 0.50 | 0.06 | 0.21 | 0.05 | 0.04 |
| 86 | R33 | 4B33 | 260 | 1.29 | 0.57 | 0.08 | -- | 0.05 | 0.07 |
| 87 | R33 | 5Cox | 300+ | -- | 0.31 | 0.06 | -- | 0.04 | 0.05 |
| | | | Riverbank Formation, middle member, 250 Ka | | | | | | |
| 88 | R2 | Ap | 25 | -- | -- | -- | -- | -- | -- |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- |
| 90 | R2 | B22t | 185 | -- | -- | -- | -- | -- | -- |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- |
| 93 | R2 | C2n | 500+ | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | 0.45 | 0.33 | 0.06 | -- | 0.06 | 0.04 |
| 95 | R10 | 2B1 | 70 | 0.56 | 0.42 | 0.06 | -- | 0.07 | 0.05 |
| 96 | R10 | 2B21t | 140 | 0.60 | 0.51 | 0.08 | -- | 0.04 | 0.03 |
| 97 | R10 | 2B22t | 210 | 0.57 | 0.43 | 0.08 | -- | 0.04 | 0.04 |
| 98 | R10 | 3B3t | 386 | 0.50 | 0.37 | 0.06 | -- | 0.03 | 0.04 |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 0.52 | 0.38 | 0.05 | 1.49 | 0.07 | 0.03 |
| 101 | R32 | A12 | 50 | 0.97 | 0.45 | 0.06 | 0.10 | 0.06 | 0.03 |
| 102 | R32 | A3 | 70 | 1.07 | 0.46 | 0.06 | 0.21 | 0.07 | 0.04 |
| 103 | R32 | B21t | 105 | 1.20 | 0.54 | 0.09 | 0.31 | 0.09 | 0.05 |
| 104 | R32 | B22t | 150 | 0.70 | 0.60 | 0.09 | 1.36 | 0.09 | 0.05 |
| 105 | R32 | B31t | 220 | 1.22 | 0.57 | 0.09 | 0.19 | 0.09 | 0.05 |
| 106 | R32 | 2B32 | 354 | 1.25 | 0.40 | 0.07 | 0.39 | 0.05 | 0.05 |
| 107 | R32 | 3Cox | 360+ | -- | 0.40 | 0.07 | -- | 0.07 | 0.05 |
| | | | Riverbank Formation, upper member, 330 Ka | | | | | | |
| 108 | R30 | Ap | 65 | 0.60 | 0.37 | 0.06 | -- | 0.12 | 0.03 |
| 109 | R30 | B10 | 78 | 0.84 | 0.59 | 0.09 | -- | 0.06 | 0.06 |
| 110 | R30 | B21t | 127 | 0.82 | 0.68 | 0.09 | -- | 0.07 | 0.06 |
| 111 | R30 | 2B22t | 179 | 0.75 | 0.58 | 0.10 | -- | 0.05 | 0.06 |
| 112 | R30 | 3B3t | 197 | 0.70 | 0.53 | 0.09 | -- | 0.04 | 0.07 |
| 113 | R30 | 3C1ox | 220 | 0.64 | 0.51 | 0.08 | -- | 0.05 | 0.06 |
| | | | Turlock Lake Formation, 600 Ka | | | | | | |
| 114 | T2 | A | 31 | 1.03 | 0.74 | 0.05 | -- | 0.04 | 0.04 |
| 115 | T2 | B21 | 173 | 2.19 | 1.70 | 0.13 | -- | 0.11 | 0.09 |
| 116 | T2 | 2B22 | 386 | 1.11 | 1.04 | 0.07 | -- | 0.03 | 0.04 |
| 117 | T2 | 3C | 417 | 0.62 | 0.44 | 0.05 | -- | 0.02 | 0.04 |
| 118 | T6 | A11 | 20 | 0.39 | 0.26 | 0.02 | -- | 0.04 | 0.03 |
| 119 | T6 | A12 | 40 | -- | 0.28 | 0.04 | -- | 0.04 | 0.03 |
| 120 | T6 | 2B21t | 90 | 0.49 | 0.48 | 0.08 | -- | 0.04 | 0.06 |
| 121 | T6 | 2B22t | 190 | -- | 0.64 | 0.10 | -- | 0.05 | 0.06 |
| 122 | T6 | 3B+C | 370 | 0.23 | 0.36 | 0.07 | -- | 0.03 | 0.05 |
| 123 | T11 | A11p | 5 | 0.42 | 0.30 | 0.04 | -- | 0.04 | 0.03 |
| 124 | T11 | 2A12p | 11 | 0.64 | 0.46 | 0.02 | -- | 0.03 | 0.03 |
| 125 | T11 | 2A+B | 20 | 1.08 | 0.82 | 0.07 | -- | 0.04 | 0.06 |
| 126 | T11 | 2B1t | 33 | 1.06 | 0.98 | 0.08 | -- | 0.07 | 0.08 |
| 127 | T11 | 2B2t | 80 | 0.90 | 0.74 | 0.08 | -- | 0.04 | 0.06 |
| 128 | T11 | 3B31t | 191 | 0.82 | 0.43 | 0.08 | -- | 0.03 | 0.06 |
| 129 | T11 | 4B32t | 256 | 0.85 | 0.55 | 0.08 | -- | 0.03 | 0.06 |
| 130 | T11 | 5B+C | 292 | 0.53 | 0.42 | 0.08 | -- | 0.03 | 0.06 |
| 131 | T11 | 5C1ox | 375 | 0.53 | 0.37 | 0.08 | -- | 0.05 | 0.05 |
| 132 | T11 | 6IC2ox | 375+ | 0.58 | 0.40 | 0.07 | -- | 0.03 | 0.05 |

**Supplementary Table 3, Part 2.** Extractive chemical analyses--Continued

| No. | Sample | Horizon | Basal depth (cm) | percentage of <2-mm | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | $Fe_d$(m) | $Fe_d$(w) | $Al_d$(w) | mags | $Fe_o$ | $Al_o$ |
| China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 1.41 | 1.42 | 0.13 | -- | 0.10 | 0.05 |
| 134 | CH1 | 2AB | 53 | 1.63 | 1.66 | 0.14 | -- | 0.10 | 0.06 |
| 135 | CH1 | 2B21t | 88 | 2.41 | 2.43 | 0.21 | -- | 0.16 | 0.11 |
| 135 | CH1 | 2B22t | 140 | 3.31 | 3.33 | 0.22 | -- | 0.13 | 0.08 |
| 137 | CH1 | 2B31 | 234 | 3.31 | 3.35 | 0.13 | -- | 0.06 | 0.06 |
| 138 | CH1 | 2B32 | 310 | 2.06 | 2.27 | 0.13 | -- | 0.03 | 0.06 |
| 139 | CH1 | 3IB33 | 350 | 2.61 | 2.35 | 0.14 | -- | 0.06 | 0.06 |
| 140 | CH2 | A1 | 8 | -- | -- | -- | -- | -- | -- |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- |
| 145 | CH2 | 2B23 | 200 | -- | -- | -- | -- | -- | -- |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- |
| 147 | CH2 | 3IIB3 | 350+ | -- | -- | -- | -- | -- | -- |
| 148 | CH3 | A1 | 9 | -- | -- | -- | -- | -- | -- |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | -- | -- | -- | -- | -- | -- |
| 154 | CH3 | 3IIB24 | 260 | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4VB31 | 340 | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | -- | -- | -- | -- | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | -- | -- | -- | -- | -- |
| 158 | CH4 | 4Clox | 1000 | -- | -- | -- | -- | -- | -- |

**Supplementary Table 4, Part 1.** Mineralogy

[Percentages of very fine sand are based on approximately 200 grain counts per slide of each heavy (sp gr, greater than 3.08) and medium (sp gr, 2.58-3.08) mineral isolate. Etching scales, which range from 0 to 5, express average degree of etching of all grains observed in grain counts (after Gillam and others, 1977). Analyst, J.W. Harden]

| No. | Soil age (Ka) | Profile | Horizon | Percentages of very fine sand for selected heavy-mineral groups | | | | | | | | Etching scales for selected heavy-mineral groups in the very fine sand fraction | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Hornblende | Orthopyroxene | Clinopyroxene | Zircon | Epidote sphene | Apatite | Opaque minerals | Unknown | Hornblende | Orthopyroxene | Clinopyroxene | Zircon | Epidote | Sphene |
| 1 | .2 | PM15 | A1 | 3.05 | 0.05 | 0.05 | 0.29 | 5.78 | 2.20 | 2.97 | 9.89 | 2.2 | 3.0 | 3.0 | 1.3 | 2.5 | -- |
| 2 | .2 | PM15 | IIC1ox | 6.26 | 0.76 | 1.22 | 0.92 | 5.01 | 0.65 | 4.54 | 13.35 | 2.1 | 2.0 | 3.9 | 1.0 | 2.9 | -- |
| 3 | .2 | PM15 | VIC5ox | 3.63 | 0.36 | 0.70 | 0.18 | 8.79 | 0.24 | 2.52 | 6.65 | 2.9 | 4.0 | 3.5 | 1.7 | 3.0 | 2.1 |
| 4 | 3 | PM17 | A | 3.81 | 0.21 | 0.31 | 0.18 | 5.25 | 0.23 | 2.42 | 1.76 | 2.6 | 3.6 | 2.5 | 1.6 | 2.8 | 2.0 |
| 5 | 3 | PM17 | IIC2ox | 4.91 | 0.35 | 0.72 | 0.42 | 4.12 | 0.20 | 1.71 | 2.06 | 2.5 | 2.9 | 2.8 | 1.0 | 2.5 | 2.3 |
| 6 | 3 | PM17 | IIIC4n | 5.41 | 0.86 | 1.85 | 0.30 | 8.98 | 0.05 | 2.11 | 5.14 | 1.8 | -- | 3.0 | -- | 2.5 | -- |
| 7 | 10 | M31 | A12 | 5.26 | 0.02 | 0.15 | 0.07 | 9.77 | 0.0 | 1.35 | 6.90 | 1.9 | 3.0 | 3.1 | 1.6 | 3.1 | 2.4 |
| 8 | 10 | M31 | IIIC2 | 5.68 | 0.33 | 0.70 | 0.16 | 5.06 | 0.34 | 1.58 | 2.80 | 3.0 | 3.3 | 2.7 | 1.6 | 3.4 | 3.7 |
| 9 | 10 | M46 | A12 | 3.82 | 0.001 | 0.30 | 0.22 | 2.13 | 0.18 | 2.16 | 2.53 | 2.3 | -- | 2.6 | 1.4 | 2.6 | 1.8 |
| 10 | 10 | M46 | AC | 4.14 | 0.18 | 0.20 | 0.11 | 1.35 | 0.47 | 2.75 | 1.80 | 2.4 | 3.2 | 3.3 | 1.2 | 2.9 | 2.3 |
| 11 | 10 | M46 | IVCdx | 5.06 | 0.17 | 0.46 | 0.18 | 1.67 | 0.10 | 2.19 | 1.63 | 2.1 | 2.8 | 2.8 | 1.2 | 2.8 | 1.6 |
| 12 | 40 | M12 | VC1 | 4.62 | 0.08 | 0.05 | 0.15 | 1.2 | 0.04 | 1.76 | 1.94 | 3.3 | -- | 3.0 | 2.0 | 3.1 | 3.1 |
| 13 | 130 | R9 | IIIB3 | -- | -- | -- | -- | -- | -- | -- | -- | 3.1 | 3.8 | 3.6 | 1.3 | 2.9 | 3.3 |
| 14 | 130 | R9 | IVC | 5.08 | 0.17 | 0.41 | 0.12 | 3.04 | 0.0 | 2.82 | 2.46 | 2.9 | 3.3 | 4.0 | 2.0 | 2.9 | 2.7 |
| 15 | 130 | R33 | IIA12 | 3.26 | 0.06 | 0.34 | 0.06 | 1.54 | 0.09 | 2.30 | 1.56 | 2.7 | 3.0 | 3.0 | 1.6 | 3.0 | 2.6 |
| 16 | 130 | R33 | IIIB23t | 2.44 | 0.11 | 0.11 | 0.20 | 1.49 | 0.0 | 1.38 | 0.34 | 3.0 | 3.6 | 3.3 | 1.3 | 3.0 | 2.5 |
| 17 | 130 | R33 | VCox | 6.00 | 0.19 | 0.04 | 0.15 | 1.03 | 0.16 | 7.85 | 1.64 | 3.4 | 3.0 | -- | 1.8 | 3.2 | 2.8 |
| 18 | 250 | R10 | A | 3.52 | 0.15 | 0.15 | 0.23 | 1.15 | 0.0 | 2.30 | 0.23 | 2.9 | 3.5 | 3.0 | 1.8 | 3.0 | 3.0 |
| 19 | 600 | T11 | IIA12p | 0.55 | 0.04 | 0.07 | 0.15 | 0.62 | 0.0 | 2.09 | 0.50 | 3.3 | 4.0 | 3.8 | 1.9 | 3.0 | 3.1 |
| 20 | 600 | T11 | IIB2t | 0.35 | 0.04 | 0.0 | 0.14 | 0.43 | 0.0 | 4.54 | 0.25 | 3.3 | 4.5 | -- | 2.0 | 3.1 | 3.4 |
| 21 | 600 | T11 | VClox | -- | -- | -- | -- | -- | -- | -- | -- | 3.7 | 4.5 | -- | -- | 3.6 | 3.3 |

## Supplementary Table 4, Part 2. Mineralogy

[Analysts: A.J. Busacca, University of California, Davis, and A.L. Walker, U.S. Geological Survey]

| No. | Sample | Horizon | Basal depth (cm) | Kaolinite | Chlorite | Chloritized Vermiculite | Vermiculite | Mica Vermiculite | Mica | Mica chloritized | Smectite | Quartz | Feldspar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Modern River Alluvium | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | |
| 5 | PM15 | A1 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6 | PM15 | 2C1ox | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | |
| 19 | PM8 | A1 | 32 | +++ | + | + | ++ | -- | +++ | -- | ++ | X | X |
| 20 | PM8 | 2C1 | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 21 | PM8 | 3C2 | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | ++ | -- | -- | ++ | -- | + | -- | -- | X | XX |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | PM14 | 3C1ox | 99 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 36 | PM14 | 7C5n | 230+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | PM18 | 2C1ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | |
| 54 | M31 | A11 | 20 | +++ | + | -- | ++ | -- | +++ | -- | + | X | X |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | +++ | + | -- | + | -- | +++ | -- | ++ | X | X |
| 57 | M31 | 2C1 | 200 | +++ | + | -- | ++ | -- | +++ | -- | ++ | X | X |
| 58 | M31 | 3C2 | 254 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 59 | M46 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | M46 | A12p | 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | M46 | 2A13p | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 62 | M46 | 3AC | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 63 | M46 | 4Cox | 250 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 4, Part 2.** Mineralogy—Continued

| No. | Sample | Horizon | Basal depth (cm) | Kaolinite | Chlorite | Chloritized Vermiculite | Vermiculite | Mica Vermiculite | Mica | Mica chloritized | Smectite | Quartz | Feldspar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | |
| 64 | M12 | A11 | 85 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | +++ | -- | -- | -- | -- | ++++ | -- | -- | XX | X |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | +++ | -- | + | +++ | + | ++ | -- | -- | X | X |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | ++ | -- | -- | +++ | + | + | -- | -- | X | X |
| 70 | M12 | 6C2 | 413+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | |
| 71 | R9 | A11p | 30 | +++ | -- | -- | -- | -- | ++ | -- | -- | XX | XX |
| 72 | R9 | A12p | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 73 | R9 | B1 | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 74 | R9 | 2B21 | 180 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 75 | R9 | 2B22 | 235 | +++ | -- | -- | ++ | -- | + | + | -- | X | X |
| 76 | R9 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 77 | R9 | 4C | 400+ | +++ | -- | -- | ++ | + | + | -- | -- | X | XX |
| 78 | R33 | A11 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | |
| 88 | R2 | Ap | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 90 | R2 | B22t | 185 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 93 | R2 | C2n | 500+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | +++ | -- | -- | -- | -- | +++ | + | -- | X | X |
| 95 | R10 | 2B10 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 96 | R10 | 2B21t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 97 | R10 | 2B22t | 210 | ++++ | -- | -- | ++ | -- | + | -- | -- | X | X |
| 98 | R10 | 3B3t | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | |
| 108 | R30 | Ap | 65 | + | +++ | -- | -- | -- | -- | ++ | -- | -- | XXX |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 111 | R30 | 2B22t | 179 | +++ | -- | -- | ++ | -- | + | -- | -- | X | X |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | ++ | -- | -- | + | -- | ++ | -- | -- | X | -- |
| | | | | | | Turlock Lake Formation, 600 Ka | | | | | | | |
| 114 | T2 | A | 31 | +++ | -- | -- | -- | -- | ++ | -- | -- | XX | X |
| 115 | T2 | B21 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 116 | T2 | 2B22 | 386 | ++++ | + | -- | + | + | + | -- | -- | X | X |
| 117 | T2 | 3C | 417 | +++ | + | -- | ++ | -- | + | + | -- | X | X |
| 118 | T6 | A11 | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 119 | T6 | A12 | 40 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 120 | T6 | 2B21t | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 121 | T6 | 2B22t | 190 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 122 | T6 | 3B+C | 370 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | +++ | + | -- | ++ | -- | ++ | + | + | X | X |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 127 | T11 | 2B2t | 80 | ++++ | -- | -- | ++ | -- | ++ | + | -- | X | X |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6C2ox | 375+ | ++++ | -- | -- | ++ | -- | ++ | -- | -- | X | X |

**Supplementary Table 4, Part 2.** Mineralogy—Continued

| No. | Sample | Horizon | Basal depth (cm) | Kaolinite | Chlorite | Chloritized Vermiculite | Vermiculite | Mica Vermiculite | Mica | Mica chloritized | Smectite | Quartz | Feldspar |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | |
| 133 | CH1 | A1 | 12 | ++++ | -- | -- | + | -- | + | -- | + | XX | X |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 136 | CH1 | 2B22t | 140 | ++++ | -- | -- | + | -- | + | -- | ++ | X | X |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | ++++ | -- | -- | -- | -- | -- | -- | ++++ | X | X |
| 139 | CH1 | 3B33 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 140 | CH2 | A1 | 8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 145 | CH2 | 2B23 | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 147 | CH2 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 148 | CH3 | A1 | 9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 154 | CH3 | 3B24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4B31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 158 | CH4 | 4C1ox | 1000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

\+ Trace
++ Moderate amount present
+++ Large amount present
++++ Dominant

**Supplementary Table 5.** Total chemical analyses of the fine (less than 47 μm) fraction by X-ray fluorescence

[All analyses in weight percent. Analysts: J. Baker, A. Bartel, J. Carr, D. Hopping, V.G. Mossotti, J. Taggart, and J.S. Wahlberg]

| No. | Sample | Horizon | Basal Depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | MnO | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Modern River Alluvium | | | | | | | |
| 1 | MRA1 | -- | -- | 60.4 | 14.3 | 7.83 | 2.1 | 2.49 | 1.6 | 1.82 | 0.86 | 0.3 | 0.14 | -- |
| 2 | MRA2 | -- | -- | 61.4 | 14.6 | 6.59 | 2.1 | 2.47 | 1.7 | 1.86 | 0.77 | 0.2 | 0.16 | -- |
| 3 | MRA3 | -- | -- | 58.6 | 14.3 | 7.31 | 1.9 | 2.33 | 2.2 | 1.86 | 0.74 | 0.3 | 0.38 | -- |
| 4 | MRA4 | -- | -- | 58.7 | 16.0 | 6.54 | 2.4 | 2.30 | 1.4 | 1.41 | 0.77 | 0.3 | 0.24 | -- |

**Supplementary Table 5.** Total chemical analyses of the fine (less than 47 μm) fraction by X-ray fluorescence—Continued

| No. | Sample | Horizon | Basal Depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | MnO | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | |
| 5 | PM15 | A1 | 4 | 67.30 | 12.82 | 5.53 | 1.72 | 3.31 | 2.07 | 1.74 | 0.86 | 0.17 | 0.123 | 0.104 |
| 6 | PM15 | 2C1ox | 19 | 66.69 | 13.11 | 5.88 | 1.80 | 3.14 | 1.99 | 1.72 | 0.88 | 0.17 | 0.109 | 0.1 |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | 65.37 | 13.39 | 6.29 | 1.85 | 3.13 | 1.95 | 1.76 | 0.89 | 0.18 | 0.154 | 0.1 |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | 61.82 | 13.63 | 6.05 | 1.80 | 2.63 | 1.75 | 2.14 | 0.77 | 0.28 | 0.119 | 0.04 |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | 63.50 | 14.45 | 6.45 | 1.95 | 2.47 | 1.84 | 2.20 | 0.79 | 0.20 | 0.124 | 0.036 |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | 63.56 | 14.28 | 6.34 | 1.82 | 2.51 | 1.62 | 2.02 | 0.77 | 0.15 | 0.112 | 0.03 |
| | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | |
| 19 | PM8 | A1 | 32 | 62.20 | 14.65 | 6.17 | 1.82 | 2.52 | 1.67 | 2.08 | 0.77 | 0.27 | 0.124 | 0.033 |
| 20 | PM8 | 2C1 | 55 | 64.65 | 14.24 | 6.26 | 2.15 | 2.81 | 1.42 | 1.79 | 0.81 | 0.12 | 0.104 | 0.037 |
| 21 | PM8 | 3C2 | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 65.41 | 13.31 | 6.05 | 2.03 | 3.05 | 1.45 | 1.77 | 0.88 | 0.15 | 0.120 | 0.081 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | 61.35 | 14.40 | 6.43 | 1.96 | 2.68 | 1.65 | 2.00 | 0.78 | 0.16 | 0.125 | 0.031 |
| 32 | PM14 | 3C1ox | 99 | 65.32 | 13.52 | 5.80 | 1.82 | 2.85 | 2.03 | 1.80 | 0.80 | 0.14 | 0.107 | 0.053 |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | 66.90 | 13.47 | 5.68 | 1.72 | 2.92 | 1.86 | 1.75 | 0.82 | 0.15 | 0.107 | 0.072 |
| 36 | PM14 | 7C5n | 230+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | 53.14 | 11.67 | 6.16 | 2.06 | 3.38 | 1.47 | 2.18 | 0.79 | 0.29 | 0.137 | 0.039 |
| 50 | PM18 | 2C1ox | 65 | 66.02 | 13.08 | 6.31 | 1.88 | 2.82 | 1.52 | 1.75 | 0.87 | 0.16 | 0.112 | 0.055 |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | 64.84 | 13.55 | 6.30 | 1.93 | 2.81 | 1.66 | 1.83 | 0.85 | 0.17 | 0.109 | 0.053 |

**Supplementary Table 5.** Total chemical analyses of the fine (less than 47 μm) fraction by X-ray fluorescence--Continued

| No. | Sample | Horizon | Basal Depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | MnO | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | | | |
| 54 | M31 | A11 | 20 | 62.55 | 14.01 | 6.04 | 1.85 | 2.79 | 1.72 | 2.13 | 0.77 | 0.25 | 0.12 | .037 |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | 64.39 | 14.74 | 6.24 | 1.89 | 2.42 | 2.02 | 2.11 | 0.81 | 0.18 | 0.103 | 0.045 |
| 58 | M31 | 3C2 | 254 | 65.80 | 14.06 | 5.87 | 1.90 | 2.70 | 2.04 | 2.05 | 0.85 | 0.17 | 0.099 | 0.062 |
| 59 | M46 | A11p | 5 | 57.8 | 14.6 | 6.09 | 2.00 | 2.60 | 2.05 | 2.51 | 0.75 | 0.28 | 0.09 | 0.0317 |
| 60 | M46 | A12p | 14 | 63.32 | 14.66 | 5.21 | 1.61 | 2.86 | 2.56 | 2.62 | 0.73 | 0.20 | 0.097 | 0.042 |
| 61 | M46 | 2A13p | 32 | 60.5 | 15.6 | 6.29 | 2.02 | 2.65 | 2.21 | 2.63 | 0.79 | 0.26 | 0.13 | 0.0350 |
| 62 | M46 | 3AC | 66 | 63.43 | 15.93 | 5.90 | 1.56 | 2.68 | 2.12 | 2.61 | 0.79 | 0.19 | 0.118 | 0.04 |
| 63 | M46 | 4Cox | 250 | 64.12 | 14.93 | 5.57 | 1.73 | 2.83 | 2.37 | 2.43 | 0.76 | 0.17 | 0.100 | 0.04 |
| | | | | Modesto Formation, lower member, 40 Ka | | | | | | | | | | |
| 64 | M12 | A11 | 15 | 57.10 | 15.80 | 7.78 | 1.90 | 1.32 | 1.30 | 1.38 | 0.76 | 0.10 | 0.13 | -- |
| 65 | M12 | A12 | 81 | 65.13 | 15.74 | 4.77 | 1.17 | 2.90 | 2.95 | 2.57 | 0.80 | 0.14 | 0.098 | 0.053 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 56.31 | 19.81 | 6.74 | 1.52 | 2.37 | 2.12 | 1.88 | 0.80 | 0.14 | 0.097 | 0.037 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 63.38 | 15.99 | 5.32 | 1.51 | 3.17 | 2.59 | 2.17 | 0.81 | 0.13 | 0.092 | 0.055 |
| 70 | M12 | 6C2 | 413+ | 59.30 | 16.20 | 7.66 | 1.70 | 1.48 | 1.40 | 1.23 | 0.81 | 0.10 | 0.13 | -- |
| | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | | | |
| 71 | R9 | A11p | 30 | 65.80 | 16.31 | 4.46 | 0.84 | 2.30 | 2.64 | 2.43 | 0.84 | 0.11 | 0.134 | 0.046 |
| 72 | R9 | A12p | 60 | 61.9 | 17.1 | 4.92 | 1.11 | 2.11 | 2.33 | 2.39 | 0.80 | 0.12 | 0.16 | 0.0346 |
| 73 | R9 | B1 | 105 | 59.1 | 19.5 | 5.65 | 1.21 | 1.76 | 2.06 | 2.35 | 0.85 | 0.14 | 0.13 | 0.0335 |
| 74 | R9 | 2B21 | 180 | 54.0 | 22.9 | 6.16 | 1.22 | 1.38 | 1.57 | 1.78 | 0.81 | 0.14 | 0.14 | 0.0265 |
| 75 | R9 | 2B22 | 235 | 56.59 | 22.48 | 6.19 | 1.02 | 1.42 | 1.58 | 1.93 | 0.86 | 0.13 | 0.115 | 0.028 |
| 76 | R9 | 3B3 | 350 | 55.8 | 20.0 | 6.82 | 1.96 | 1.77 | 1.63 | 2.32 | 0.83 | 0.12 | 0.1 | 0.0213 |
| 77 | R9 | 4C | 400+ | 57.71 | 18.94 | 6.51 | 1.88 | 2.79 | 1.97 | 2.19 | 1.08 | 0.18 | 0.092 | 0.044 |
| 78 | R33 | A11 | 4 | 63.30 | 15.69 | 4.33 | 1.00 | 2.27 | 2.66 | 2.53 | 0.81 | 0.15 | 0.163 | 0.05 |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | 55.53 | 21.22 | 6.28 | 0.87 | 1.31 | 1.55 | 1.96 | 0.87 | 0.16 | 0.092 | 0.029 |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | 51.30 | 20.60 | 7.70 | 1.63 | 1.90 | 1.05 | 1.68 | 0.85 | 0.23 | 0.078 | 0.035 |

**Supplementary Table 5.** Total chemical analyses of the fine (less than 47 μm) fraction by X-ray fluorescence—Continued

| No. | Sample | Horizon | Basal Depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | $P_2O_5$ | MnO | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | | |
| 88 | R2 | Ap | 25 | 65.01 | 15.57 | 4.08 | 0.74 | 2.85 | 3.12 | 2.55 | 0.79 | 0.13 | 0.108 | 0.069 |
| 89 | R2 | B21 | 81 | 6.10 | 18.3 | 5.20 | 1.18 | 1.96 | 2.30 | 2.62 | 0.84 | 0.16 | 0.12 | 0.0416 |
| 90 | R2 | B22t | 185 | 58.45 | 21.30 | 6.29 | 1.06 | 1.51 | 1.68 | 2.28 | 0.86 | 0.20 | 0.123 | 0.032 |
| 91 | R2 | B3 | 386 | 52.4 | 22.2 | 7.24 | 1.85 | 1.64 | 1.54 | 2.01 | 0.83 | 0.16 | 0.11 | 0.0263 |
| 92 | R2 | C1 | 500 | 49.4 | 21.7 | 9.13 | 2.81 | 1.65 | 1.36 | 2.34 | 0.93 | 0.19 | 0.16 | 0.0240 |
| 93 | R2 | C2n | 500+ | 55.01 | 18.30 | 6.04 | 1.59 | 2.77 | 2.04 | 2.70 | 0.69 | 0.30 | 0.186 | 0.047 |
| 94 | R10 | A | 46 | 65.98 | 15.93 | 4.36 | 1.04 | 2.36 | 2.75 | 2.66 | 0.83 | 0.12 | 0.085 | 0.062 |
| 95 | R10 | 2B10 | 70 | 59.5 | 19.3 | 5.58 | 1.12 | 1.76 | 2.13 | 2.42 | 0.84 | 0.15 | 0.11 | 0.0396 |
| 96 | R10 | 2B21t | 140 | 60.07 | 18.92 | 5.65 | 0.85 | 1.84 | 2.04 | 2.11 | 0.87 | 0.12 | 0.093 | 0.04 |
| 97 | R10 | 2B22t | 210 | 55.6 | 21.6 | 6.18 | 1.33 | 1.68 | 1.79 | 1.78 | 1.78 | 0.13 | 0.10 | 0.0297 |
| 98 | R10 | 3B3t | 386 | 55.99 | 19.61 | 6.45 | 1.32 | 2.14 | 2.03 | 1.96 | 0.85 | 0.13 | 0.073 | 0.038 |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 64.32 | 15.95 | 4.54 | 0.98 | 2.50 | 2.73 | 2.61 | 0.84 | 0.13 | 0.102 | 0.05 |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | 58.02 | 20.29 | 6.03 | 0.95 | 1.66 | 1.95 | 2.19 | 0.85 | 0.15 | 0.088 | 0.035 |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | 54.45 | 18.84 | 8.08 | 1.70 | 2.35 | 1.59 | 2.17 | 1.01 | 0.15 | 0.051 | 0.051 |
| | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | | | | |
| 108 | R30 | Ap | 65 | 65.88 | 16.27 | 4.45 | 0.99 | 2.19 | 2.71 | 2.74 | 0.86 | 0.08 | 0.072 | 0.062 |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | 53.87 | 21.75 | 6.86 | 0.89 | 1.39 | 1.60 | 1.89 | 0.96 | 0.11 | 0.077 | 0.03 |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | 49.05 | 20.93 | 8.98 | 1.18 | 1.32 | 0.77 | 1.41 | 0.95 | 0.14 | 0.070 | 0.014 |
| | | | | Turlock Lake Formation, 600 Ka | | | | | | | | | | |
| 114 | T2 | A | 31 | 69.07 | 14.20 | 4.70 | 0.38 | 0.82 | 1.56 | 3.02 | 1.02 | 0.10 | 0.151 | 0.067 |
| 115 | T2 | B21 | 173 | 53.89 | 22.40 | 7.01 | 0.32 | 0.27 | 0.61 | 2.03 | 1.01 | 0.12 | 0.037 | 0.035 |
| 116 | T2 | 2B22 | 386 | 57.72 | 21.52 | 6.23 | 0.77 | 1.66 | 1.95 | 1.70 | 0.89 | 0.09 | 0.049 | 0.055 |
| 117 | T2 | 3C | 417 | 61.93 | 18.10 | 6.41 | 0.90 | 1.38 | 1.59 | 1.96 | 0.89 | 0.10 | 0.055 | 0.051 |
| 118 | T6 | A11 | 20 | 61.17 | 16.75 | 5.07 | 1.36 | 2.77 | 2.92 | 2.51 | 0.90 | 0.15 | 0.173 | 0.062 |
| 119 | T6 | A12 | 40 | 56.5 | 18.1 | 7.00 | 1.70 | 2.29 | 2.18 | 2.75 | 1.04 | 0.16 | 0.15 | 0.0402 |
| 120 | T6 | 2B21t | 90 | 47.7 | 23.0 | 8.80 | 2.08 | 1.17 | 0.37 | 1.64 | 0.90 | 0.11 | 0.06 | 0.0150 |
| 121 | T6 | 2B22t | 190 | 47.61 | 23.06 | 8.83 | 1.12 | 1.14 | 0.86 | 1.84 | 1.08 | 0.13 | 0.080 | 0.02 |
| 122 | T6 | 3B+C | 370 | 54.45 | 18.60 | 7.50 | 2.15 | 4.35 | 2.37 | 1.95 | 1.16 | 0.11 | 0.280 | 0.061 |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | 66.62 | 15.59 | 4.20 | 0.47 | 1.64 | 2.47 | 3.04 | 0.81 | 0.12 | 0.079 | 0.051 |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | 56.35 | 20.88 | 6.13 | 0.49 | 0.88 | 1.33 | 2.29 | 0.92 | 0.12 | 0.043 | 0.035 |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6C2ox | 375+ | 50.32 | 21.19 | 8.35 | 0.90 | 1.32 | 0.88 | 1.51 | 0.87 | 0.17 | 0.038 | 0.019 |

**Supplementary Table 5.** Total chemical analyses of the fine (less than 47 m) fraction by X-ray fluorescence--Continued

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 73.93 | 12.55 | 4.52 | 0.29 | 0.41 | 1.17 | 2.17 | 0.94 | 0.11 | 0.058 | 0.067 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 62.50 | 20.57 | 6.81 | 0.36 | 0.28 | 0.99 | 1.55 | 0.99 | 0.15 | 0.080 | 0.044 |
| 136 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3B33 | 350 | 53.54 | 23.81 | 10.34 | 0.47 | 0.17 | 0.51 | 1.25 | 0.92 | 0.15 | 0.024 | 0.024 |
| 140 | CH2 | A1 | 8 | 71.8 | 12.5 | 4.94 | 0.61 | 0.18 | 0.5 | 2.11 | 0.98 | 0.1 | 0.05 | -- |
| 141 | CH2 | A3 | 30 | 64.2 | 16.4 | 6.54 | 0.65 | 0.12 | 0.46 | 1.83 | 1.02 | 0.17 | 0.03 | 0.0513 |
| 142 | CH2 | 2A+B | 50 | 61.2 | 18.5 | 7.18 | 0.68 | 0.08 | 0.41 | 1.68 | 1.05 | 0.18 | 0.03 | 0.0470 |
| 143 | CH2 | 2B21t | 110 | 53.1 | 23.6 | 8.56 | 0.55 | 0.05 | 0.28 | 1.03 | 1.02 | 0.20 | 0.08 | 0.0350 |
| 144 | CH2 | 2B22 | 170 | 49.5 | 25.6 | 10.0 | 0.49 | 0.07 | 0.22 | 0.41 | 0.93 | 0.14 | 0.02 | 0.0261 |
| 145 | CH2 | 2B23 | 200 | 51.3 | 25.3 | 8.58 | 0.55 | 0.07 | 0.2 | 0.66 | 0.86 | 0.1 | 0.02 | -- |
| 146 | CH2 | 3B24 | 290 | 48.7 | 24.5 | 11.3 | 0.75 | 0.11 | 0.21 | 0.57 | 0.98 | 0.1 | 0.02 | 0.0192 |
| 147 | CH2 | 3B3 | 350 | 48.6 | 25.2 | 10.4 | 0.80 | 0.1 | 0.2 | 0.55 | 0.83 | 0.1 | 0.02 | -- |
| 148 | CH3 | A1 | 9 | 69.8 | 13.2 | 4.95 | 0.61 | 0.38 | 0.7 | 2.17 | 1.00 | 0.1 | 0.1 | -- |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | 48.0 | 27.2 | 8.31 | 0.55 | 0.12 | 0.2 | 0.58 | 0.84 | 0.1 | 0.02 | -- |
| 154 | CH3 | 3B24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4B31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | 49.3 | 23.9 | 9.91 | 0.98 | 0.11 | 0.2 | 0.66 | 0.87 | 0.1 | 0.02 | -- |
| 157 | CH4 | 2B31 | 750 | 52.3 | 24.6 | 8.09 | 0.98 | 0.05 | 0.4 | 1.32 | 0.70 | 0.1 | 0.02 | -- |
| 158 | CH4 | 4Clox | 1000 | 50.9 | 26.4 | 6.24 | 1.1 | 0.11 | 0.4 | 1.16 | 0.71 | 0.1 | 0.02 | -- |

**Supplementary Table 6.** Total chemical analyses of the less-than-2-mm fraction by X-ray fluorescence

[All analyses in weight percent. Analysts: J. Baker, A. Bartel, J. Lindsay, V.G. Mossotti, S. Ramage, B. Scott, J.Taggart, J.S. Wahlberg, and K. Wong]

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Modern River Alluvium | | | | | | | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 6.** Total chemical analyses of the less-than-2-mm fraction by X-ray fluorescence—Continued

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | |
| 5 | PM15 | A1 | 4 | 70.65 | 12.85 | 4.32 | 1.37 | 3.21 | 2.47 | 2.30 | 0.58 | 0.082 | 0.09 | 0.035 |
| 6 | PM15 | 2C1ox | 19 | 68.52 | 13.33 | 5.14 | 1.59 | 3.43 | 2.63 | 2.09 | 0.71 | 0.107 | 0.11 | 0.028 |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | 70.16 | 13.67 | 4.29 | 1.49 | 3.33 | 2.58 | 2.27 | 0.57 | 0.090 | 0.09 | 0.033 |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | |
| 19 | PM8 | A1 | 32 | 61.32 | 14.41 | 5.91 | 2.01 | 2.87 | 1.88 | 2.13 | 0.71 | 0.139 | 0.19 | 0.033 |
| 20 | PM8 | 2C1 | 55 | 64.48 | 14.38 | 5.60 | 2.00 | 3.09 | 2.20 | 1.98 | 0.71 | 0.114 | 0.09 | 0.035 |
| 21 | PM8 | 3C2 | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 70.27 | 13.45 | 3.52 | 1.27 | 2.91 | 2.82 | 2.46 | 0.42 | 0.080 | 0.04 | 0.017 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | PM14 | 3C1ox | 99 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 36 | PM14 | 7C5n | 239+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | PM18 | 2C1ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 6.** Total chemical analyses of the less-than-2-mm fraction by X-ray fluorescence—Continued

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | |
| 54 | M31 | A11 | 20 | 65.56 | 14.00 | 5.23 | 1.69 | 3.10 | 2.21 | 2.32 | 0.66 | 0.108 | 0.19 | 0.029 |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | 66.81 | 14.14 | 5.00 | 1.64 | 3.16 | 2.69 | 2.26 | 0.65 | 0.094 | 0.12 | 0.036 |
| 58 | M31 | 3C2 | 254 | 70.10 | 13.57 | 4.09 | 1.45 | 3.20 | 2.86 | 2.38 | 0.57 | 0.077 | 0.09 | 0.033 |
| 59 | M46 | A11p | 5 | 66.3 | 13.4 | 3.21 | 0.98 | 2.72 | 2.68 | 2.72 | 0.41 | 0.04 | 0.14 | 0.0185 |
| 60 | M46 | A12p | 14 | 68.5 | 14.0 | 3.51 | 1.07 | 2.75 | 2.69 | 2.83 | 0.46 | 0.05 | 0.14 | 0.0199 |
| 61 | M46 | 2A13p | 32 | 69.6 | 14.0 | 3.45 | 0.99 | 2.75 | 2.63 | 2.84 | 0.45 | 0.06 | 0.12 | 0.0186 |
| 62 | M46 | 3AC | 66 | 68.2 | 14.4 | 4.00 | 1.25 | 2.73 | 2.49 | 2.81 | 0.50 | 0.07 | 0.13 | 0.0195 |
| 63 | M46 | 4Cox | 250 | 68.2 | 14.4 | 4.01 | 1.26 | 2.82 | 2.46 | 2.68 | 0.49 | 0.07 | 0.12 | 0.0211 |
| | | | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | |
| 64 | M12 | A11 | 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 70.91 | 13.86 | 2.79 | 0.48 | 2.57 | 2.98 | 2.96 | 0.38 | 0.080 | 0.03 | 0.020 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 67.69 | 16.00 | 4.08 | 0.77 | 2.65 | 2.77 | 2.51 | 0.44 | 0.080 | 0.04 | 0.021 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 69.58 | 14.96 | 3.22 | 0.66 | 3.02 | 3.39 | 2.69 | 0.36 | 0.080 | 0.03 | 0.017 |
| 70 | M12 | 6C2 | 413+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | |
| 71 | R9 | A11p | 30 | 71.71 | 13.43 | 3.14 | 0.38 | 2.19 | 2.95 | 2.50 | 0.45 | 0.080 | 0.01 | 0.023 |
| 72 | R9 | A12p | 60 | 72.7 | 13.3 | 2.80 | 0.55 | 2.10 | 2.96 | 2.42 | 0.40 | 0.060 | 0.05 | 0.0199 |
| 73 | R9 | B1 | 105 | 71.7 | 14.0 | 3.12 | 0.60 | 1.98 | 2.97 | 2.25 | 0.44 | 0.050 | 0.06 | 0.0171 |
| 74 | R9 | 2B21 | 180 | 68.9 | 15.4 | 3.45 | 0.61 | 1.75 | 2.77 | 1.86 | 0.44 | 0.060 | 0.06 | 0.0167 |
| 75 | R9 | 2B22 | 235 | 68.96 | 15.45 | 3.67 | 0.45 | 1.78 | 2.75 | 1.91 | 0.48 | 0.082 | 0.02 | 0.019 |
| 76 | R9 | 3B3 | 350 | 67.5 | 16.0 | 3.20 | 0.94 | 2.53 | 2.67 | 2.71 | 0.41 | 0.040 | 0.05 | 0.0136 |
| 77 | R9 | 4C | 400+ | 64.74 | 16.52 | 3.82 | 1.25 | 3.58 | 2.63 | 3.04 | 0.52 | 0.080 | 0.06 | 0.017 |
| 78 | R33 | A11 | 4 | 71.2 | 13.1 | 2.73 | 0.53 | 2.04 | 3.00 | 2.35 | 0.41 | 0.05 | 0.07 | 0.0227 |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | 68.0 | 15.9 | 3.57 | 0.65 | 1.53 | 2.83 | 1.90 | 0.43 | 0.07 | 0.08 | 0.0172 |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | 72.3 | 14.0 | 2.43 | 0.53 | 2.33 | 3.06 | 2.68 | 0.25 | 0.02 | 0.06 | 0.0082 |

**Supplementary Table 6.** Total chemical analyses of the less-than-2-mm fraction by X-ray fluorescence--Continued

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | | |
| 88 | R2 | Ap | 25 | 74.39 | 12.36 | 2.61 | 0.40 | 2.13 | 3.14 | 2.26 | 0.38 | 0.08 | 0.02 | 0.025 |
| 89 | R2 | B21 | 81 | 72.6 | 13.3 | 3.03 | 0.52 | 1.92 | 3.21 | 2.37 | 0.45 | 0.05 | 0.06 | 0.0193 |
| 90 | R2 | B22t | 185 | 69.68 | 14.86 | 4.09 | 0.42 | 1.69 | 3.03 | 1.94 | 0.52 | 0.08 | 0.04 | 0.022 |
| 91 | R2 | B3 | 386 | 69.0 | 15.2 | 3.41 | 0.68 | 2.31 | 2.78 | 2.67 | 0.38 | 0.03 | 0.05 | 0.0132 |
| 92 | R2 | C1 | 500 | 72.0 | 14.3 | 2.02 | 0.54 | 2.34 | 3.28 | 3.21 | 0.25 | 0.02 | 0.05 | 0.0104 |
| 93 | R2 | C2n | 500+ | 72.89 | 14.76 | 1.29 | 0.31 | 2.20 | 4.01 | 3.23 | 0.16 | 0.08 | 0.02 | 0.008 |
| 94 | R10 | A | 46 | 74.77 | 12.68 | 2.68 | 0.31 | 1.81 | 3.27 | 2.34 | 0.41 | 0.067 | 0.06 | 0.025 |
| 95 | R10 | 2B1 | 70 | 72.2 | 13.5 | 2.91 | 0.51 | 1.68 | 3.23 | 1.85 | 0.43 | 0.04 | 0.05 | 0.0201 |
| 96 | R10 | 2B21t | 140 | 71.48 | 14.29 | 3.42 | 0.43 | 1.74 | 3.09 | 2.29 | 0.45 | 0.066 | 0.06 | 0.020 |
| 97 | R10 | 2B22t | 210 | 71.4 | 14.1 | 3.05 | 0.55 | 1.82 | 2.99 | 2.28 | 0.38 | 0.04 | 0.05 | 0.0167 |
| 98 | R10 | 3B3t | 386 | 70.09 | 15.04 | 3.53 | 0.68 | 2.37 | 2.74 | 2.74 | 0.41 | 0.04 | 0.05 | 0.018 |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 72.4 | 13.5 | 3.39 | 0.59 | 2.21 | 3.01 | 2.52 | 0.47 | 0.05 | 0.05 | 0.0251 |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | 68.6 | 15.0 | 4.15 | 0.66 | 1.87 | 2.84 | 2.18 | 0.50 | 0.06 | 0.07 | 0.0234 |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | 68.0 | 15.4 | 3.87 | 0.81 | 3.10 | 2.61 | 3.09 | 0.41 | 0.04 | 0.05 | 0.0136 |
| | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | | | | |
| 108 | R30 | Ap | 65 | 74.69 | 12.38 | 3.58 | 0.29 | 1.68 | 3.29 | 2.23 | 0.44 | 0.06 | 0.04 | 0.031 |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | 69.43 | 15.11 | 4.55 | 0.41 | 1.55 | 2.89 | 2.00 | 0.52 | 0.051 | 0.05 | 0.023 |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | 67.94 | 14.71 | 4.63 | 0.58 | 2.31 | 2.85 | 2.37 | 0.54 | 0.043 | 0.05 | 0.014 |
| | | | | Turlock Lake Formation, 600 Ka | | | | | | | | | | |
| 114 | T2 | A | 31 | 77.66 | 10.18 | 3.18 | 0.02 | 0.64 | 3.70 | 1.03 | 0.48 | 0.08 | 0.02 | 0.040 |
| 115 | T2 | B21 | 173 | 66.96 | 16.26 | 5.17 | 0.08 | 0.23 | 3.02 | 0.51 | 0.44 | 0.028 | 0.08 | 0.028 |
| 116 | T2 | 2B22 | 386 | 66.39 | 16.29 | 4.13 | 0.33 | 2.01 | 2.30 | 2.42 | 0.50 | 0.08 | 0.01 | 0.035 |
| 117 | T2 | 3C | 417 | 72.03 | 13.64 | 3.08 | 0.27 | 1.72 | 3.24 | 2.67 | 0.34 | 0.08 | 0.01 | 0.016 |
| 118 | T6 | A11 | 20 | 74.1 | 12.6 | 2.35 | 0.46 | 2.10 | 3.17 | 2.48 | 0.31 | 0.03 | 0.05 | 0.0166 |
| 119 | T6 | A12 | 40 | 73.4 | 12.9 | 2.72 | 0.53 | 2.14 | 3.18 | 2.47 | 0.36 | 0.04 | 0.05 | 0.0199 |
| 120 | T6 | 2B21t | 90 | 69.4 | 14.4 | 3.57 | 0.77 | 2.11 | 2.68 | 2.11 | 0.39 | 0.03 | 0.05 | 0.0104 |
| 121 | T6 | 2B22t | 190 | 66.9 | 16.0 | 3.85 | 0.80 | 1.70 | 2.90 | 1.91 | 0.42 | 0.04 | 0.05 | 0.0103 |
| 122 | T6 | 3B+C | 370 | 74.8 | 12.7 | 1.64 | 0.57 | 2.07 | 3.20 | 2.51 | 0.22 | 0.03 | 0.05 | 0.0095 |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | 74.8 | 12.2 | 2.38 | 0.27 | 1.30 | 3.59 | 2.13 | 0.35 | 0.03 | 0.05 | 0.0224 |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | 69.2 | 15.2 | 3.46 | 0.42 | 0.90 | 3.30 | 1.60 | 0.46 | 0.02 | 0.06 | 0.0194 |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 58+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6IC2ox | 375+ | 70.5 | 14.2 | 3.52 | 0.53 | 1.97 | 2.69 | 2.53 | 0.35 | 0.02 | 0.06 | 0.0112 |

**Supplementary Table 6.** Total chemical analyses of the less-than-2-mm fraction by X-ray fluorescence—Continued

| No. | Sample | Horizon | Basal depth (cm) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | MgO | CaO | $Na_2O$ | $K_2O$ | $TiO_2$ | MnO | $P_2O_5$ | $ZrO_2$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 78.82 | 10.02 | 3.92 | 0.10 | 0.34 | 0.56 | 1.75 | 0.74 | 0.04 | 0.1 | 0.049 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 66.93 | 16.75 | 6.06 | 0.17 | 0.26 | 0.47 | 1.35 | 0.84 | 0.08 | 0.08 | 0.040 |
| 135 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3IB33 | 350 | 64.39 | 17.11 | 7.59 | 0.23 | 0.20 | 0.06 | 1.36 | 0.67 | 0.08 | 0.05 | 0.020 |
| 140 | CH2 | A1 | 8 | 77.8 | 8.89 | 3.80 | 0.41 | 0.15 | 0.39 | 1.62 | 0.74 | 0.02 | 0.12 | 0.0436 |
| 141 | CH2 | A3 | 30 | 74.4 | 11.4 | 4.76 | 0.44 | 0.10 | 0.37 | 1.52 | 0.77 | 0.02 | 0.13 | 0.0394 |
| 142 | CH2 | 2A+B | 50 | 70.4 | 13.6 | 5.45 | 0.49 | 0.07 | 0.33 | 1.48 | 0.82 | 0.07 | 0.16 | 0.0448 |
| 143 | CH2 | 2B21t | 110 | 60.8 | 19.3 | 7.13 | 0.46 | 0.04 | 0.21 | 0.99 | 0.87 | 0.02 | 0.12 | 0.0319 |
| 144 | CH2 | 2B22 | 170 | 56.7 | 21.4 | 8.77 | 0.40 | 0.05 | 0.17 | 0.36 | 0.79 | -- | -- | 0.0208 |
| 145 | CH2 | 2B23 | 200 | 58.6 | 19.8 | 8.80 | 0.46 | 0.07 | 0.15 | 0.55 | 0.75 | 0.02 | 0.08 | 0.0221 |
| 146 | CH2 | 2B24 | 290 | 57.0 | 19.5 | 9.46 | 0.60 | 0.08 | 0.17 | 0.66 | 0.85 | 0.02 | 0.08 | 0.0178 |
| 147 | CH2 | 3IIB3 | 350 | 59.0 | 18.5 | 9.25 | 0.64 | 0.09 | 0.16 | 0.76 | 0.82 | 0.02 | 0.09 | 0.0155 |
| 148 | CH3 | A1 | 9 | 75.4 | 8.88 | 3.61 | 0.43 | 0.34 | 0.47 | 1.62 | 0.71 | 0.09 | 0.09 | 0.0436 |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | 60.6 | 19.9 | 6.62 | 0.44 | 0.08 | 0.15 | 0.65 | 0.72 | 0.02 | 0.09 | 0.0199 |
| 154 | CH3 | 3IIB24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4VB31 | 340 | 65.3 | 16.0 | 6.53 | 0.59 | 0.08 | 0.19 | 1.14 | 0.57 | 0.02 | 0.06 | 0.0167 |
| 156 | CH3 | 5B32 | 750+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 158 | CH4 | 4Clox | 1000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 7, Part 1.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation

[Fe and K values in weight percent; all others in parts per million. Analysts: J. Budahn, R. Knight, and D. McKown]

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Modern River Alluvium | | | | | | | | | | | | | |
| 1 | MRA1 | -- | -- | 916 | 54.6 | 16.5 | 104 | 4.32 | 4.90 | 1.15 | 5.41 | 4.2 | 16.0 | 1.65 | 32.0 | 0.462 | 1090 |
| 2 | MRA2 | -- | -- | 970 | 51.5 | 16.3 | 96.7 | 4.47 | 4.72 | 1.10 | 4.53 | 4.12 | 6.76 | 1.68 | 29.7 | 0.391 | 1250 |
| 3 | MRA3 | -- | -- | 1180 | 52.7 | 18.8 | 90.7 | 4.55 | 4.36 | 1.10 | 5.09 | 3.97 | 7.35 | 1.61 | 30.3 | 0.350 | 2780 |
| 4 | MRA4 | -- | -- | 1040 | 64.5 | 18.9 | 67.0 | 4.84 | 4.51 | 1.30 | 4.57 | 5.42 | 5.84 | 1.22 | 39.3 | 0.345 | 1850 |

**Supplementary Table 7, Part 1.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | | | |
| 5 | PM15 | A1 | 4 | 824 | 59.9 | 16.7 | 99.2 | 4.01 | 4.56 | 1.13 | 4.37 | 4.61 | 14.1 | 1.66 | 31.5 | 0.453 | 1040 |
| 6 | PM15 | 2C1ox | 19 | 891 | 63.5 | 19.3 | 110 | 4.62 | 5.22 | 1.23 | 4.92 | 5.3 | 12.1 | 1.56 | 32.9 | 0.458 | 1080 |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | 908 | 63.2 | 21.3 | 106 | 4.54 | 5.11 | 1.23 | 4.93 | 5.34 | 12.3 | 1.74 | 33.7 | 0.462 | 1510 |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | 952 | 50.8 | 16.0 | 98.0 | 4.98 | -- | 1.02 | 4.67 | 3.92 | 6.02 | 2.06 | 26.9 | 0.369 | 979 |
| 13 | PM1s | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | 908 | 55.8 | 16.6 | 93.0 | 3.82 | 4.40 | 1.08 | 4.18 | 4.69 | 7.01 | 1.79 | 27.8 | 0.399 | 907 |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 58C6n | 80+ | 926 | 55.1 | 16.7 | 94.6 | 4.18 | 4.55 | 1.11 | 4.30 | 4.42 | 5.15 | 1.77 | 29.3 | 0.368 | 880 |
| | | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | | | |
| 19 | PM8 | A1 | 32 | 1080 | 55.0 | 15.9 | 115 | 4.15 | 4.78 | 1.05 | 3.88 | -- | 6.43 | 1.81 | 30.2 | 0.459 | 896 |
| 20 | PM8 | 2C1 | 55 | 1010 | 60.5 | 15.0 | 108 | 3.68 | 4.43 | 1.12 | 3.75 | 6.2 | 7.24 | 1.44 | 31.1 | 0.475 | 753 |
| 21 | PM8 | 3C2 | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 1110 | 64.2 | 14.9 | 119 | 3.44 | 4.89 | 1.13 | 3.75 | -- | 17.8 | 1.33 | 31.0 | 0.572 | 856 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | 991 | 54.5 | 17.9 | 98.3 | 4.74 | 4.25 | 1.08 | 4.66 | 4.02 | 4.84 | 1.83 | 28.7 | 0.377 | 1010 |
| 32 | PM14 | 3C1ox | 99 | 972 | 65.0 | 18.9 | 102 | 4.75 | 4.72 | 1.15 | 4.84 | 4.93 | 8.26 | 1.56 | 32.2 | 0.398 | 1010 |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | 939 | 67.2 | 20.4 | 107 | 4.70 | 5.27 | 1.25 | 5.07 | 5.18 | 10.6 | 1.62 | 34.0 | 0.414 | 1130 |
| 36 | PM14 | 7C5n | 230+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | 936 | 43.4 | 16.4 | 94.3 | 4.53 | -- | 0.912 | 4.40 | 3.67 | 6.16 | 2.05 | 23.5 | 0.336 | 1100 |
| 50 | PM18 | 2C1ox | 65 | 982 | 54.0 | 17.3 | 105 | 4.11 | 5.33 | 1.18 | 4.63 | 5.15 | 8.42 | 1.51 | 30.1 | 0.411 | 989 |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | 1190 | 57.3 | 20.5 | 122 | 5.23 | 5.24 | 1.19 | 5.56 | 5.36 | 8.47 | 1.71 | 30.2 | 0.461 | 1010 |
| | | | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | | |
| 54 | M31 | A11 | 20 | 1050 | 53.4 | 18.1 | 99.2 | 4.90 | 4.73 | 1.14 | 4.66 | 4.44 | 5.33 | 2.04 | 29.1 | 0.388 | 1070 |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | 986 | 52.8 | 16.0 | 92.6 | 4.66 | 4.23 | 1.01 | 4.47 | 3.58 | 5.99 | 1.75 | 27.1 | 0.346 | 845 |
| 58 | M31 | 3C2 | 254 | 1010 | 56.5 | 17.4 | 98.6 | 5.14 | 4.36 | 1.02 | 4.63 | 4.48 | 8.19 | 1.85 | 27.6 | 0.351 | 904 |
| 59 | M46 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | M46 | A12p | 14 | 1160 | 75.5 | 21.6 | 109 | 6.54 | 4.62 | 1.31 | 5.58 | 6.38 | 7.83 | 2.06 | 38.7 | 0.491 | 1010 |
| 61 | M46 | 2A13p | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 62 | M46 | 3AC | 66 | 982 | 63.8 | 16.1 | 70.6 | 5.34 | 4.03 | 1.07 | 4.30 | 4.72 | 7.08 | 2.11 | 30.5 | 0.356 | 1040 |
| 63 | M46 | 4Cox | 250 | 958 | 62.9 | 16.0 | 72.0 | 5.19 | 4.14 | 0.999 | 4.25 | 4.83 | 6.46 | 2.12 | 28.5 | 0.325 | 990 |

**Supplementary Table 7, Part 1.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | | | |
| 64 | M12 | A11 | 85 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 821 | 69.0 | 10.6 | 73.8 | 4.17 | 4.38 | 1.24 | 3.23 | 5.39 | 11.7 | 2.07 | 35.1 | 0.374 | 673 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 741 | 89.9 | 14.7 | 84.5 | 4.85 | 5.52 | 1.36 | 4.70 | -- | 8.20 | 1.50 | 49.0 | 0.372 | 671 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 681 | 74.3 | 11.5 | 58.6 | 3.72 | 4.98 | 1.12 | 3.57 | -- | 11.9 | 1.69 | 36.1 | 0.345 | 617 |
| 70 | M12 | 6C2 | 413+ | 1680 | 129 | 31.1 | 47.0 | 9.43 | 5.83 | 1.24 | 5.80 | 0.00 | 8.54 | 2.17 | 61.2 | 0.420 | 1930 |
| | | | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | | |
| 71 | R9 | A11p | 30 | 928 | 69.1 | 13.2 | 86.3 | 4.00 | 4.51 | 1.28 | 3.00 | 5.06 | 9.69 | 2.08 | 35.5 | 0.390 | 888 |
| 72 | R9 | A12p | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 73 | R9 | B1 | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 74 | R9 | 2B21 | 180 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 75 | R9 | 2B22 | 235 | 660 | 85.3 | 15.0 | 88.6 | 4.90 | 4.37 | 1.38 | 4.19 | 5.31 | 6.25 | 1.54 | 43.7 | 0.349 | 823 |
| 76 | R9 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 77 | R9 | 4C | 400+ | 971 | 110 | 15.1 | 46.6 | 6.38 | 6.26 | 1.65 | 4.70 | -- | 10.0 | 1.84 | 52.3 | 0.466 | 659 |
| 78 | R33 | A11 | 4 | 1070 | 73.4 | 13.6 | 81.7 | 5.21 | 3.95 | 1.29 | 3.66 | 4.95 | 9.49 | 2.12 | 38.6 | 0.437 | 1110 |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | 618 | 83.0 | 13.6 | 67.8 | 5.43 | 4.59 | 1.50 | 4.57 | 5.51 | 5.06 | 1.68 | 47.8 | 0.316 | 813 |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | 665 | 167 | 14.0 | 55.2 | 6.31 | 5.50 | 1.54 | 6.07 | 8.18 | 2.60 | 1.24 | 85.0 | 0.352 | 758 |
| | | | | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | |
| 88 | R2 | Ap | 25 | 827 | 64.2 | 10.3 | 77.0 | 3.10 | 4.23 | 1.24 | 2.80 | 5.32 | 15.6 | 1.99 | 31.9 | 0.409 | 716 |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 90 | R2 | B22t | 185 | 746 | 80.5 | 15.6 | 97.1 | 5.46 | 5.15 | 1.37 | 4.31 | 6.38 | 6.80 | 1.90 | 42.2 | 0.357 | 880 |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 93 | R2 | C2n | 500+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | 812 | 64.9 | 9.73 | 68.4 | 4.58 | 4.31 | 1.16 | 3.15 | 5.37 | 6.98 | 2.34 | 33.2 | 0.344 | 786 |
| 95 | R10 | 2B1 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 96 | R10 | 2B21t | 140 | 691 | 82.7 | 12.9 | 87.7 | 6.11 | 4.24 | 1.43 | 4.69 | 6.82 | 6.15 | 1.77 | 50.3 | 0.427 | 680 |
| 97 | R10 | 2B22t | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 98 | R10 | 3B3t | 386 | 590 | 107 | 13.1 | 57.0 | 6.21 | 4.32 | 1.27 | 4.87 | 6.25 | 4.38 | 1.54 | 62.6 | 0.362 | 689 |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 843 | 63.7 | 10.1 | 65.8 | 4.33 | 4.01 | 1.09 | 3.04 | 4.81 | 7.88 | 2.20 | 34.3 | 0.359 | 831 |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | 649 | 77.6 | 12.4 | 71.5 | 4.94 | 4.36 | 1.27 | 4.11 | 4.73 | 6.32 | 2.07 | 42.2 | 0.322 | 809 |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | 624 | 149 | 18.3 | 61.9 | 7.16 | 4.79 | 1.34 | 6.37 | 5.90 | 3.99 | 1.74 | 76.1 | 0.372 | 845 |
| | | | | | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | | | |
| 108 | R30 | Ap | 65 | 863 | 77.0 | 11.7 | 72.1 | 5.80 | 4.51 | 1.33 | 3.74 | 5.33 | 8.58 | 2.52 | 40.0 | 0.375 | 667 |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | 503 | 95.1 | 14.5 | 59.4 | 5.72 | 3.82 | 1.19 | 4.51 | 5.03 | 4.65 | 1.56 | 43.5 | 0.291 | 725 |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3Clox | 220 | 404 | 112 | 12.4 | 56.8 | 6.09 | 6.10 | 1.46 | 6.26 | 7.58 | 2.34 | 1.08 | 73.5 | 0.479 | 534 |

**Supplementary Table 7, Part 1.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Turlock Lake Formation, 600 Ka | | | | | | | | | |
| 114 | T2 | A | 31 | 1080 | 77.2 | 18.4 | 114 | 4.28 | 4.45 | 1.09 | 3.00 | 5.52 | 13.1 | 2.72 | 33.0 | 0.447 | 1070 |
| 115 | T2 | B21 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 116 | T2 | 2B22 | 386 | 697 | 124 | 13.2 | 60.2 | 3.33 | 6.92 | 1.73 | 4.11 | -- | 12.6 | 1.57 | 52.6 | 0.571 | 363 |
| 117 | T2 | 3C | 417 | 667 | 114 | 12.6 | 74.5 | 4.58 | 7.69 | 2.17 | 4.26 | -- | 10.9 | 1.80 | 57.5 | 0.556 | 416 |
| 118 | T6 | A11 | 20 | 1020 | 110 | 19.7 | 74.8 | 5.15 | 5.63 | 1.63 | 4.62 | 7.58 | 10.2 | 2.33 | 57.1 | 0.521 | 975 |
| 119 | T6 | A12 | 40 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 120 | T6 | 2B21t | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 121 | T6 | 2B22t | 190 | 474 | 76.9 | 12.5 | 66.6 | 6.28 | 5.57 | 1.40 | 6.17 | 6.46 | 2.87 | 1.45 | 55.9 | 0.380 | 569 |
| 122 | T6 | 3B+C | 370 | 707 | 193 | 30.1 | 56.2 | 6.04 | 6.77 | 2.09 | 7.07 | 10.5 | 6.36 | 1.43 | 90.2 | 0.642 | 2230 |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | 964 | 78.1 | 16.1 | 70.6 | 5.13 | 4.01 | 1.14 | 3.32 | 4.64 | 10.4 | 2.52 | 38.0 | 0.387 | 641 |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | 625 | 65.5 | 12.9 | 67.5 | 6.04 | 2.97 | 0.904 | 4.52 | 4.31 | 6.81 | 1.70 | 30.2 | 0.288 | 368 |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6C2ox | 375+ | 333 | 152 | 12.8 | 68.2 | 5.86 | 6.69 | 1.62 | 6.90 | 9.80 | 2.61 | 1.09 | 91.0 | 0.529 | 360 |
| | | | | | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 828 | 58.3 | 8.04 | 114 | 4.08 | 4.45 | 1.03 | 2.77 | 6.05 | 13.2 | 1.75 | 28.3 | 0.469 | 401 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 644 | 76.1 | 15.8 | 111 | 4.43 | 3.47 | 1.00 | 4.28 | -- | 8.85 | 1.30 | 31.1 | 0.408 | 597 |
| 136 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3B33 | 350 | 749 | 32 | 8.19 | 122 | 2.77 | 2.86 | 0.735 | 6.71 | -- | 3.88 | 1.10 | 21.1 | 0.364 | 168 |
| 140 | CH2 | A1 | 8 | 755 | 44.5 | 6.99 | 103 | 4.66 | 3.40 | 0.637 | 3.24 | 3.37 | 9.54 | 1.86 | 23.8 | 0.330 | 449 |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 145 | CH2 | 2B23 | 200 | 540 | 26.1 | 5.25 | 77.8 | 2.88 | 2.56 | 0.506 | 5.40 | 2.40 | 4.03 | 0.560 | 17.4 | 0.272 | 192 |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 147 | CH2 | 3B3 | 350 | 383 | 37.8 | 8.80 | 84.2 | 2.58 | 3.90 | 0.962 | 6.51 | 4.58 | 2.52 | 0.50 | 26.1 | 0.295 | 215 |
| 148 | CH3 | A1 | 9 | 926 | 48.6 | 9.27 | 99.1 | 4.86 | 3.72 | 0.756 | 2.98 | 3.71 | 8.72 | 1.80 | 27.3 | 0.337 | 776 |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | 339 | 25.8 | 6.25 | 90.0 | 4.46 | 2.24 | 0.514 | 5.47 | 0.00 | 3.09 | 0.523 | 17.9 | 0.236 | 152 |
| 154 | CH3 | 3B24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4B31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | 522 | 58.9 | 9.67 | 101 | 2.63 | 4.22 | 1.31 | 6.27 | 5.3 | 2.49 | 0.530 | 33.9 | 0.341 | 187 |
| 157 | CH4 | 2B31 | 750 | 656 | -- | 8.61 | 70.9 | 3.48 | 5.02 | 1.41 | 5.32 | 5.95 | 3.31 | 1.12 | 32.1 | 10.422 | 170 |
| 158 | CH4 | 4C1ox | 1000 | 641 | 114 | 10.9 | 57.2 | 4.23 | 7.84 | 2.31 | 4.64 | 8.43 | 3.42 | 0.987 | 39.4 | 0.671 | 163 |

**Supplementary Table 7, Part 2.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation

[Na values in weight percent; all others in parts per million. Analysts: J. Budahn, R. Knight, and D. McKown]

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modern River Alluvium | | | | | | | | | |
| 1 | MRA1 | -- | -- | 1.24 | 29.2 | 81.1 | 1.07 | 18.0 | 5.63 | 168 | 0.947 | 0.760 | 15.5 | 0.520 | 12.8 | 2.99 | 582 |
| 2 | MRA2 | -- | -- | 1.18 | 26.1 | 76.8 | 1.01 | 17.9 | 5.37 | 178 | 0.830 | 0.745 | 12.4 | 0.430 | 10.6 | 2.57 | 225 |
| 3 | MRA3 | -- | -- | 1.60 | 29.4 | 81.5 | 1.04 | 16.5 | 5.48 | 206 | 0.813 | 0.692 | 13.4 | 0.390 | 16.4 | 2.48 | 230 |
| 4 | MRA4 | -- | -- | 0.981 | 38.2 | 58.9 | 0.931 | 15.3 | 6.45 | 160 | 0.881 | 0.730 | 16.4 | 0.400 | 7.35 | 2.33 | 194 |
| | | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | | | |
| 5 | PM15 | A1 | 4 | 1.15 | 27.1 | 69.8 | 0.915 | 17.5 | 5.49 | 195 | 0.970 | 0.735 | 13.6 | 0.460 | 8.82 | 2.83 | 479 |
| 6 | PM15 | 2C1ox | 19 | 1.18 | 28.6 | 79.3 | 1.11 | 19.1 | 5.89 | 190 | 1.01 | 0.768 | 14.2 | -- | 9.56 | 3.01 | 418 |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | 1.10 | 27.2 | 79.3 | 1.08 | 18.8 | 5.91 | 189 | 0.989 | 0.799 | 14.5 | -- | 11.1 | 3.02 | 420 |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | 1.10 | 21.7 | 116 | 0.926 | 17.8 | 4.76 | 152 | 0.873 | 0.616 | 11.4 | -- | 6.39 | 2.39 | 222 |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | 1.22 | 23.3 | 77.8 | 1.14 | 17.9 | 5.02 | 182 | 0.868 | 0.686 | 10.5 | -- | 5.66 | 2.48 | 254 |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | 1.18 | 24.5 | 75.5 | 1.01 | 17.9 | 5.02 | 167 | 0.847 | 0.707 | 10.9 | 0.420 | 6.47 | 2.55 | 165 |
| | | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | | | |
| 19 | PM8 | A1 | 32 | 1.24 | 28.5 | 90.6 | 1.04 | 17.2 | 4.66 | 224 | 0.825 | 0.776 | 12.8 | 0.487 | 6.34 | 2.41 | 174 |
| 20 | PM8 | 2C1 | 55 | 1.22 | 27.7 | 73.8 | 0.939 | 15.1 | 4.93 | 223 | 0.880 | 0.788 | 12.8 | 0.409 | 6.91 | 2.58 | 206 |
| 21 | PM8 | 3C2 | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 1.19 | 29.9 | 71.0 | 1.01 | 15.6 | 4.97 | 264 | 1.03 | 0.815 | 15.3 | 0.441 | 11.1 | 2.49 | 518 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | 1.08 | 26.1 | 92.3 | 0.986 | 18.4 | 5.04 | 180 | 0.822 | 0.658 | 11.3 | -- | 5.60 | 2.43 | 165 |
| 32 | PM14 | 3C1ox | 99 | 1.19 | 29.9 | 82.5 | 0.939 | 19.0 | 5.36 | 173 | 1.00 | 0.765 | 13.3 | -- | 11.0 | 2.64 | 290 |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | 1.22 | 34.1 | 83.2 | 1.02 | 19.5 | 5.40 | 190 | 0.986 | 0.814 | 15.3 | 0.440 | 12.1 | 2.82 | 359 |
| 36 | PM14 | 7C5n | 230+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | 0.872 | 23.0 | 95.7 | 1.06 | 16.6 | 4.40 | 178 | 0.816 | 0.568 | 9.15 | 0.36 | 6.10 | 2.20 | 226 |
| 50 | PM18 | 2C1ox | 65 | 1.03 | 27.7 | 75.6 | 1.05 | 19.3 | 5.56 | 152 | 0.901 | 0.834 | 10.9 | 0.41 | 6.25 | 2.77 | 287 |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | 1.05 | 28.3 | 87.5 | 1.09 | 21.8 | 5.63 | 146 | 0.976 | 0.848 | 11.5 | 0.470 | 6.66 | 2.78 | 292 |

**Supplementary Table 7, Part 2.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | | |
| 54 | M31 | A11 | 20 | 1.12 | 26.0 | 96.5 | 0.917 | 18.3 | 5.19 | 202 | 0.915 | 0.679 | 11.1 | 0.390 | 5.24 | 2.47 | 174 |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | 1.59 | 26.4 | 87.5 | 0.854 | 17.2 | 4.67 | 158 | 0.864 | 0.672 | 11.4 | 0.35 | 3.77 | 2.22 | 200 |
| 58 | M31 | 3C2 | 254 | 1.49 | 24.2 | 99.1 | 0.900 | 17.0 | 4.75 | 180 | 1.02 | -- | 12.5 | 0.370 | 4.51 | 2.27 | 277 |
| 59 | M46 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 235 |
| 60 | M46 | A12p | 14 | 1.34 | 33.3 | 118 | 1.38 | 21.0 | 6.15 | 223 | 1.14 | 0.828 | 17.5 | 0.500 | 7.80 | 3.03 | 287 |
| 61 | M46 | 2A13p | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 259 |
| 62 | M46 | 3AC | 66 | 1.48 | 24.7 | 109 | 1.01 | 14.4 | 4.86 | 204 | 1.01 | 0.653 | 15.5 | 0.360 | 5.98 | 2.25 | 222 |
| 63 | M46 | 4Cox | 250 | 1.49 | 26.0 | 95.0 | 0.989 | 14.2 | 4.62 | 207 | 1.01 | 0.646 | 15.5 | 0.360 | 5.36 | 2.17 | 219 |
| | | | | | | | | Modesto Formation, upper member, 40 Ka | | | | | | | | | |
| 64 | M12 | A11 | 85 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 160 |
| 65 | M12 | A12 | 81 | 2.07 | 29.3 | 106 | 1.01 | 11.3 | 5.05 | 332 | 1.17 | 0.669 | 17.3 | 0.351 | 6.42 | 2.50 | 308 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 1.40 | 35.8 | 86.6 | 0.867 | 14.7 | 5.77 | 212 | 0.938 | 0.741 | 22.8 | 0.405 | 6.57 | 2.55 | 205 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 1.84 | 27.2 | 78.4 | 0.703 | 11.5 | 5.05 | 293 | 1.01 | 0.661 | 20.1 | 0.331 | 6.46 | 2.27 | 312 |
| 70 | M12 | 6C2 | 413+ | 1.54 | 41.9 | 142 | 1.07 | 13.5 | 7.81 | 278 | 1.14 | 0.867 | 51.6 | 0.450 | 9.77 | 2.75 | 318 |
| | | | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | | |
| 71 | R9 | A11p | 30 | 1.85 | 28.0 | 115 | 1.00 | 10.9 | 5.21 | 279 | 1.08 | 0.691 | 13.4 | 0.349 | 5.08 | 2.41 | 267 |
| 72 | R9 | A12p | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 256 |
| 73 | R9 | B1 | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 248 |
| 74 | R9 | 2B21 | 180 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 196 |
| 75 | R9 | 2B22 | 235 | 1.15 | 34.8 | 103 | 1.02 | 14.3 | 5.95 | 182 | 1.01 | 0.673 | 17.5 | 0.370 | 5.44 | 2.27 | 159 |
| 76 | R9 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 158 |
| 77 | R9 | 4C | 400+ | 1.40 | 40.6 | 89.5 | 1.10 | 14.9 | 7.52 | 253 | 1.22 | 0.873 | 32.5 | 0.491 | 6.69 | 3.18 | 271 |
| 78 | R33 | A11 | 4 | 1.66 | 30.3 | 131 | 1.15 | 12.7 | 5.62 | 274 | 1.25 | 0.679 | 15.1 | 0.460 | 5.38 | 2.69 | 310 |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | 0.937 | 40.5 | 97.1 | 0.968 | 15.1 | 6.76 | 143 | 1.00 | 0.709 | 18.0 | 0.330 | 5.77 | 2.23 | 170 |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | 0.320 | 55.1 | 88.0 | 0.892 | 17.5 | 8.98 | 110 | 0.843 | 0.924 | 38.7 | 0.410 | 11.9 | 2.63 | 51 |
| | | | | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | |
| 88 | R2 | Ap | 25 | 2.16 | 26.2 | 103 | 1.14 | 9.11 | 4.92 | 340 | 1.21 | 0.610 | 16.0 | -- | 5.28 | 2.46 | 425 |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 308 |
| 90 | R2 | B22t | 185 | 1.22 | 29.8 | 107 | 1.12 | 14.1 | 5.63 | 156 | 1.09 | 0.727 | 18.8 | 0.401 | 6.45 | 2.40 | 157 |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 195 |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 177 |
| 93 | R2 | C2n | 500+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 94 | R10 | A | 46 | 1.86 | 30.6 | 121 | 1.04 | 10.7 | 5.02 | 242 | 1.13 | 0.649 | 14.5 | 0.370 | 5.17 | 2.18 | 221 |
| 95 | R10 | 2B10 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 293 |
| 96 | R10 | 2B21t | 140 | 1.17 | 38.0 | 105 | 1.04 | 16.0 | 6.66 | 169 | 1.16 | 0.762 | 19.2 | -- | 6.10 | 2.67 | 223 |
| 97 | R10 | 2B22t | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 220 |
| 98 | R10 | 3B3t | 386 | 1.17 | 38.7 | 102 | 0.974 | 15.3 | 6.59 | 176 | 0.964 | 0.716 | 25.6 | 0.360 | 6.52 | 2.28 | 143 |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | 1.86 | 26.1 | 107 | 1.03 | 10.7 | 4.93 | 265 | 1.09 | 0.626 | 14.0 | 0.350 | 5.00 | 2.26 | 274 |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | 1.37 | 35.6 | 98.4 | 1.01 | 13.6 | 5.84 | 188 | 1.03 | 0.736 | 18.9 | 0.390 | 5.82 | 2.20 | 238 |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | 0.532 | 49.1 | 114 | 0.891 | 18.3 | 7.76 | 118 | 1.03 | 0.882 | 36.6 | 0.430 | 10.1 | 2.52 | 112 |

**Supplementary Table 7, Part 2.** Total chemical analyses of the fine (less than 47 μm) fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Riverbank Formation, lower member, 330 Ka** | | | | | | | | | | | | | | | | | |
| 108 | R30 | Ap | 65 | 1.78 | 35.0 | 134 | 1.13 | 11.8 | 5.93 | 246 | 1.41 | 0.811 | 18.8 | 0.360 | 6.34 | 2.55 | 278 |
| 109 | R30 | B1O | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | 1.03 | 36.1 | 87.4 | 0.980 | 14.8 | 6.23 | 144 | 1.30 | 0.618 | 23.5 | -- | 6.05 | 2.00 | 157 |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | 0.261 | 47.3 | 75.5 | 1.02 | 18.8 | 8.29 | 100 | 1.02 | 0.995 | 32.8 | 0.500 | 6.98 | 2.94 | 110 |
| **Turlock Lake Formation, 600 Ka** | | | | | | | | | | | | | | | | | |
| 114 | T2 | A | 31 | 1.05 | 29.5 | 129. | 0.959 | 9.36 | 4.79 | 169 | 1.37 | 0.703 | 15.8 | 0.353 | 5.25 | 2.45 | 414 |
| 115 | T2 | B21 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 116 | T2 | 2B22 | 386 | 1.63 | 45.0 | 74.1 | 1.03 | 15.0 | 8.21 | 254 | 1.58 | 1.08 | 26.1 | 0.563 | 6.05 | 3.79 | 362 |
| 117 | T2 | 3C | 417 | 1.30 | 57.1 | 96.2 | 1.19 | 12.6 | 9.92 | 210 | 1.17 | 1.30 | 26.2 | 0.487 | 5.64 | 3.34 | 334 |
| 118 | T6 | A11 | 20 | 1.78 | 43.0 | 126 | 0.93 | 14.4 | 7.43 | 301 | 1.37 | 0.925 | 20.0 | 0.510 | 5.54 | 3.33 | 355 |
| 119 | T6 | A12 | 40 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 298 |
| 120 | T6 | 2B21t | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 111 |
| 121 | T6 | 2B22t | 190 | 0.233 | 42.2 | 104 | 0.940 | 21.0 | 7.42 | 100 | 1.13 | 0.822 | 27.1 | 0.470 | 5.45 | 2.64 | 110 |
| 122 | T6 | 3B+C | 370 | 0.826 | 64.5 | 113 | 1.06 | 24.1 | 10.4 | 199 | 1.24 | 1.22 | 41.6 | 0.630 | 8.64 | 4.21 | 249 |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | 1.60 | 25.7 | 131 | 1.14 | 9.70 | 5.19 | 246 | 1.31 | 0.628 | 17.4 | 0.420 | 5.12 | 2.44 | 360 |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | 0.786 | 25.4 | 96.8 | 1.23 | 13.8 | 4.58 | 115 | 1.31 | 0.495 | 20.8 | 0.271 | 5.30 | 1.89 | 235 |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6C2ox | 375+ | 0.216 | 61.8 | 79.4 | 0.881 | 21.9 | 10.1 | 103 | 1.20 | 1.07 | 36.0 | 0.483 | 6.47 | 3.22 | 110 |
| **China Hat gravel member of Laguna Formation, 3,000 Ka** | | | | | | | | | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 0.702 | 25.7 | 98.5 | 0.942 | 9.46 | 4.38 | 97.9 | 1.01 | 0.718 | 13.5 | 0.396 | 5.22 | 2.54 | 412 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 0.524 | 29.0 | 73.0 | 1.16 | 13.7 | 4.17 | 79.1 | 1.16 | 0.665 | 15.8 | 0.410 | 5.48 | 2.33 | 270 |
| 136 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3B33 | 350 | 0.0733 | 15.9 | 53.0 | 1.46 | 24.6 | 2.89 | 45 | 0.608 | 0.571 | 14.0 | 0.345 | 6.36 | 2.10 | 174 |
| 140 | CH2 | A1 | 8 | 0.373 | 18.9 | 99.8 | 0.937 | 10.3 | 3.55 | 100 | 1.11 | 0.480 | 11.8 | 0.340 | 4.73 | 2.03 | 293 |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 380 |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 348 |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 254 |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 193 |
| 145 | CH2 | 2B23 | 200 | 0.0335 | 11.8 | 35.1 | 1.06 | 21.2 | 2.44 | 100 | 0.901 | 0.454 | 8.97 | 0.270 | 3.13 | 1.65 | 127 |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 142 |
| 147 | CH2 | 3B3 | 350 | 0.0580 | 24.7 | 33.9 | 1.34 | 27.9 | 5.13 | 0.00 | 0.693 | 0.603 | 11.9 | 0.000 | 3.76 | 1.85 | 100 |
| 148 | CH3 | A1 | 9 | 0.447 | 20.9 | 98.3 | 0.907 | 11.1 | 4.23 | 100 | 1.14 | 0.535 | 12.5 | 0.360 | 4.78 | 2.22 | 269 |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | 0.0333 | 14.5 | 34.9 | 1.06 | 19.2 | 2.59 | 0.00 | 1.06 | 0.313 | 10.9 | 0.200 | 4.29 | 1.35 | 77.9 |
| 154 | CH3 | 3B24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4B31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | 0.0557 | 38.5 | 31.7 | 1.25 | 25.9 | 7.29 | 0.00 | 0.609 | 0.705 | 9.78 | 0.334 | 5.58 | 2.22 | 140 |
| 157 | CH4 | 2B31 | 750 | 0.106 | 31.8 | 56.5 | 1.27 | 29.4 | 6.67 | 100 | 0.778 | 0.872 | 12.1 | 0.51 | 6.84 | 2.74 | 107 |
| 158 | CH4 | 4C1ox | 1000 | 0.153 | 42.9 | 55.1 | 1.13 | 29.2 | 9.68 | 100 | 1.09 | 1.32 | 17.4 | 0.81 | 7.19 | 4.40 | 191 |

**Supplementary Table 8, Part 1.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation

[Na values in weight percent; all others in parts per million. Analysts: J. Baker, A. Bartel, D. Burgi, R. Johnson, R. Knight, H.T. Millard, V.G. Mossotti, S. Ramage, B. Scott, J. Taggart, J.S. Wahlberg, and K. Wong]

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modern River Alluvium | | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | | | |
| 5 | PM15 | A1 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6 | PM15 | 2C1ox | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | | | |
| 19 | PM8 | A1 | 32 | 899 | 49.4 | 17.9 | 110 | 4.02 | 4.32 | 1.12 | 4.12 | 5.78 | 5.82 | 1.77 | 25.7 | 0.328 | 875 |
| 20 | PM8 | 2C1 | 55 | 932 | 51.6 | 16.4 | 114 | 3.80 | 4.23 | 1.11 | 3.91 | 4.56 | 6.76 | 1.53 | 26.2 | 0.349 | 766 |
| 21 | PM8 | 3C2 | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 839 | 32.7 | 9.40 | 58.8 | 2.70 | 2.32 | 0.770 | 2.34 | -- | 3.12 | 2.01 | 17.4 | 0.184 | 480 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | PM14 | 3C1ox | 99 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 36 | PM14 | 7C5n | 239+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | PM18 | 2C1ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 8, Part 1.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | | | |
| 54 | M31 | A11 | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 58 | M31 | 3C2 | 254 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 59 | M46 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | M46 | A12p | 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | M46 | 2A13p | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 62 | M46 | 3AC | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 63 | M46 | 4Cox | 250 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | | | | |
| 64 | M12 | A11 | 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 902 | 49.7 | 5.12 | 19.9 | 2.65 | 2.73 | 0.855 | 1.96 | 2.43 | 4.04 | 2.43 | 25.1 | 0.189 | 344 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 738 | 55.6 | 4.66 | 30.1 | 2.57 | 2.63 | 0.651 | 2.63 | -- | 3.51 | 1.98 | 29.3 | 0.199 | 347 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 870 | 43.2 | 5.64 | 18.3 | 2.45 | 2.54 | 0.859 | 2.24 | 4.02 | 3.13 | 2.17 | 22.0 | 0.179 | 311 |
| 70 | M12 | 6C2 | 413+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | | | |
| 71 | R9 | A11p | 30 | 971 | 39.8 | 6.16 | 36.2 | 2.38 | 2.45 | 0.829 | 2.07 | 2.95 | 4.36 | 2.47 | 20.0 | 0.208 | 461 |
| 72 | R9 | A12p | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 73 | R9 | B1 | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 74 | R9 | 2B21 | 180 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 75 | R9 | 2B22 | 235 | 840 | 49.4 | 8.69 | 41.3 | 2.88 | 2.5 | 0.903 | 2.49 | 3.1 | 3.64 | 2.33 | 23.6 | 0.221 | 523 |
| 76 | R9 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 77 | R9 | 4C | 400+ | 875 | 43.6 | 8.81 | 18.9 | 3.31 | 2.56 | 0.906 | 2.65 | -- | 2.71 | 2.25 | 21.8 | 0.197 | 466 |
| 78 | R33 | A11 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | | |
| 88 | R2 | Ap | 25 | 917 | 34.0 | 3.88 | 18.0 | 1.86 | 3.45 | 0.756 | 1.70 | -- | 4.84 | 2.54 | 16.9 | 0.189 | 289 |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 90 | R2 | B22t | 185 | 914 | 53.1 | 8.09 | 37.8 | 2.97 | 2.86 | 0.897 | 2.69 | 3.41 | 4.31 | 2.41 | 25.4 | 0.256 | 467 |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 93 | R2 | C2n | 500+ | 1210 | 18.5 | 2.63 | 3.64 | 3.67 | 0.982 | 0.448 | 0.843 | -- | 1.26 | 3.54 | 11.5 | 0.066 | 167 |
| 94 | R10 | A | 46 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 95 | R10 | 2B1 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 96 | R10 | 2B21t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 97 | R10 | 2B22t | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 98 | R10 | 3B3t | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | | | | |
| 108 | R30 | Ap | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B3t | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 8, Part 1.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Ba | Ce | Co | Cr | Cs | Dy | Eu | Fe | Gd | Hf | K | La | Lu | Mn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Turlock Lake Formation, 600 Ka | | | | | | | | | |
| 114 | T2 | A | 31 | 1210 | 42.4 | 10.0 | 85.6 | 2.82 | 1.96 | 0.543 | 2.20 | 2.56 | 7.31 | 3.15 | 16.9 | 0.178 | 605 |
| 115 | T2 | B21 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 116 | T2 | 2B22 | 386 | 739 | 67.1 | 8.72 | 36.0 | 2.35 | 4.22 | 1.25 | 2.85 | 3.2 | 6.75 | 1.89 | 33.1 | 0.339 | 236 |
| 117 | T2 | 3C | 417 | 989 | 31.4 | 4.33 | 25.6 | 2.45 | 2.48 | 0.959 | 2.08 | 3.03 | 2.73 | 2.57 | 19.9 | 0.182 | 210 |
| 118 | T6 | A11 | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 119 | T6 | A12 | 40 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 120 | T6 | 2B21t | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 121 | T6 | 2B22t | 190 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 122 | T6 | 3B+C | 370 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6IC2ox | 375+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | China Hat gravel member of Laguna Formation, 3000 Ka | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 666 | 50.6 | 7.73 | 112 | 3.10 | 3.18 | 0.770 | 2.63 | 3.5 | 9.36 | 1.39 | 22.3 | 0.332 | 342 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 549 | 64.4 | 18.4 | 107 | 3.77 | 3.50 | 0.854 | 4.17 | 3.59 | 8.06 | 1.14 | 26.4 | 0.306 | 603 |
| 136 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3IB33 | 350 | 615 | 24.5 | 7.54 | 120 | 2.48 | 2.37 | 0.623 | 5.40 | 3.94 | 3.08 | 1.14 | 18.6 | 0.270 | 127 |
| 140 | CH2 | A1 | 8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 145 | CH2 | 2B23 | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 147 | CH2 | 3IIB3 | 350+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 148 | CH3 | A1 | 9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 154 | CH3 | 3IIB24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4VB31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 158 | CH4 | 4C1ox | 1000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 8, Part 2.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation

[Na values in weight percent; all others in parts per million. Analysts: J. Baker, A. Bartel, D. Burgi, R. Johnson, R. Knight, H.T. Millard, V.G. Mossotti, S. Ramage, B. Scott, J. Taggart, J.S. Wahlberg, and K. Wong]

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modern River Alluvium | | | | | | | | | |
| 1 | MRA1 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 2 | MRA2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 3 | MRA3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 4 | MRA4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Post-Modesto Deposits, .2 Ka | | | | | | | | | |
| 5 | PM15 | A1 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 6 | PM15 | 2C1ox | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 7 | PM15 | 3C2ox | 42 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 8 | PM15 | 4C3ox | 47 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 9 | PM15 | 5C4ox | 51 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 10 | PM15 | 6C5ox | 51+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 11 | PM19 | A11 | 7 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 12 | PM19 | 2A12 | 12 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 13 | PM19 | 3C1ox | 23 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 14 | PM19 | 4C2ox | 43 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 15 | PM19 | 5C3ox | 49 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 16 | PM19 | 6C4n | 55 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 17 | PM19 | 7C5n | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 18 | PM19 | 8C6n | 80+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Post-Modesto Deposits, 3 Ka | | | | | | | | | |
| 19 | PM8 | A1 | 32 | 1.35 | 23.6 | 93.6 | 0.995 | 16.9 | 4.76 | 227 | 0.864 | 0.628 | 10.3 | 0.362 | 6.03 | 2.31 | 167 |
| 20 | PM8 | 2C1 | 55 | 1.58 | 22.9 | 87.1 | 0.903 | 16.1 | 4.92 | 258 | 0.911 | 0.535 | 11.2 | 0.429 | 5.77 | 2.15 | 223 |
| 21 | PM8 | 3C2 | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 22 | PM8 | 4C3 | 76+ | 1.96 | 14.2 | 80.7 | 0.526 | 0.890 | 2.96 | 302 | 0.611 | 0.335 | 6.75 | -- | 3.85 | 1.26 | 89.2 |
| 23 | PM13 | A11 | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 24 | PM13 | A12 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 25 | PM13 | 2C1ox | 86 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 26 | PM13 | 3C2ox | 112 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 27 | PM13 | 4C3ox | 136 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 28 | PM13 | 5C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 29 | PM13 | 6C5n | 720 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 30 | PM14 | A11 | 3 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 31 | PM14 | 2A12 | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 32 | PM14 | 3C1ox | 99 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 33 | PM14 | 4C2ox | 130 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 34 | PM14 | 5C3ox | 175 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 35 | PM14 | 6C4ox | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 36 | PM14 | 7C5n | 239+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 37 | PM16 | A | 2 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 38 | PM16 | C1ox | 25 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 39 | PM16 | 2C2ox | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 40 | PM16 | 3C3ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 41 | PM16 | 4C4ox | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 42 | PM16 | 5C5ox | 116 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 43 | PM16 | 5C6n | 236 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 44 | PM17 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 45 | PM17 | 2C2ox | 45 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 46 | PM17 | 2C2ox | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 47 | PM17 | 2C3ox | 74 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 48 | PM17 | 3C4n | 120+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 49 | PM18 | A | 6 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 50 | PM18 | 2C1ox | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 51 | PM18 | 2C2ox | 115 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 52 | PM18 | 3C3ox | 164 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 53 | PM18 | 4C4ox | 175+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

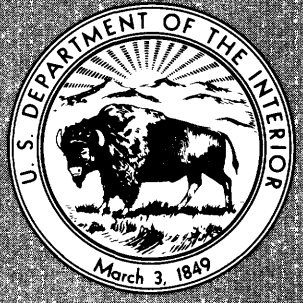
**Supplementary Table 8, Part 2.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Modesto Formation, upper member, 10 Ka | | | | | | | | | |
| 54 | M31 | A11 | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 55 | M31 | A12 | 63 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 56 | M31 | AC | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 57 | M31 | 2C1 | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 58 | M31 | 3C2 | 254 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 59 | M46 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 60 | M46 | A12p | 14 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 61 | M46 | 2A13p | 32 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 62 | M46 | 3AC | 66 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 63 | M46 | 4Cox | 250 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Modesto Formation, lower member, 40 Ka | | | | | | | | | |
| 64 | M12 | A11 | 15 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 65 | M12 | A12 | 81 | 2.31 | 21.2 | 95.4 | 0.695 | 4.89 | 3.77 | 370 | 0.895 | 0.373 | 9.81 | 0.20 | 3.20 | 1.42 | 120 |
| 66 | M12 | 2B21t | 102 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 67 | M12 | 3B22t | 170 | 1.98 | 24.0 | 82.5 | 0.448 | 7.29 | 4.14 | 313 | 0.778 | 0.436 | 13.6 | 0.271 | 3.95 | 1.37 | 132 |
| 68 | M12 | 4B3 | 201 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 69 | M12 | 5C1 | 231 | 2.40 | 19.2 | 85.6 | 0.494 | 5.21 | 3.03 | 421 | 0.726 | 0.318 | 11.1 | -- | 3.11 | 1.15 | 88.1 |
| 70 | M12 | 6C2 | 413+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| | | | | | | | | Riverbank Formation, upper member, 130 Ka | | | | | | | | | |
| 71 | R9 | A11p | 30 | 1.94 | 18.8 | 96.4 | 0.491 | 5.41 | 3.46 | 300 | 0.817 | 0.321 | 12.0 | 0.170 | 3.18 | 1.20 | 132 |
| 72 | R9 | A12p | 60 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 148 |
| 73 | R9 | B1 | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 127 |
| 74 | R9 | 2B21 | 180 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 124 |
| 75 | R9 | 2B22 | 235 | 1.60 | 22.8 | 93.5 | 0.534 | 7.06 | 3.92 | 254 | 0.862 | 0.380 | 9.42 | -- | 2.84 | 1.25 | 111 |
| 76 | R9 | 3B3 | 350 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 101 |
| 77 | R9 | 4C | 400+ | 2.38 | 20.0 | 83.0 | 0.614 | 7.86 | 3.49 | 418 | 0.570 | 0.369 | 11.3 | -- | 2.47 | 1.25 | 863 |
| 78 | R33 | A11 | 4 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 168 |
| 79 | R33 | 2A12 | 19 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 80 | R33 | 3A3 | 39 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 81 | R33 | 3B21t | 62 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 82 | R33 | 3B22t | 83 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 83 | R33 | 3B23t | 122 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 127 |
| 84 | R33 | 3B31 | 151 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 85 | R33 | 3B32 | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 86 | R33 | 4B33 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 87 | R33 | 5Cox | 300+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 61 |
| | | | | | | | | Riverbank Formation, middle member, 250 Ka | | | | | | | | | |
| 88 | R2 | Ap | 25 | 1.87 | 18.8 | 89.4 | 0.533 | 3.58 | 3.09 | 308 | 0.819 | 0.332 | 8.85 | 0.192 | 2.61 | 1.23 | 158 |
| 89 | R2 | B21 | 81 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 143 |
| 90 | R2 | B22t | 185 | 1.43 | 23.9 | 99.8 | 0.674 | 6.80 | 4.32 | 253 | 0.929 | 0.397 | 11.2 | -- | 3.84 | 1.71 | 134 |
| 91 | R2 | B3 | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 98 |
| 92 | R2 | C1 | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 77 |
| 93 | R2 | C2n | 500+ | 2.60 | 7.20 | 136 | 0.829 | 1.63 | 1.21 | 451 | 0.271 | 0.098 | 5.22 | -- | 1.66 | 0.421 | 53 |
| 94 | R10 | A | 46 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 95 | R10 | 2B1 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 149 |
| 96 | R10 | 2B21t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 97 | R10 | 2B22t | 210 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 124 |
| 98 | R10 | 3B3t | 386 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 99 | R10 | 3Cox | 500 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 100 | R32 | A11 | 26 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 186 |
| 101 | R32 | A12 | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 102 | R32 | A3 | 70 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 103 | R32 | B21t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 104 | R32 | B22t | 150 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 173 |
| 105 | R32 | B31t | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 106 | R32 | 2B32 | 354 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 107 | R32 | 3Cox | 360+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 101 |
| | | | | | | | | Riverbank Formation, lower member, 330 Ka | | | | | | | | | |
| 108 | R30 | Ap | 65 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 109 | R30 | B10 | 78 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 110 | R30 | B21t | 127 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 111 | R30 | 2B22t | 179 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 112 | R30 | 3B2c | 197 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 113 | R30 | 3C1ox | 220 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

**Supplementary Table 8, Part 2.** Total chemical analyses of the less-than-2-mm fraction by instrumental neutron activation--Continued

| No. | Sample | Horizon | Basal depth (cm) | Na | Nd | Rb | Sb | Sc | Sm | Sr | Ta | Tb | Th | Tm | U | Yb | Zr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | Turlock Lake Formation, 600 Ka | | | | | | | | | |
| 114 | T2 | A | 31 | 0.812 | 13.3 | 124 | 0.547 | 4.31 | 2.42 | 197. | 0.780 | 0.285 | 8.54 | -- | 2.29 | 1.12 | 228 |
| 115 | T2 | B21 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 116 | T2 | 2B22 | 386 | 1.94 | 30.8 | 79 | 0.587 | 8.23 | 5.50 | 313. | 0.986 | 0.598 | 16.1 | -- | 3.53 | 1.90 | 214 |
| 117 | T2 | 3C | 417 | 1.97 | 22.0 | 109 | 0.550 | 3.81 | 3.64 | 324. | 0.822 | 0.371 | 11.6 | 0.177 | 2.49 | 1.16 | 86.5 |
| 118 | T6 | A11 | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 123 |
| 119 | T6 | A12 | 40 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 147 |
| 120 | T6 | 2B21t | 90 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 77 |
| 121 | T6 | 2B22t | 190 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 76 |
| 122 | T6 | 3B+C | 370 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 70 |
| 123 | T11 | A11p | 5 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 124 | T11 | 2A12p | 11 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 166 |
| 125 | T11 | 2A+B | 20 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 126 | T11 | 2B1t | 33 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 144 |
| 127 | T11 | 2B2t | 80 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 128 | T11 | 3B31t | 191 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 129 | T11 | 4B32t | 256 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 130 | T11 | 5B+C | 292 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 131 | T11 | 5C1ox | 375 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 132 | T11 | 6IC2ox | 375+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 83 |
| | | | | | | | | China Hat gravel member of Laguna Formation, 3,000 Ka | | | | | | | | | |
| 133 | CH1 | A1 | 12 | 0.453 | 22.4 | 78.8 | 0.822 | 7.91 | 3.65 | 65.1 | 0.882 | 0.460 | 10.1 | 0.38 | 3.73 | 1.90 | 292 |
| 134 | CH1 | 2AB | 53 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 135 | CH1 | 2B21t | 88 | 0.341 | 23.2 | 66.2 | 1.12 | 12.2 | 4.08 | -- | 1.08 | 0.454 | 12.6 | 0.16 | 4.42 | 2.03 | 241 |
| 135 | CH1 | 2B22t | 140 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 137 | CH1 | 2B31 | 234 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 138 | CH1 | 2B32 | 310 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 139 | CH1 | 3IB33 | 350 | 0.067 | 15.1 | 49.3 | 1.27 | 22.2 | 2.85 | 77.3 | 0.722 | 0.335 | 9.99 | -- | 4.25 | 1.49 | 142 |
| 140 | CH2 | A1 | 8 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 141 | CH2 | A3 | 30 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 142 | CH2 | 2A+B | 50 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 143 | CH2 | 2B21t | 110 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 144 | CH2 | 2B22 | 170 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 145 | CH2 | 2B23 | 200 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 146 | CH2 | 3B24 | 290 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 147 | CH2 | 3IIB3 | 350+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 148 | CH3 | A1 | 9 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 149 | CH3 | A3 | 35 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 150 | CH3 | A+B | 68 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 151 | CH3 | B2t | 105 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 152 | CH3 | B22t | 153 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 153 | CH3 | 2B23 | 173 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 154 | CH3 | 3IIB24 | 260 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 155 | CH3 | 4VB31 | 340 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 156 | CH3 | 5B32 | 750+ | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 157 | CH4 | 2B31 | 750 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 158 | CH4 | 4C1ox | 1000 | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |

GPO 785-048/48019


U.S. DEPARTMENT OF THE INTERIOR
March 3, 1849