Soils Developed on Coastal and Fluvial Terraces near Ventura, California

U.S. GEOLOGICAL SURVEY BULLETIN 1590–B

Soils Developed on Coastal and Fluvial Terraces near Ventura, California

By J.W. HARDEN, A.M. SARNA-WOJCICKI,
and G.R. DEMBROFF

U.S. GEOLOGICAL SURVEY BULLETIN 1590–B

SOIL CHRONOSEQUENCES IN THE WESTERN UNITED STATES

DEPARTMENT OF THE INTERIOR
DONALD PAUL HODEL, Secretary

U.S. GEOLOGICAL SURVEY
Dallas L. Peck, Director

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1986

For sale by the
Books and Open-File Reports Section
U.S. Geological Survey
Federal Center, Box 25425
Denver, CO 80225

Library of Congress Cataloging-in-Publication Data

Harden, Jennifer Willa, 1954–
Soils developed on coastal and fluvial terraces near
Ventura, California.

(Soil chronosequences in the Western United States)
(U.S. Geological Survey Bulletin 1590–B)
Bibliography: p. B17–B18
Supt. of Docs. no.: I 19.3:1590–B
1. Soils—California—Ventura region. 2. Soil formation—California—Ventura region. 3. Soil chronosequences—California—Ventura region. 4. Geology—California—Ventura region. I. Sarna-Wojcicki, Andrei M. II. Dembroff, Glenn R. III. Title. IV. Series: Soil chronosequences in the Western United States. V. Series: United States. Geological Survey. Bulletin 1590–B.
QE75.B9 no. 1590–B   557.3s   86–600092
[S599.C2]   [551.3'55]

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, 1982; Harden and Taylor, 1983; Machette, 1983; Machette and Steven, 1983; Machette and others, 1983; Busacca 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

CONTENTS

FIGURES

TABLES

SUPPLEMENTARY TABLES

Soils Developed on Coastal and Fluvial Terraces near Ventura, California

By J.W. Harden, A.M. Sarna-Wojcicki, *and* G.R. Dembroff

Abstract

We sampled and analyzed soils developing in the coastal and fluvial terraces near Ventura, Calif.: (1) to test the usefulness of studies of such soils as a chronologic tool, (2) to characterize the soils in this geologic and climatic setting, (3) to document the composition of the soils and long-term rates of soil development in this area, and (4) to compare these rates with those of soils in other climatic and geomorphic settings. The coastal terraces in the Ventura area consist of a marine wave-cut platform overlain by a thin veneer of beach sand and gravel, which, in turn, are overlain by terrestrial sediment. This area is tectonically active, but sampling sites were chosen on flat, relatively stable surfaces. Radiometric and amino-acid-racemization data on the terrace deposits provide maximum ages for the soils. Six terraces, four marine and two fluvial, range in age from about 0.5 ka to older than about 80 ka. Systematic changes with age in many morphologic, physical, and chemical characteristics of the soils developed on the terraces suggest that the geomorphic surfaces are stable enough for soil development to proceed.

Some characteristics of the Ventura soils appear to change more rapidly over time than those of soils in inland, central California. Clay accumulation is especially rapid near Ventura, although the mineralogy of the clays does not alter significantly with increasing age. This absence of clay-mineral alteration suggests that many of the clays are products of mechanical weathering, or are inherited from eolian sources or colluvial reworking. The rate of accumulation of dithionite-extractable iron oxides is faster, and the rate of change of the morphologic soil development index higher, for Ventura soils than for soils in central California.

INTRODUCTION

Marine terraces along the California coast provide age control for studies of soil chronosequences (in which soils differ in age but have similar climate, parent material, vegetation, and slope position). Soil development, which is most pronounced on stable or slowly active landscapes, can be studied on the different-age terraces where the surfaces are flat or slope gently.

Near Ventura, Calif., the formation of three marine terraces was dated previously by radiometric and amino-acid methods (Lajoie and others, 1979, 1982). In addition, two fluvial units have been mapped but not accurately dated. The younger of these two fluvial deposits is similar in texture and mineralogy to deposits in the marine terraces; therefore, the parent materials of the soils are similar enough to study as a soil chronosequence. The older fluvial unit is composed of coarse gravel of slightly different mineralogy, and so this unit is not considered part of the soil chronosequence. We studied this unit and the soil developed on it, however, for comparison with the chronosequence.

The purpose of this study was to examine, sample, and analyze soils associated with the marine and fluvial terraces near Ventura so as to determine: (1) whether the soils developed systematically with terrace age, (2) how the soils developed in comparison with those other areas, and (3) whether the soils developed on marine terraces can be used to identify and correlate the terraces near Ventura or elsewhere along the coast.

Acknowledgments.—Many thanks to Ken Lajoie for his generosity with time, ideas, and materials. The late D.E. Marchand participated in the planning and sampling stages of this study. We thank R.M. Burke for early reconnaissance of the study area, and E.M. Taylor, C. Terhune, and S. Walker for compiling information pertinent to the manuscript. We also thank M.C. Reheis and T.K. Rockwell for helpful discussions.

GEOGRAPHIC AND CLIMATIC SETTING

Three marine terraces near the town of Ventura (fig. 1) were studied by Putnam (1942), Sarna-Wojcicki and others (1976), and Lajoie and others (1982). Because tectonic deformation is so active in the study area, the terraces near Ventura cannot be reliably correlated by geomorphic criteria with those west of Santa Barbara or with those south of Oxnard. The Mediterranean climate of the study area is character-

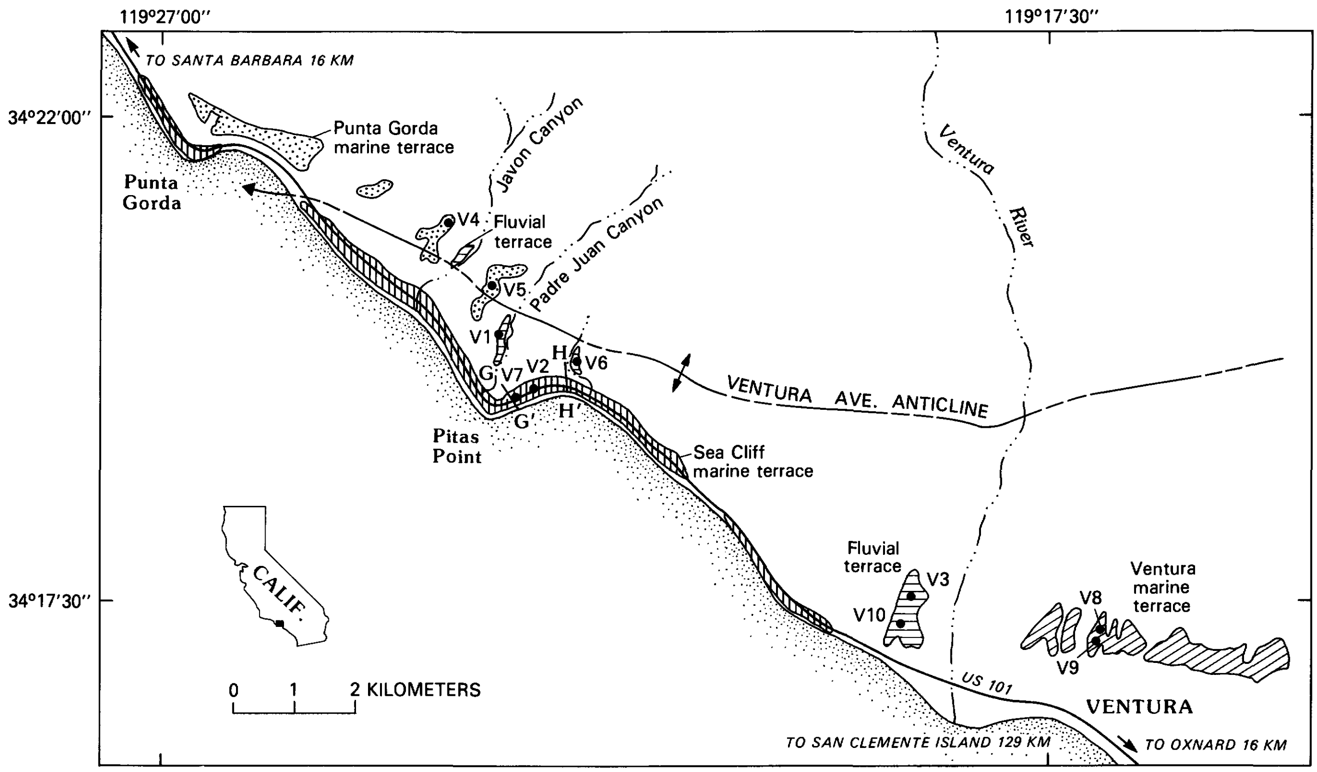

Figure 1. Sketch map of Ventura, Calif., area, showing location of study area, sampling sites (dots), and cross sections.

ized by a mean annual temperature of about 15° C and a mean annual precipitation of about 36 cm. Most of the precipitation falls during the cool winters, and the xeric soil-moisture regime indicates cycles of effective wetting during winter and desiccation during summer seasons. The soil-temperature regime is thermic. Vegetation in the study area consists of annual grasses and coastal scrub, such as baccharis and blackberry.

GEOLOGIC SETTING

The late Cenozoic geology and seismicity in the Ventura, Calif., area were studied by Putnam (1942), Natland (1952), Palmer (1967), Sarna-Wojcicki and others (1976, 1980), Yeats (1977), Lajoie and others (1979, 1982), Yerkes and Lee (1979), and Yerkes and others (in press). Dembroff (1982), Dembroff and others (1982), and Rockwell (1983) studied the late Cenozoic geology, neotectonics, and soils in the vicinity, concentrating on terraces along the Ventura River. Most of the stratigraphy and chronology in our study are based on the work of Lajoie and others (1979, 1982), although some new data and interpretations are included in this report. Deposits that constitute the soils' parent materials are derived from marine sandstone and conglomerate, including, from youngest to oldest, the San Pedro, Santa Barbara, Pico, Sisquoc, Santa Margarita, Monterey, Rincon, Vaqueros, and Sespe Formations.

Rapid tectonic deformation, in combination with eustatic sea-level fluctuations, has created three elevated marine terraces that are cut into Cenozoic marine rocks. These marine terraces consist of a wave-cut platform veneered with fossiliferous marine gravel and sand, which, in turn, are overlain by alluvial and (or) colluvial sediment containing admixtures of eolian material (fig. 2). Fossil mollusk shells in the platforms and beach deposits provide information on age and climate: first, they indicate the general temperature regime that existed during platform cutting; and, second, they provide age estimates from uranium-series, radiocarbon, and amino-acid-racemization analytical methods. In general, platform cutting of these terraces probably occurred during relative highstands of sea level later than oxygen-isotope stage 5e (approx 120 ka; Lajoie and others, 1979, 1982). The temperature regime of the shells, somewhat cooler than that at present, indicates that these terraces are younger than oxygen-isotope stage 5e. Terrestrial deposits overlie the platforms and marine veneers; this terrestrial sediment generally constitutes the parent materials of the soils, although in some places the soils may have developed below the platform on the underlying bedrock sandstone.

In addition to the marine terraces, we also studied two sets of fluvial terraces. The younger of

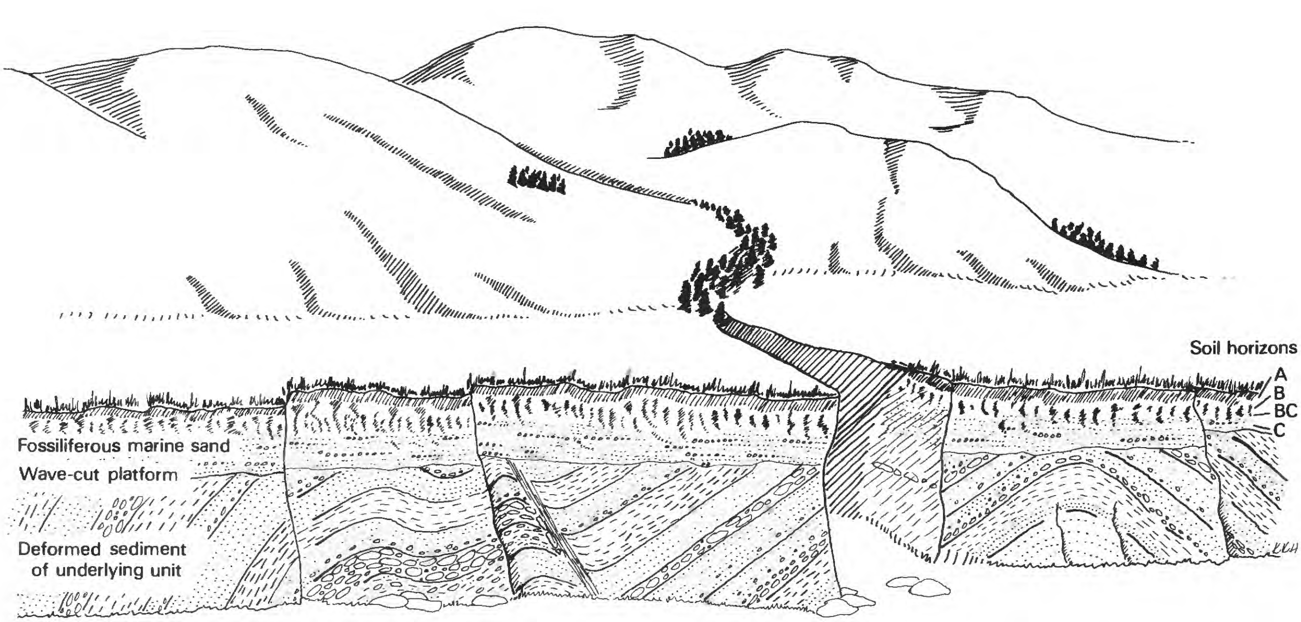

Figure 2. Schematic cross section of a marine terrace near Ventura, Calif.

these terraces are situated in small canyons along the coast; the older terraces are derived from the Ventura River (fig. 1).

Origin and Age of Geologic Units

Soils developed in six units of different ages were sampled for this study, but only the youngest four units have numerical age control. Each unit and its age control are discussed in more detail below. The youngest unit consists primarily of beach sand that underlies the Sea Cliff marine terrace (geomorphic surface) near Pitas Point and Punta Gorda (fig. 1). The next unit, referred to as fluvial deposits in coastal canyons, consists of mixed fluvial sediment that slightly postdates the erosional platform of the Sea Cliff marine terrace. The next oldest units, referred to as mixed terrestrial deposits of the Punta Gorda and Ventura marine terraces, are composed primarily of alluvial and (or) colluvial sediment that overlies both fossiliferous marine deposits and a wave-cut platform (fig. 2) and is of late Pleistocene age. The two oldest units of this study are here referred to as fluvial deposits of the Ventura River, which are also of late Pleistocene age. These oldest units are situated at a complex structure in the Ventura Avenue anticline, and their ages relative to the marine terraces are not well constrained.

Beach Sand Underlying the Sea Cliff Marine Terrace

The youngest unit of this study was sampled in two localities (soil samples V2, V7; see table 1). Analysis of detailed topographic maps (1:1,200) and aerial photographs reveals that the broad geomorphic surface (Sea Cliff marine terrace) actually is com-

Table 1. Stratigraphic units of the Ventura soil sequence

Parent-material deposits	Soil samples	Age control (ka)	Age of surface: Best estimate (ka)	Age of surface: Conservative range (ka)
Beach sand----------------	V2, V7	[1]0.7 [2,3]2.5	0.7	0.5-0.7
Fluvial deposits----------	V1, V6	[3]2.55 [1]5.6	2	2-5.6
Punta Gorda marine terrace.	V4, V5	35(?) [4,5]40 [5]60 120	40	35-60
Ventura marine terrace----	V8, V9	60 [4,5]85 [5]105	80	60-105
Ventura River gravel------	V3, V10	85	80	60-105(?)

[1]Uplift rate.
[2]Uranium-series age.
[3]^{14}C age on shells or charcoal.
[4]Amino-acid-racemization age on prototheca fossil shells.
[5]Cool-water fauna indicate an age younger than 120 ka.

posed of several platforms and shorelines that were uplifted and isolated from marine erosion and deposition. Near Pitas Point, nine such shorelines have been recognized as scarps that parallel the modern beach (figs. 3, 4; K.R. Lajoie, written commun., 1984). Maximum ages of the shorelines or beaches can be inferred from uplift rates calculated from the elevation of underlying and nearby dated platforms (fig. 4). With corrections for the rise in Holocene sea level (Bloom and others, 1974), these uplift rates are 5.0 and 4.2 m/ka. Rates were also calculated for other dated localities on the Sea Cliff marine terrace (data not shown), and range from about 4.7 to 6.0 m/ka. Because the platforms formed below but near the level of the corresponding beach, we assumed that these rates also approximate the age of the beach sand overlying the platforms. The age of this unit is about 0.5 to 0.7

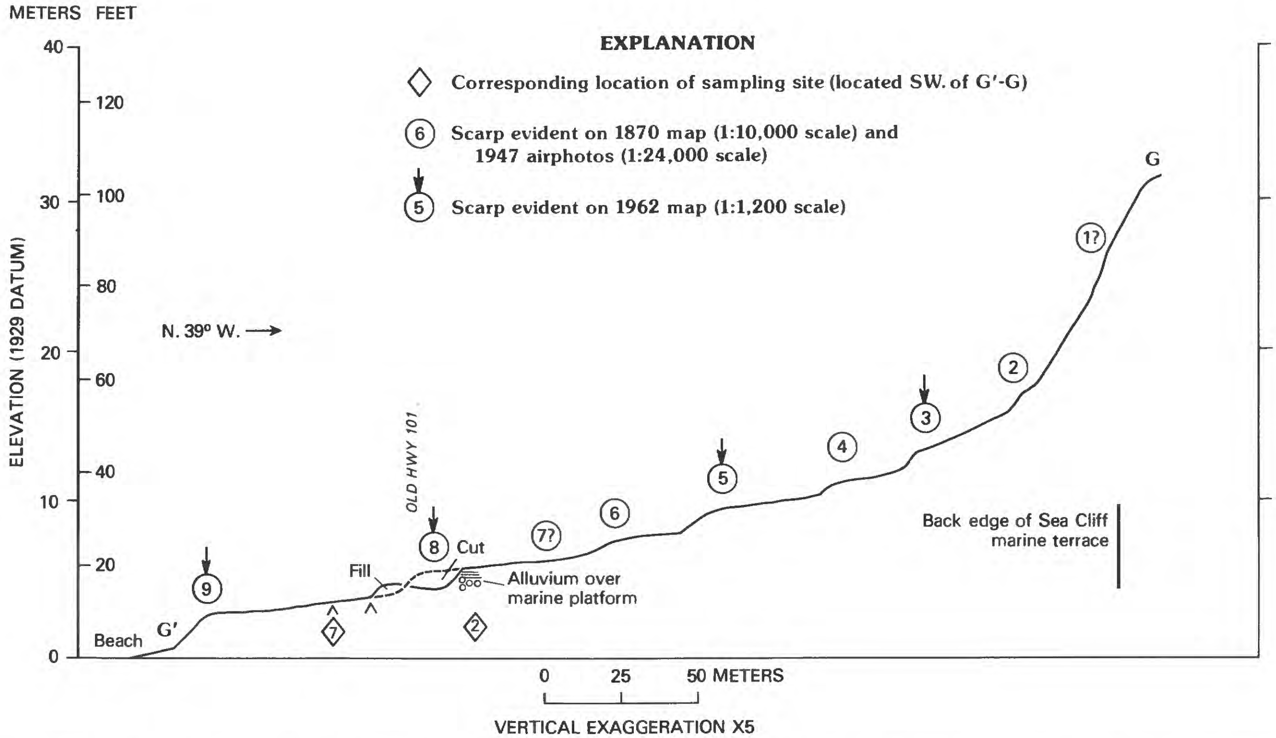

Figure 3. Cross section G-G' through the Sea Cliff marine terrace, showing scarps of abandoned beaches (see fig. 1 for location).

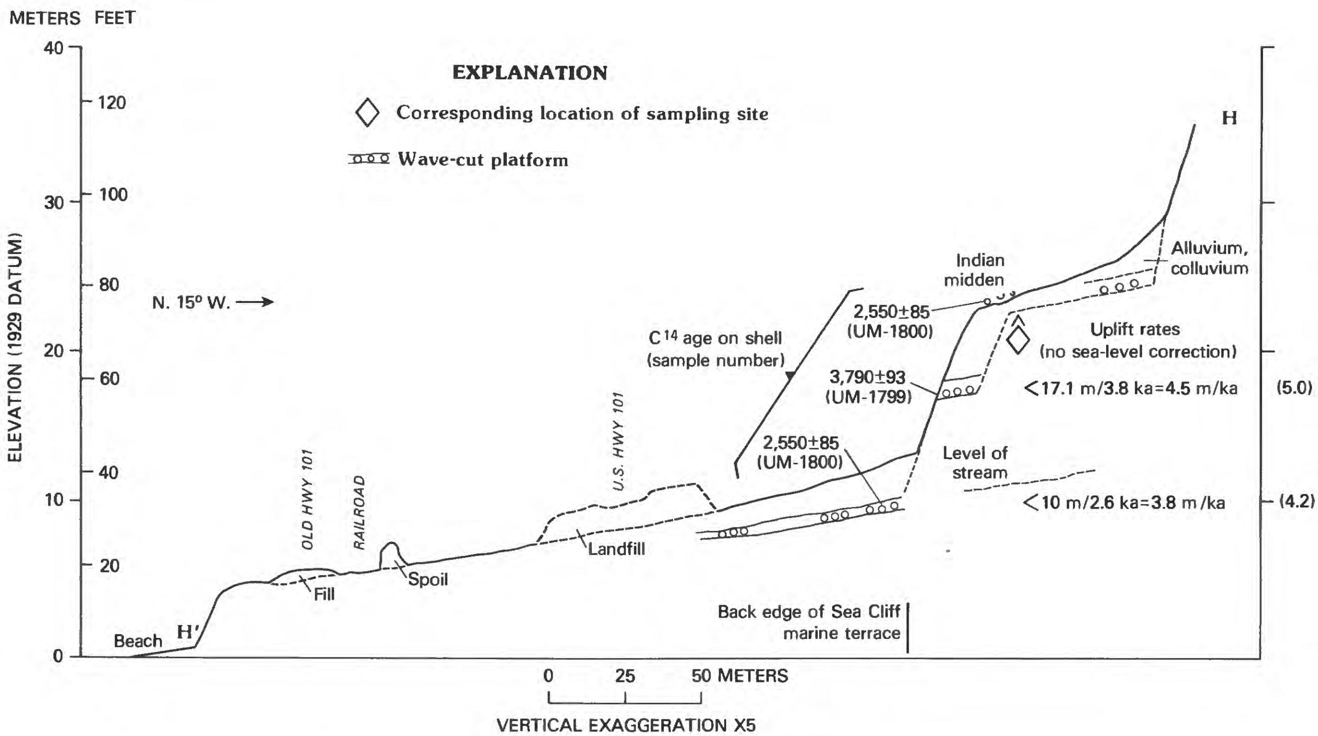

Figure 4. Cross section H-H' of the Sea Cliff marine terrace, showing locations of samples used for determining ^{14}C ages and uplift rates (see fig. 1 for location). Indian midden is directly across stream from soil profile V6.

ka, on the basis of uplift rates measured at scarps 8 and 9 in figure 3 at an elevation of 3 to 4 m. Sample V7 might be slightly younger than V2 on the basis of scarp elevation, but we assumed that the sampling sites are too close together to differentiate the overlying dune sand.

Fluvial Deposits in Coastal Canyons

Two fluvial terraces, both about 2 ka old, postdate the platform of the Sea Cliff marine terrace. These terraces here are considered as one unit, labeled "fluvial deposits" in table 1.

Site V6 is located across the canyon from a stream terrace at a similar elevation that is overlain by an Indian midden site (fig. 4), from which shells were collected and ^{14}C-dated at 2.55 ka[1]. The age of the wave-cut platform at this locality is about 4.2 to 5.6 ka, on the basis of maximum and minimum uplift rates (fig. 4). The surface and soil, then, are probably about 2 to 2.5 ka old and no older than about 5.6 ka.

Site V1 is located on a fluvial terrace along Padre Juan Canyon (fig. 1). The apparent absence of buried soils within the upper 3 m of the surface suggests no significant hiatuses in deposition. In Javon Canyon to the northwest is a similar, prominent stream terrace that probably is correlative with the terrace in Padre Juan Canyon, on the basis of its elevation above the streams. Charcoal from the terrace in Padre Juan Canyon at a depth of about 1.5 m was ^{14}C-dated at 2.365±0.065 ka (sample Beta-1085). Sampling sites V1 and V6 were combined to represent a single time-stratigraphic unit that dates from 2 to 5.6 ka.

Mixed Terrestrial Deposits of the Punta Gorda Marine Terrace

The next oldest unit is associated with the Punta Gorda marine terrace (fig. 1; Lajoie and others, 1982), which includes a wave-cut platform overlain by terrestrial deposits (fig. 2). This platform was cut from about 60 to 40 ka, on the basis of the cold-water aspect of molluscan fauna, uranium-series ages, and amino-acid data on fossil shells found at the contact between the marine and terrestrial units (table 1; Lajoie and others, 1979). Given the limitation of uranium-series and amino-acid dating techniques, the platform could be from 35 to 60 ka old, corresponding to relative sea-level highstands (Bloom and others, 1974) during which the platforms could have been cut.

The age of terrestrial deposits of the Punta Gorda marine terrace has not been determined directly. If sedimentation processes are similar on the Punta Gorda and Sea Cliff marine terraces (see next subsection), the sediment probably postdates platform cutting by about 3 ka. If sedimentation was continuous since platform erosion, or if sedimentation rates were relatively low in comparison with those on the Sea Cliff marine terrace, the sediment and surface of the Punta Gorda marine terrace could be significantly younger than the platform. This is unlikely, however, because (1) the Punta Gorda marine terrace lies north of the axis of the Rincon anticline, and so tilting has been toward the north, away from the distal edge of the terrace; and (2) stream incision probably followed shortly after uplift. Fluctuation of the clay content of the sediment with depth (fig. 5) indicates cycles of clay and silt deposition and, possibly, pulses of sedimentation. Although we assigned an approximate age of 40 ka to the surface and soil of the Punta Gorda marine terrace, this terrace could be from 35 to 60 ka old.

Mixed Terrestrial Deposits of the Ventura Marine Terrace

The geomorphic surface referred to by Lajoie and others (1982) as the Ventura terrace is older than the Punta Gorda marine terrace but occurs at lower elevations than the Punta Gorda marine terrace because of its relative position on the southern limb of the Ventura Avenue anticline (fig. 1; Lajoie and others, 1982, p. 46). The Ventura marine terrace is cut into older, deformed bedrock. Amino-acid-racemization analyses of fossil mollusks yield estimates of 85 to 105 ka for the age of the platform (fig. 2). These shells also indicate cooler water conditions in comparison

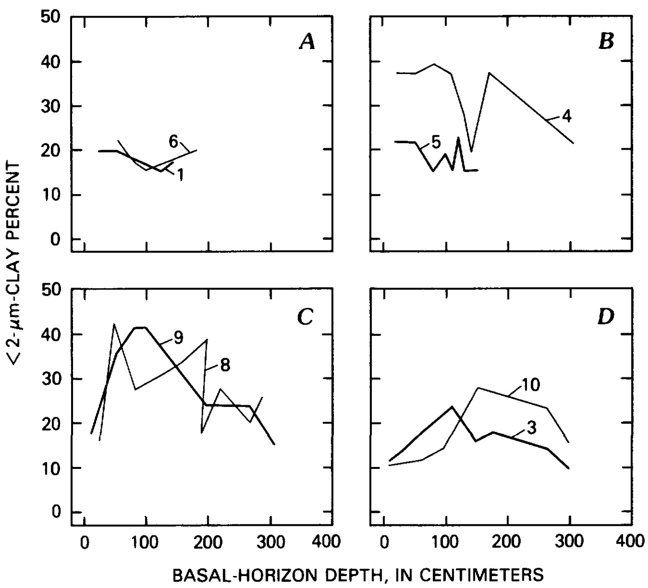

Figure 5. Percent clay versus basal-horizon depth for four age groups of Ventura soils. A, Soils in post-Sea Cliff marine terrace (approx 2 ka). B, Soils in Punta Gorda marine terrace (approx 40 ka). C, Soils in Ventura marine terrace (approx 80 ka). D, Soils in Ventura River gravel (approx 80 ka). Numbers denote profiles (see supp. table 2).

[1]Shells from the midden were discovered in a plowed field, and so these shells could have come from just below the surface.

with the present and with oxygen-isotope stage 5e; thus, the shells and platform are less than about 120 ka old.

Fossil marine shells that were found at about 3-m depth in both soil pits in the Ventura marine terrace, directly on top of the marine platform, indicate the approximate depth of the platform. The thickness of terrestrial sediment is about the same as on the Sea Cliff marine terrace, and sedimentation and subsequent surface stabilization apparently occurred soon after platform erosion. An approximate age of 80 ka was assigned to this surface and soil, but the unit could be as old as about 105 ka; a constraining minimum age is more difficult to assess. Modern analogs of terrace formation, rapid tectonic uplift, and rapid incision rates that isolate terraces from stream deposition, and the fact that we sampled away from colluviated slopes, led us to assume that the surface age is within a few thousand years of the platform age.

Fluvial Deposits Derived from the Ventura River

In addition to soils developed on marine terraces, we examined soils developed in stream gravel from the Ventura River. Two stream terraces west of the river (fig. 1) are the highest (150-200 m) and, thus, possibly the oldest Ventura River terraces at the coast. The deposits are composed of coarse gravel containing rounded clasts reworked from Tertiary sedimentary rocks to the north. The surfaces and bedrock platform dip about 9°-15° S., about the same as the Ventura marine terrace and platform to the east. These dips are too steep to be original fluvial-terrace gradients, and so the deposits must have been tilted by folding on the Ventura Avenue anticline. The similar tilts on the river-terrace and marine-terrace platforms suggest that the units were formed approximately coevally. We assign an age of about 80 to 105 ka to the two river terraces and their soils.

Because these soils have much coarser parent materials, they are not part of the soil chronosequence that includes the younger units of this study. Some interesting comparisons, however, can be made between soils on the Ventura marine terrace and soils on the Ventura River gravel.

Relation of Ages to Surfaces and Soils

Specific ages of surfaces and soils are assigned to the geologic units of this study (figs. 5-8; table 1) to demonstrate the age trends of soils. Some of the ages of these units are only tentative and, as is apparent from the preceding discussion, of varying reliability. The text figures demonstrate graphically the uncertainties in age assignments that are outlined above.

Most of the ages in this study provide maximum ages for the landform surface and, thus, for the soil; however, minimum ages are not well constrained. Most of the ages are for materials 2 to 4 m below the landform surface (for example, shells from the marine platform; see fig. 2). The uncertainties in these ages, listed in table 1, account for as much as a 20-ka error, which might be possible if age calibration for uranium-series or amino-acid analyses was off by one entire interstadial. A more difficult question pertains to a mimimum age for the surface and soil; that is, how long did it take (1) for the upper 2 to 4 m of sediment to accumulate and (2) for sedimentation to cease so that soil development could commence? As discussed above, several lines of evidence suggest that sedimentation of these deposits and subsequent abandonment of the surfaces were relatively rapid. First, the near-modern analog of a marine terrace is the Sea Cliff marine terrace, the surface of which is 0.5 to 0.7 ka old at its front edge and about 2.5 ka old at its back edge. The terrestrial sediment is composed of beach sand and (or) fluvial deposits and is about 2 to 3 m thick. Second, stream incision has begun and is significant at the backedge, features suggesting that the backedge of the terrace is no longer accumulating material and has stabilized. Our estimate of the date for surface stabilization of the Punta Gorda and Ventura marine terraces is 3 ka to no earlier than 5 ka. Rapid stabilization is also suggested by the absence of buried soils that would indicate hiatuses, by the similarity in the thicknesses of terrestrial sediment within the Sea Cliff and Ventura marine terraces, and by similar slopes of the platforms and terrace surfaces. The two most significant uncertainties in regard to the terrestrial deposits are colluvial-sediment and eolian-dust additions, which are discussed in the next section.

Members of the Soil Chronosequence

The soil chronosequence of this study is composed of four different-age soils that are developed in various types of deposits: (1) beach sand that overlies the platform of the Sea Cliff marine terrace, (2) fluvial deposits that slightly postdate the platform of the Sea Cliff marine terrace, (3) terrestrial deposits that overlie the platform of the Punta Gorda marine terrace, and (4) terrestrial deposits that overlie the Ventura marine terrace. All of these deposits appear to have been composed primarily of sand and silt before the onset of soil formation and eolian-dust accumulation. Therefore, these deposits and their soils are here considered as members of a soil chronosequence, in which parent material, climate, vegetation, and slope position are comparable but the duration or time of soil development differs.

Soils developed in the Ventura River gravel are not considered to be members of this chronosequence, however, because the parent materials are composed primarily of gravel, which differs significantly from the finer grained deposits of other units. Nonetheless, some interesting comparisons can be made between these soils and those of the marine terraces.

SOIL DEVELOPMENT ON THE COASTAL TERRACES

Soils of this study range from minimally developed Entisols that lack any diagnostic soil horizons to well-developed Mollisols that have thick, dark A horizons enveloping or "tonguing into" the underlying

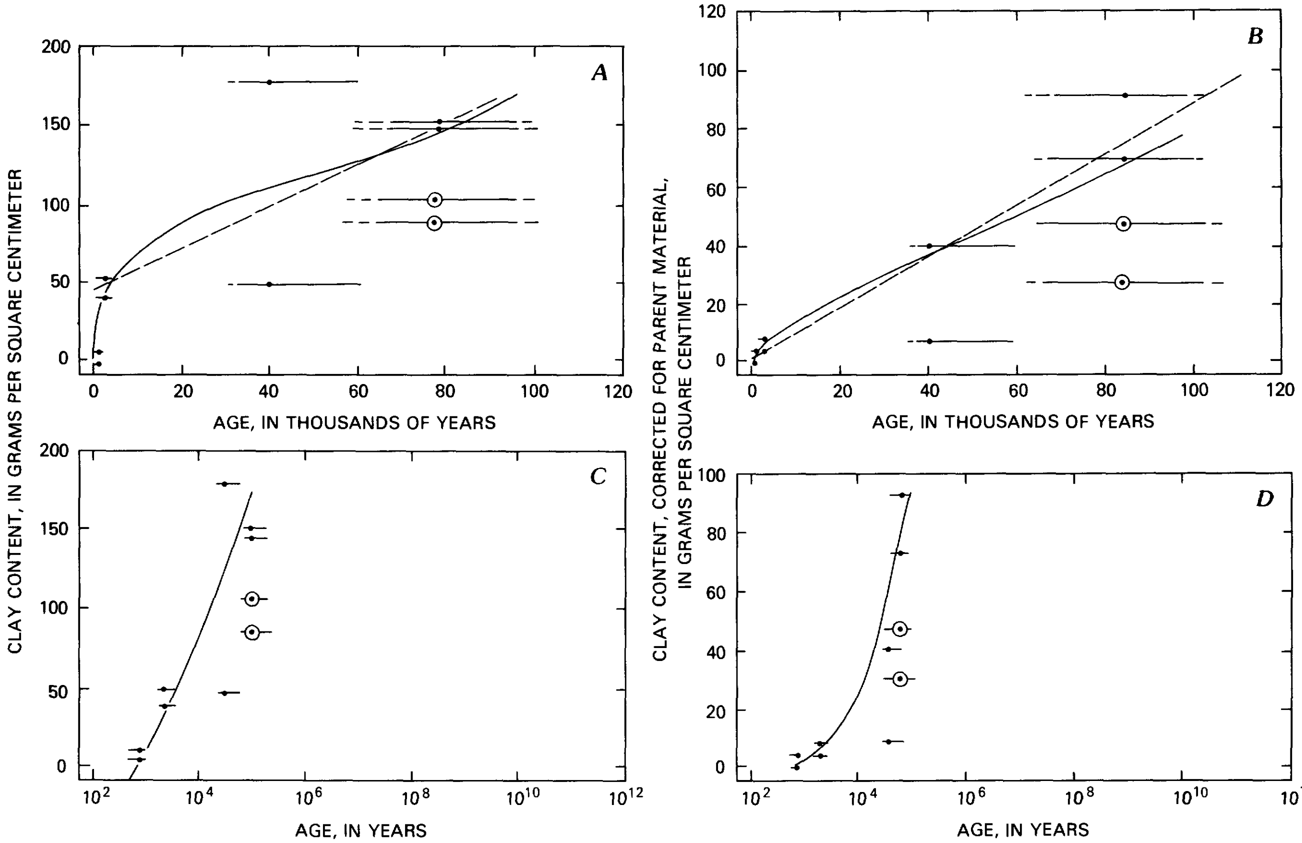

Figure 6. Profile sums of clay content versus linear (A, B) and log (C, D) age. Percent clay was multiplied by horizon thickness (in centimeters) and bulk density (in grams per cubic centimeter), and the products were summed for each profile (A, C); to correct for parent material, minimum percent clay content in profile was subtracted before multiplying by horizon thickness (B, D). Horizontal lines, age uncertainty; dots, best-estimate ages of soils on coastal terraces; circled dots, soils developed in Ventura River gravel (table 1). Solid lines (A–D) approximate trends of data; dashed lines (A, B) indicate trend if linear rates are assumed.

argillic horizons. The dark colors, found as deep as about 1.5 m, appear to be those of clay and silt associated with organic carbon. The salts of the sea spray probably play an important role in dispersing organic matter into a mobile form, as well as in binding the organic compounds into clay and silt, resulting in a dark complex of organic material and clay.

The influence of sea spray on the rate and type of soil development was discussed by Yaalon and Lomas (1970) and Hingston and Gailitis (1976). More recently, in the Ventura area, Dembroff and others (1982) and Rockwell (1983) proposed that soil-development rates are accelerated in part by the sodium influence on clays. Harden and Taylor (1983), however, concluded that many aspects of soil development were not profoundly affected by salt spray, because similar-age soils of this study and of the Central Valley of California are morphologically similar. One objective of this more detailed study of the Ventura soils was to characterize the physical, chemical, and mineralogic aspects of soil development and to determine whether the development rates of these properties are significantly affected by the coastal salt spray.

Amount and Mineralogy of Clays

To evaluate and compare soil development, patterns and characteristics of the parent materials must be identified and separated from pedogenic features. Deposits associated with the young Sea Cliff marine terrace contain about 18 to 20 percent clay (see supp. tables 2, 8), relatively uniformly distributed with depth, at least to about 2 m (fig. 5A). Older marine-terrace units (Punta Gorda and Ventura), which appear to be stratified with respect to particle size, generally contain about 20 percent clay in A and C horizons, values suggesting that the higher clay content in B horizons is pedogenic and (or) eolian (figs. 5B, 5C). A and C horizons of the soils in Ventura River gravel (fig. 5D) contain about 10 percent clay and are much less stratified than the marine-terrace soils.

The stratification of the Punta Gorda and Ventura sediment suggests that not all of the B-horizon clay may be pedogenic, although determination of the original clay content is nearly impossible. If the volume of clay in each soil profile is simply calculated, clay content increases significantly with age for the chronosequence soils (figs. 6A, 6C), but the fluvial

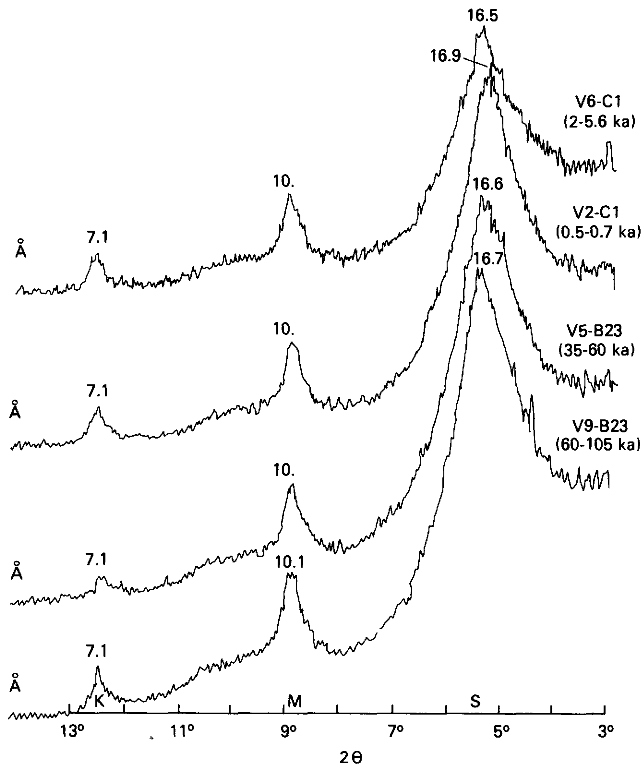

Figure 7. X-ray diffractograms of glycolated samples from four Ventura soils. Numbers are angstrom spacings above peaks of kaolinite (K), mica-illite (M), and smectite (S) for each sample. Values in parentheses are ages of soils (see table 1).

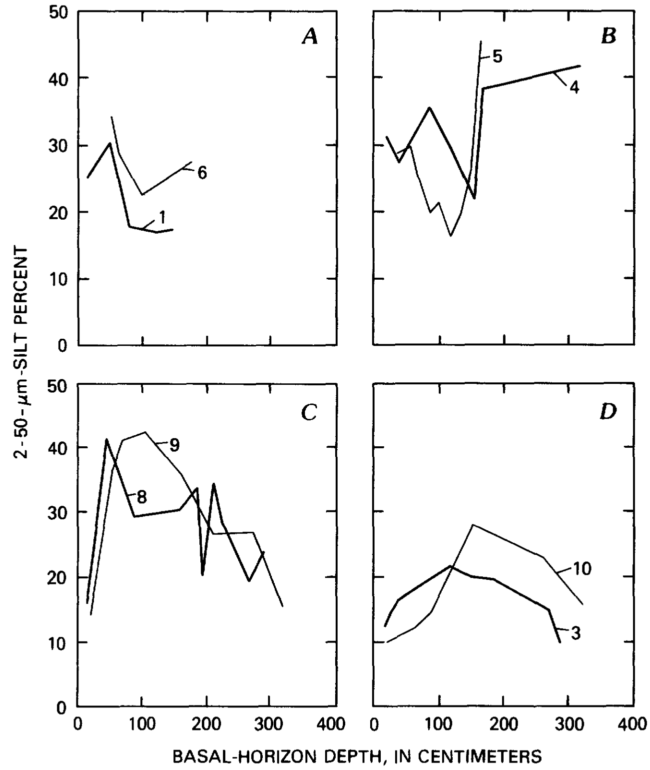

Figure 8. Percent silt versus basal-horizon depth for four age groups of Ventura soils. A, Soils in post-Sea Cliff marine terrace (approx 2 ka). B, Soils in Punta Gorda marine terrace (approx 40 ka). C, Soils in Ventura marine terrace (approx 80 ka). D, Soils in Ventura River gravel (approx 80 ka). Numbers denote profiles (see supp. table 2).

units contain less clay than soils in the oldest marine terrace (Ventura). This difference suggests that parent material and, more specifically, rock type and original grain size influence to some extent the content of pedogenic clay. In comparison with the clay content of Merced soils in central California (Harden, in press), Ventura soils of the main terraces contain much more clay for similar-age soils. For example, the 80-ka-old Ventura soils contain about 150 g clay/cm^2, whereas the 130-ka-old Merced soils contain about 90 to 100 g clay/cm^2. To compensate for some of the original clay content among these soils, we subtracted the minimum clay content within each profile from the percent clay of each soil horizon (figs. 6B, 6D). This simplified correction for parent material appears to smooth the time curve or reduce the variation in scatter diagrams, but the Ventura soils still contain more clay than the Merced soils. For example, the 80-ka-old soils now contain 70 to 90 g clay/cm^2 (fig. 6), whereas the 130-ka-old Merced soils contain about 40 to 50 g clay/cm^2 (Harden, in press).

Although the rates of clay accumulation are higher in the Ventura than in the Merced area, there is little mineralogic evidence for inplace clay formation or alteration. Diffractograms of B-horizon clay (see supp. table 8) show virtually no change in the peak heights of different clay types throughout the age range of the marine terraces (fig. 7). The clays of all the marine-terrace soils consist predominantly of smectites, with smaller amounts of mica or illite and kaolinite. Local sources for alluvial and colluvial parent materials are also dominated by these clays (Quaide, 1957; Kerr and others, 1971). The similarity in amounts and types of clay minerals in the different-age soils suggests that the clays either are formed from coarser particles of similar mineralogy or are depositional (rather than pedogenic) and from a consistent source.

Mechanical breakdown of silt and sand may be one source of B-horizon clays in the Ventura soils. If coarser particles were of similar mineralogy, disaggregation or physical breakdown—without chemical weathering—might account for the observed increase in clay content and the absence of clay-mineral transformation. In figure 8, the depth functions of silt appear nearly identical to those of clay (fig. 5); increases and decreases of both size fractions with depth occur in similar horizons. The parallelism and covariance of the silt and clay fractions suggest that these particles were deposited in similar sedimentologic regimes; it also suggests, but does not prove, that significant amounts of pedogenic clay are not forming by breakdown of silt particles. Formation of clay and silt from weathering sand grains might have occurred, as suggested by inverse relation of the general depth trends of silt and clay to that of sand (fig. 9). Alternatively, this proportionality may represent depositional changes between sand-rich and silt- and clay-rich material, or influx of eolian silt and clay with corresponding decrease (dilution) of sand. A slight decrease of silt/clay ratios (fig. 8C) in B horizons suggests that the clays, if a product of mechanical breakdown, are just as likely formed from sand- as from silt-size particles.

One probable origin of B-horizon clays is eolian deposition. Muhs (1980, 1982) studied a series of marine terraces on San Clemente Island to the south of the town of Ventura (fig. 1) and concluded that large volumes of silt and clay had been deposited onto the terraces by Santa Ana winds (a common meteorologic condition due to formation of high-pressure areas to the east of southwestern California, and of any easterly winds that transport material form those areas to the west). The mineralogy of clays in Muhs' dust traps and soils consisted of kaolinite, mica or altered mica, and smectite, as well as feldspar and quartz. Muhs (1980, p. 91) calculated an average annual rate of eolian deposition during a timespan of about 3 ka, although he believed that most of the sediment was generated historically during immigration and settlement. For the Ventura soils of this study, we subtracted the annual volume of eolian clay reported by Muhs from the pedogenic volume of clay (corrected for parent material). The remaining clay might provide a minimum estimate of the clay formed in place in Ventura soils, separately from eolian clay added to the soils. Assuming that eolian deposition was continuous over time throughout the 80-ka age range of the soils (table 2), net clay formed in place is generally lower in Ventura than in Merced soils. Assuming that deposition of eolian clay took place within the past 3 ka (Muhs, 1980, p. 91), then the clay volume of Ventura soils is about the same as that of Merced soils except for soils on the 80-ka-old Ventura terrace, which still contains more clay (table 2).

One argument against an exclusively eolian source for the clays is that the soils on Ventura River gravel do not contain a significant amount of clay in comparison with soils of similar age near Merced. In other words, if excessive amounts of clay were due only to eolian input in Ventura soils, then profiles on the fluvial gravel would also have very high clay contents, which is not the case (fig. 6). This observation is inconsistent, however, because Dembroff and others (1982) and Rockwell (1983) demonstrated rapid rates of clay accumulation in gravelly terraces of the Ventura River upstream from the study area.

Another source for clay in the Ventura soils is local slopewash. Local slopes contain the same clay minerals as the soils and eolian dust, and so it is difficult to distinguish slopewash from materials of eolian and pedogenic origins. Although accretion rates of eolian clays may account for the high clay content of these soils, the soils undoubtedly have inherited some clay from upslope as well.

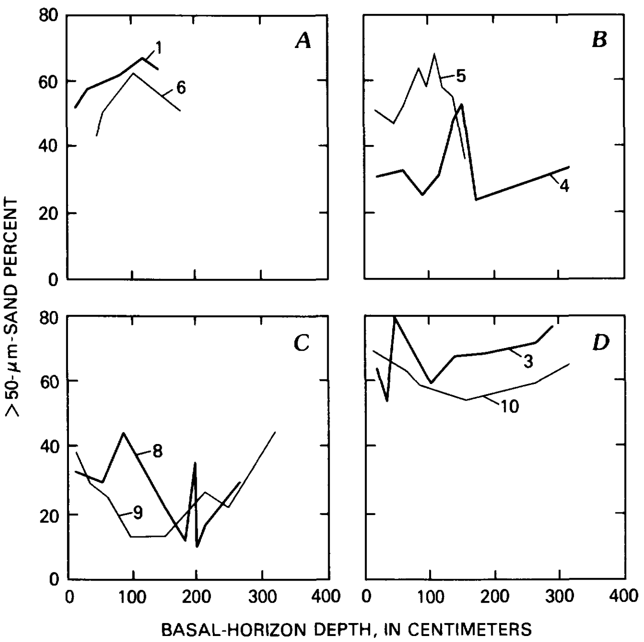

Figure 9. Percent sand versus basal-horizon depth for four age groups of Ventura soils. A, Soils in post-Sea Cliff marine terrace (approx 2 ka). B, Soils in Punta Gorda marine terrace (approx 40 ka). C, Soils in Ventura marine terrace (approx 80 ka). D, Soils in Ventura River gravel (approx 80 ka). Numbers denote profiles (see supp. table 2).

Some Chemical Characteristics of Ventura Soils

Several chemical characteristics of Ventura soils change progressively as a function of estimated soil (surface) age, despite the absence of clay-mineral alteration discussed earlier. Furthermore, Harden and Taylor (1983) demonstrated highly systematic changes in morphology of these soils with age, indicating that the coastal terraces are stable enough to develop soils, at least for the slope positions and age ranges of deposits examined in this study. Chemical characteristics that change most systematically with age include organic-carbon content (very young soils only; see supp. tables 3, 8), total acidity, dithionite-extractable iron (see tables 3, 8), and total Ca, Mg, and Fe of fine size fractions (silt plus clay or less than 47 μm; see supp. tables 6, 8).

Organic-carbon content of these Ventura soils, expressed as the total volume of carbon in the soil (fig. 10), increases significantly in about the first 2 ka; by about 40 ka, the carbon content has declined and apparently reaches a steady state or begins to decrease (figs. 10A, 10C). The change from accumulation to loss of soil carbon occurs sometime between about 2 and 40 ka in Ventura soils. This pattern of accumulation and attrition is documented in other studies that have chronosequences ranging from the Holocene through pre-Holocene, and the change to carbon attrition generally occurs in the middle to early Holocene (Jenny, 1979; Harden, in press). In soil chronosequences that demonstrate a significant

Table 2. Estimates of eolian-clay influx into Ventura soils

[Estimates based on data of Muhs (1981) for dust trap 3 at 31 (g soil/m^2)/yr, or 0.81×10^{-3} (g clay/m^2)/yr. Maximum and minimum estimates for eolian clay are based on maximum and minimum ages, respectively, of Ventura units. Merced data from Harden (in press)]

Sample	Approx. minimum age (ka)	Maximum age (ka)	Clay gained, corrected for parent material (g/cm^2)	Eolian clay (estimated) (g/cm^2) (max)	Eolian clay (estimated) (g/cm^2) (min)	Net clay formed (g/cm^2) (max)	Net clay formed (g/cm^2) (min)	Merced clay (g/cm^3)	Estimated age (ka)
				Assuming that eolian deposition occurred continuously for 105 ka					
V2	0.7	2.5	3.02	0.57	2.03	2.45	0.99	---	---
V1	2.5	5.6	4.35	2.03	4.54	2.32	-.10	---	---
V6	2.5	5.6	7.65	2.03	4.54	5.62	3.11	5.3	3
V4	35	60	39.60	28.35	48.60	11.25	-9.0	---	---
V5	35	60	9.44	28.35	48.60	-18.91	-39.16	25.6	40
V8	60	105	71.50	48.6	85.05	22.90	-13.55	---	---
V9	60	105	93.70	48.6	85.05	45.10	8.65	48.14	130
				Assuming that eolian deposition occurred within the past 3 ka					
V2	0.7	2.5	3.02	0.57	2.03	2.45	0.99	---	---
V1	2.5	5	4.35	2.03	2.43	2.32	1.92	---	---
V6	2.5	5	7.65	2.03	2.43	5.62	5.22	5.3	---
V4	35	60	39.60	2.43	2.43	37.17	37.17	---	---
V5	35	35	9.44	2.43	2.43	7.01	7.01	25.6	---
V8	60	105	71.50	2.43	2.43	69.07	69.07	---	---
V9	60	105	93.70	2.43	2.43	91.27	91.27	48.14	---

increase followed by a decline in soil organic-matter content, soil fertility may increase in the early stages of soil development. At some later stage, a key nutrient(s) or property may then become limiting, causing a decline in the vegetative input to soil organic matter.[2] In Ventura soils, accumulation ceases at or after about 2 ka, but soil carbon does not decline significantly in older soils. Carbon retention and (or) soil fertility apparently are maintained for more than 80 ka after the organic matter is established.

Total acidity (extractable hydrogen) increases with age in the Ventura soils, although variation within age groups is significant in older soils (figs. 10B, 10D). This increase in acidity suggests that leaching of basic cations is effective in these soils, despite the high clay content and salt influx from the ocean.

Increase in dithionite-extractable-iron content with age may indicate recrystallization of Fe from primary minerals into oxide forms, recrystallization of other iron oxides, and (or) influx of iron oxides from eolian or other sources. Dithionite-extractable-iron content (Mehra and Jackson, 1960) increases highly systematically with age, and soils developed in Ventura River gravel contain considerably more Fe than soils of similar age on the Ventura marine terrace (fig. 11A).

[2] Alternatively, the decline in soil carbon content could be related to decomposition, although most studies do not demonstrate a significant change in C/N ratio at the time of the decline.

Total Chemical Analyses of Size Separates

Total chemical analysis of size separates demonstrates the relative concentration of elements and, thus, the chemical differentiation that has occurred in soils of this study. The fine (less than 47 μm) fraction of selected horizons was separated after sonic dispersal (Busacca and others, 1984b) and wet sieving, then analyzed by X-ray fluorescence (see supp. table 3). Two methods were used to examine chemical differentiation over time: the accumulation-series method (Harden, in press), in which relative gains and losses are compared by using elemental ratios and relative ages; and the percent-loss method, which calculates the loss of elements relative to a stable species and a standard (Merrill, 1921).

Relative Rates of Element Loss from Ventura Soils

In the accumulation series methods, described in more detail by Harden (in press), we (1) calculate a ratio of the concentration of each element to that of every other element, (2) rank each ratio from smallest to largest, (3) rank the ages of soils from young to old, and (4) perform linear regression on ranked ratio versus ranked age. If the correlation coefficient (Spearman's rho) is significant for a positive slope, for example, then the element in the numerator is accumulating more rapidly than that in the denominator. Each elemental ratio is tallied into a series. Relative accumulation could be a result of either net gain or concentration relative to the loss of other elements;

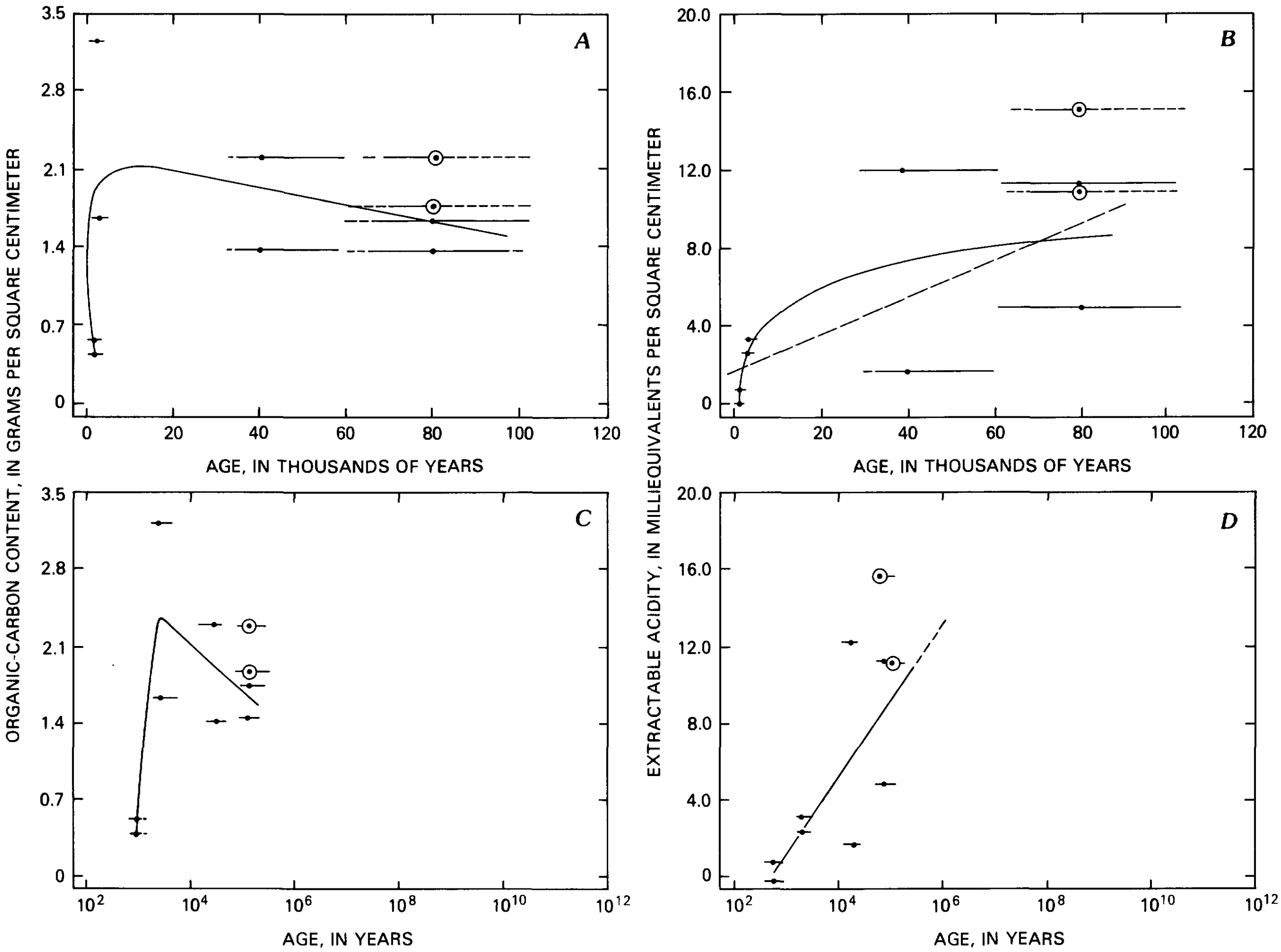

Figure 10. Organic-carbon content (A, C) and extractable acidity (B, D) versus linear (A, B) and log (C, D) age. Percent carbon or milliequivalents of hydrogen were multiplied by horizon thickness (in centimeters) and bulk density (in grams per cubic centimeter), and the products were summed for each profile. Horizontal lines, age uncertainty; dots, best-estimate age of soils on coastal terraces; circled dots, soils developed in Ventura River gravel (see table 1). Solid lines approximate trends of data; dashed lines indicate trends if linear rates are assumed.

relative depletion could be a result of either actual loss or dilution by other incoming species.

There are several advantages to the accumulation-series method over the percent-loss method. First, because each element is examined relative to several other elements, fortuitous correlations of elements that are unrelated to time are generally recognized. Likewise, extreme variation in the content of an element is also recognized. Second, associations of elements—in some cases related to weathering and in other cases to mineralogy or deposition—are recognized as groups whose ratios do or do not correlate over time. Third, the regression is based on ranked or relative ages rather than absolute ages, and so uncertainties associated with absolute age are not of concern. Fourth, curve fitting (for example, by polynomial or exponential functions) is unnecessary because the axes are ranked.

For the fine (less than 47 μm) fraction of soils developed on marine terraces[3], relative accumulations of elements are best defined in A horizons (fig. 12). The alkaline-earth elements Mg and Ca are lost most readily and (or) are being diluted by the net increase of other elements listed to their left in figure 12. Phosphorus is also lost or diluted relative to everything but Ca and Mg. Fe and Mn are intermediate in the series and could be either depleted or stable relative to Si, Al, K, and Na. Relative to soils near Merced, in

[3]The two soils developed in Ventura River gravel were omitted because of their dissimilarity of parent material and because their ages relative to the oldest marine terrace and to each other are somewhat tenuous.

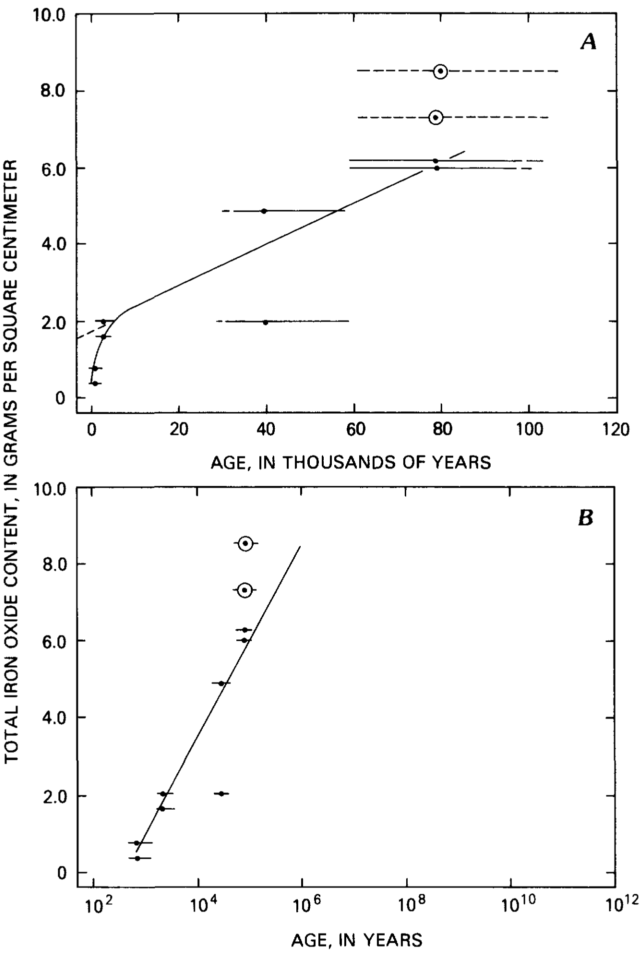

Figure 11. Total iron oxide content in soil profiles versus linear (A) and log (B) age. Dithionite-extractable-iron content (in percent) was multiplied by horizon thickness (in centimeters) and bulk density (in grams per cubic centimeter), and the products were summed for each profile. Horizontal lines, age uncertainty; dots, best-estimate age of soils on coastal terraces; circled dots, soils developed in Ventura River gravel (see table 1). Solid lines approximate trends of data; dashed lines indicate trend if linear rates are assumed.

	Relative accumulation ⟵⟶ Relative depletion or dilution	Comments:
A horizons	⊢Zr, Ti⊣ ⊢——K——⊣ Si>Al>Na>Fe, Mn>Mg>Ca ⊢P⊣	Influx of Si? depletion of Mg, Ca, P
B horizons	⊢Mg, Na, K⊣ Si, Fe, Al>Zr>Ca Ti Mn	Influx of Si, Al, Fe; depletion of Ca; retention of Mg, Na?
C horizons	Na>Si	Influx of Na?

Figure 12. Relative accumulation of elements in fine (silt plus clay) fraction of A, B, and C horizons. Elemental ratios (see supp. table 6) are ranked and correlated with relative age; significant increases/decreases with age are incorporated into accumulation series shown. A series is indicated by elements in a line; elements outside of a series do not show significant gain or loss relative to other elements within the same series. Samples exclude soils in Ventura River gravel (see table 1).

both studies Si is retained relative to Al Na Mg Ca. In Merced soils, Fe accumulates more rapidly than Si, K, Al, and Mg, whereas in Ventura soils, Fe is depleted or diluted relative to these four elements. In Ventura soils, either there is a net influx of Si, K, Al, and Na, or Fe is depleted from this size fraction. If Zr is stable and immobile (Wild, 1961; Barshad, 1964; Busacca, 1982; Harden, in press), then at least some Fe is lost from the fine fraction of A horizons, as are Mn, Mg, and Ca. Alternatively, if some Zr is blowing in, then Fe may be stable or may be blowing in more slowly than Zr. Chemical analyses of airborne dust would help to answer this question.

Trends of elemental ratios over time are less well defined in B and C horizons (fig. 12). In the fine fraction of B horizons, Ventura soils accumulate Si, Fe, and Al and lose Ca relative to Zr; most other elemental ratios do not change significantly over time. As measured in A horizons, Ca is depleted relative to Zr. In contrast to A horizons, there is a net influx of Fe (relative to Zr) into the fine fraction of B horizons. In BC or C horizons, the only significant trend is an increase of Na relative to Si. In A horizons, Si increases relative to Na, and so Na may be leached into C horizons from overlying strata. (Alternatively, A horizons may receive Si from eolian sources.) The absence of significant trends over time in C horizons is probably due to both the varying depth of C horizons (see supp. table 1) and the absence or variation of pedogenic processes at these depths.

Despite the ambiguity of some elemental trends over time, there are some general patterns in the total chemistry that may be the result of soil formation. In A horizons, the composition of the fine fraction appears to be dominated by leaching of the alkaline-earth elements. Zr does not increase relative to any other element, and so without certain evidence for the stability of other elements (such as Fe), we cannot conclude that there is a net gain of any element. Most likely, however, on the basis of the volume of clay that appears to be accumulating in these soils, there is a net gain of not only Si, Al, Na, and K but also Zr and Ti. Analysis of slopewash and eolian materials might help to resolve this question. In B horizons, the net increase of Si, Fe, and Al is probably the result of clay formation and (or) translocation. Ca is lost at a significant rate, as evidenced by its depletion relative to all other elements. The apparent retention of Mg could be due to the presence (and possibly the influx) of smectite.

Both similiarities and differences exist between the trends in Ventura and Merced soils; further study of these soils may resolve the question of eolian influence and the effect of slopewash. Similarities in the analysis of Merced soils (Harden, in press) include the loss of several elements from A horizons relative to Zr, the loss of only the alkaline-earth elements from B-horizon fines, and the apparent gain of Fe, Al, Ti, and, possibly, Si into B-horizon fines. In contrast to Ventura soils, Merced soils show a significant loss of Mg in B horizons (although Mg is lost more slowly than Ca, whereas the reverse is true in A horizons). There is no evidence for the formation of smectite or vermiculite in Merced soils, and so the retention of Mg in Ventura clays may, indeed, be related to the formation or influx of these clay types. Also in contrast to Ventura soils, Merced soils retain Fe in the fine fraction of A horizons. This difference might be a clue to eolian sources or to differences in Fe transformations.

Percent Loss of Elements

The relative accumulation of elements helps to decipher chemical differentiation, but using units for net loss and gain of constituents has the advantage of comparability to other size fractions, horizons, and soils from other areas. Zr is probably the best candidate for a stable or resistant element, on the basis of several studies (Wild, 1961; Barshad, 1964; Busacca, 1982; Harden, in press), and can be used to calculate net losses and gains of other elements (Merrill, 1921). To calculate Ca loss relative to Zr in that horizon, the equation is:

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

$$= 1 - \frac{Ca_{A}Zr_{pm}}{Ca_{pm}Zr_{A}}$$

where pm refers to the parent material and A to the A horizon.

In this calculation, a parent material must also be chosen to calculate the net loss or gain of constituents. One alternative would be to use the C horizon of each soil as the parent material; however, C horizons are weathered or altered to varying degrees (see supp. table 1), owing to their varying depth and age. For example, note the varying dithionite-extractable-iron content in lowermost C horizons (see supp. table 3). The main advantage of using individual C horizons for parent materials is that the variation between parent materials is incorporated directly into the calculation; the disadvantage is that a bias is introduced if the C horizons are weathered to varying degrees.

One standard for all soils can be used to estimate parent material. This method is favorable because the parent material is not biased by weathering. (Percent loss in this case is calculated to one standard, much as laboratory standards are used to standardize experimental results.) Clearly, the main disadvantage to using single common parent material is that variation in parent materials is represented only in replicate soils on units of the same age and in the scatter inherent to time plots; also, the units of percent loss are not meaningful if the standard soil used for parent material is weathered (negative units are not uncommon, even when the time plots suggest net loss of an element). We note that the standard (parent material) used for the calculation can be changed without affecting the slope of the time curves (rates). Much more work is needed to make these calculations more reliable for comparison with other studies.

Merrill's equation was used to calculate the percent loss for four elements that had significant correlations over time relative to Zr (fig. 12). Zr was used as the index, and the elemental composition of sample V2-C2 was used for the parent material. From these calculations, Ca and Mg are lost from the fine fraction of A horizons (fig. 13), and Fe and Al are gained in the B horizons (fig. 14). It is unclear, however, whether the rates of loss and gain are linear or exponential, because there are so few points and because the youngest two units vary and are somewhat similar with respect to percent loss. We examined plots of the residuals (predicted y minus observed y), but there were no obvious biases to indicate that either type of curve is unsuitable. Until more data are available from this or similar areas, rates will not be calculated because of this problem with curve fitting.

Estimating the Rates of Soil Development

This study documents soil development over time, and the next logical use of these data is to estimate the rate at which the soils and their properties develop over a geologic timespan. Properties that change systematically over time are most conducive to estimating rates of development. For the soils of this study, these properties include iron oxide content, clay content, and the soil-development index (using total texture, clay films, rubification, and dry consistence; see Harden and Taylor, 1983). Percent loss of elements (figs. 13, 14) is inappropriate for rate calculations at present because it is unclear whether the rates are linear or exponential and because there is a large uncertainty about parent material.

The paucity of data for Ventura soils makes it difficult to ascertain the type of curve that is most appropriate for estimating rates of soil development. Comparing Ventura with Merced soils helps to consider some possible curve shapes because the Merced study area (Harden, in press) has soils of a very wide age range. For Merced soils, the clay content (fig. 15A) increases nonlinearly; the rates of clay increase appear to be highest at first, then decline in later stages of soil development. Ventura soils contain consistently more clay than Merced soils of similar age (figs. 6, 15), but because there are no early Pleistocene Ventura soils along the coast, it is unclear whether the rate of clay increase in Ventura soils would decline after about 100 ka or so, or whether it would be maintained as a linear function (fig. 15A). The steepest part of the curve for Merced data is in the first 10 ka, after which the slope (rate) falls off significantly.

Time curves for Ventura data (fig. 15) could be either linear or nonlinear over long timespans. Some authors (Reheis, in press) speculate that exponential

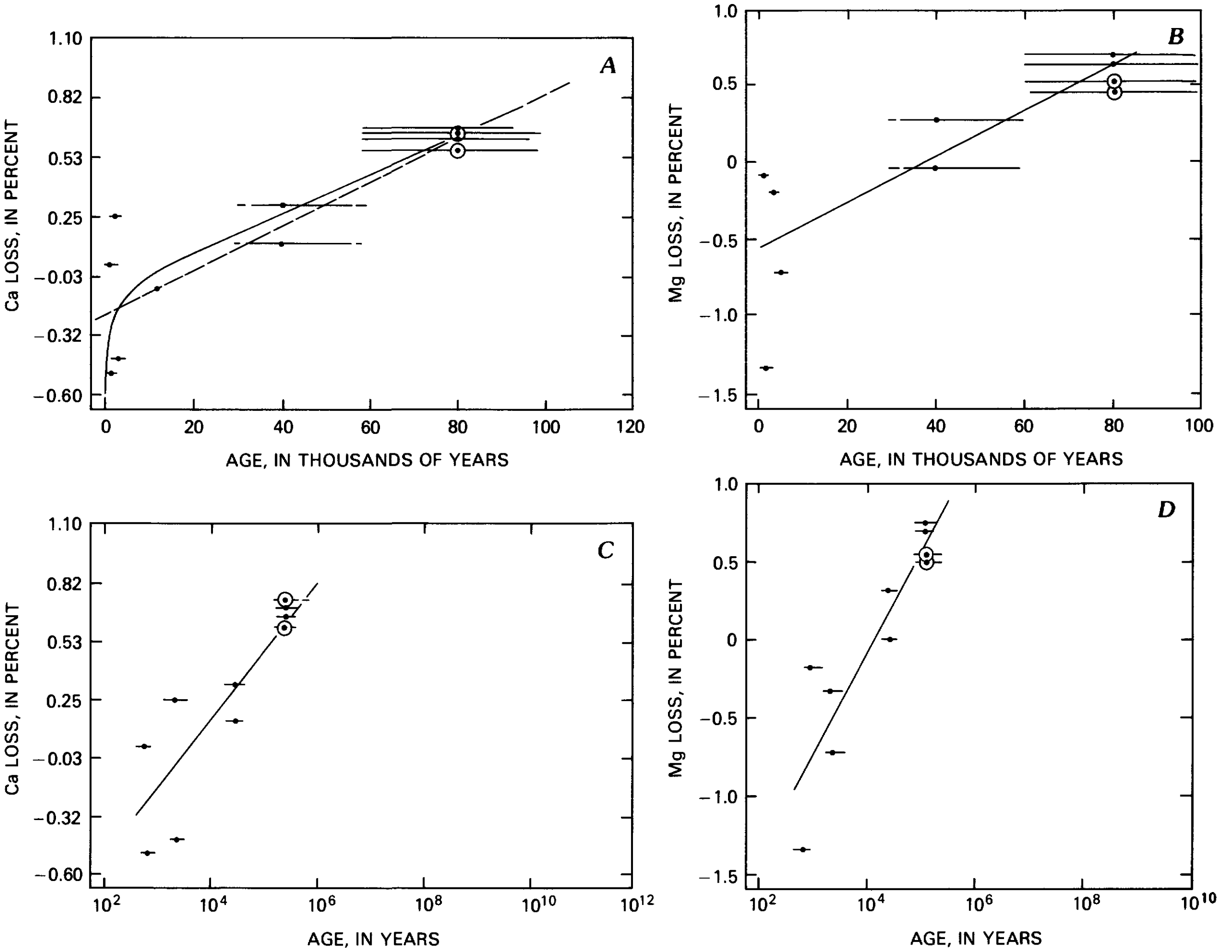

Figure 13. Net losses of Ca (A, C) and Mg (B, D) from fine (silt plus clay) fraction of A horizons versus linear (A, B) and log (C, D) age. Losses calculated according to method of Merrill (1921), using Zr as stable index and sample V2-3C2 as parent material. Horizontal lines, age uncertainty; dots, best-estimate age of soils on coastal terraces; circled dots, soils developed in Ventura River gravel (see table 1). Solid lines (A-D) approximate trends of data; dashed line (A) indicates trend if linear rates are assumed.

rates are typical of weathering processes (Coleman, 1981), whereas linear rates are more typical of eolian accretion rates (Machette, 1985). If eolian input is the dominant process responsible for clay accumulation in Ventura soils and if accretion rates are maintained for geologic timespans, then the rates of clay accumulation at Ventura may be linear and maintained at such high values for long time periods. Both linear and exponential curves are considered below for estimating rates of clay increase. For linear rates, all but the soils on Ventura River gravel are used in regressions, and only Holocene soils of the Merced study are used (Holocene rates are higher than Pliocene and Pleistocene rates at Merced; see fig. 15A; Harden, in press). There is also a question of curve shape for iron oxide content and the soil-development index, and both linear and exponential functions are considered in estimating the rates of these properties (figs. 11, 15C).

As discussed by Harden and Taylor (1983) and Harden (in press), uncertainties in the ages of the deposits must be considered when soil-development rates are calculated. For data in both linear and logarithmic units, we used simple linear regression of a property versus (1) best-estimate ages for all deposits, (2) minimum ages for young and maximum ages for old deposits, and (3) maximum ages for young and minimum ages for old deposits (table 3). The combinations of constraining ages help to estimate minimum and maximum possible rates of soil development, using linear regression.[4]

Both linear and logarithmic transformations were used in regressions for soil-development rates. If the logarithm of age was used for the x-axis, the differ-

[4]Two-error regression (Deming, 1943) would be more suitable, but this model does not allow (or assumes there is no) natural scatter in the regression—clearly inappropriate for soils.

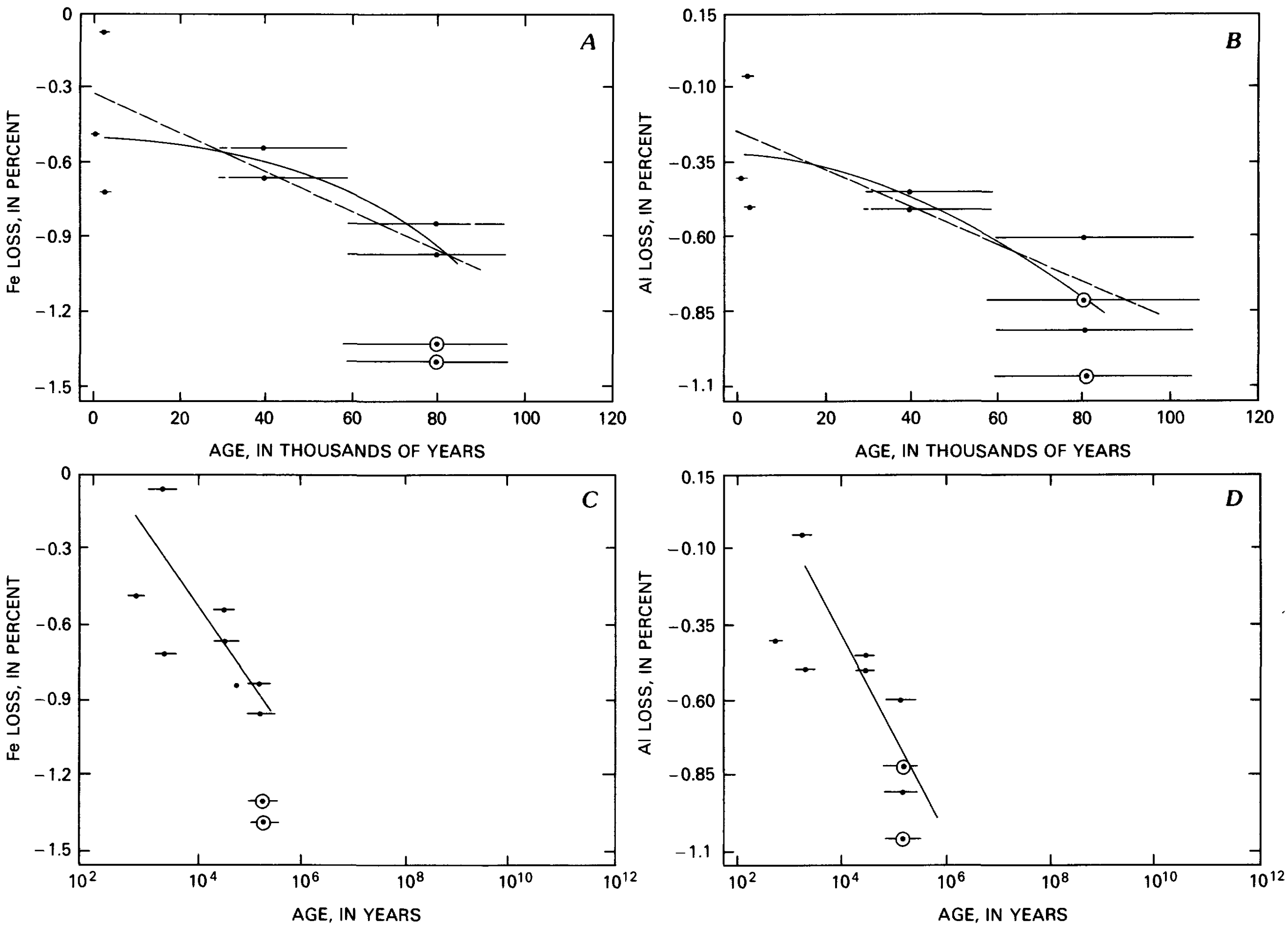

Figure 14. Net gains of Fe (A, C) and Al (B, D) from fine (silt plus clay) fraction of B horizons versus linear (A, B) and log (C, D) age. Losses calculated according to method of Merrill (1921), using Zr as stable index and sample V2-3C2 as parent material. Horizontal lines, age uncertainty; dots, best-estimate age of soils on coastal terraces; circled dots, soils developed in Ventura River gravel (see table 1). Negative slope indicates net gain of an element. Solid lines (A-D) approximate trends of data; dashed lines (A, B) indicate trend if linear rates are assumed.

ences between the youngest two units are considered to be significant and suggest an exponential function (figs. 6, 11). For the soil-development index, the logarithm of soil property was used for the regression because soil property versus logarithm of age was bowl shaped and because the curve straightened out on a log-log plot (Harden and Taylor, 1983). Here, again, the residuals were examined, but no biases toward age were found. The rates reported for these properties (table 3) are constrained to within about 5 percent. In comparison, rates for Merced soils had uncertainties of about 50 percent, mainly because of the larger age uncertainties in ages of those soils.

SUMMARY AND CONCLUSIONS

The systematic change in several soil properties with increasing age indicates that at least some parts of the marine terraces near Ventura were stable enough for soil development to proceed. By studying the flat, relatively preserved parts of the terraces in areas less subject to local slope processes, this study demonstrates that marine terraces could be used to characterize soil development in coastal regimes. The potential for finding datable material at the contact between marine and terrestrial deposits makes the terraces especially useful for studies of the long-term rates of soil development. In addition, new studies on the changes in soil development in different parts of the terrace surfaces may reveal more information on terrace stability and deformation at a larger geographic scale. Because the soils on the Punta Gorda marine terrace are considerably less developed than those on the Ventura terrace, soils can be used to differentiate the marine terraces where other age or correlation criteria cannot be used.

Although the age controls on soils of this study have some limitations, the available ages allow long-term soil-development rates in Ventura to be compared with those in other areas. The increase of clay content in these soils appears to be very rapid in

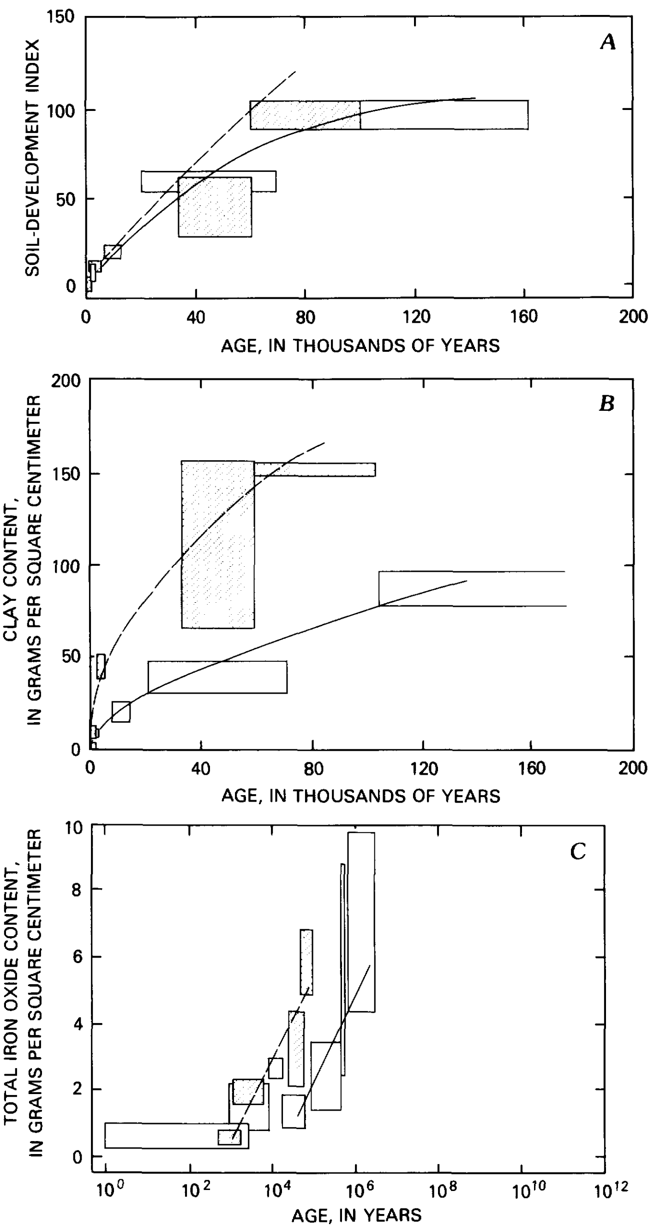

Figure 15. Comparison of soil-development index (A), percent clay (B), and total iron oxide content (C) in Ventura soils (shaded boxes) with those in Merced soils (unshaded boxes). Dithionite-extractable-iron and clay contents were multiplied by horizon thickness and bulk density, and the products were summed for each profile. For each geologic unit, vertical dimension of box represents mean and one standard deviation of all soils in the unit, and horizontal dimension represents age uncertainty. Solid lines approximate trends of data; dashed lines indicate trend if linear rates are assumed.

comparison with clay accumulation in the Central Valley of California. In contrast to this rapid clay accumulation, however, there is no apparent change in clay mineralogy with increasing age. This absence of mineral alteration suggests that the clays are not authigenic and that most of the clay is probably deposited by eolian and slope processes and by physical breakdown of coarser grains.

Many chemical parameters, such as organic-carbon content, extractable acidity, dithionite-extractable-iron content, and total chemical analysis, change with increasing age. Increasing extractable acidity and decreasing total Ca and Mg suggest that the soils are relatively well drained and leached over time. Extractable iron oxides and total analysis of Fe indicate that iron oxides are forming over time but that some Fe may be lost by leaching in A horizons. Some iron oxides may also be deposited with eolian or depositional clays. More mineralogic analyses are needed to distinguish between clay production by in place processes and influx of previously weathered materials to the soil profiles.

REFERENCES CITED

Barshad, Isaac, 1964, Soil development, chap. 1 of Bear, F.E., ed., Chemistry of the soil: New York, Reinhold, p. 1-52.

Bloom, A.L., Broeker, W.S., Chappell, J.M.A., Matthews, R.K., and Mesolella, K.J., 1974, Quaternary sea level fluctuations on a tectonic coast: New $^{230}Th/^{234}U$ dates from the Huron Peninsula, New Guinea: Quaternary Research, v. 4, no. 2, p. 185-205.

Burke, R.M., and Birkeland, P.W., 1979, Reevaluation of multiparameter relative dating techniques and their application to the glacial sequence along the eastern escarpment of the Sierra Nevada, California: Quaternary Research, v. 11, no. 1, p. 21-51.

Busacca, A.J., 1982, Geologic history and soil development, northeastern Sacramento Valley, California: Davis, University of California, Ph.D. thesis, 348 p.

Busacca, A.J., Aniku, J.R., and Singer, M.J., 1984, Dispersion of soils by an ultrasonic method that eliminates probe contact: Soil Science Society of America Journal, v. 48, no. 5, p. 1125-1129.

----- 1984, Dispersion of soils by an ultrasonic method that eliminates probe contact: Soil Science Society of America Journal, v. 48, no. 5, p. 1125-1129.

Colman, S.M., 1981, Rock-weathering rates as functions of time: Quaternary Research, v. 15, p. 250-264.

Dembroff, G.R., 1982, Tectonic geomorphology and soil chronology of the Ventura Avenue Anticline,

Table 3. Estimated rates of soil development

Trial / Unit			Age used for trials (ka) 1	2	3
Post-Sea Cliff II			0.7	1	0.5
Post-Sea Cliff I			2	5.6	1.5
Punta Gorda marine terrace			40	60	30
Ventura marine terrace			80	100	60
Property	**Regression**	**Units**			
Clay ($\underline{n}$=8)	Slope	$(g/cm^2)/\log_{10}$ yr	64.2	67.9	65.2
	$\underline{y}$-intercept	g/cm^2	-172.0	-201.0	-170.0
	$\underline{r}^2$	.01 percent	.716	.70	.714
	$\underline{S}$	g/cm^2	40.0	41.0	43.86
Dithionite-extractable iron.	Slope	$(g/cm^2)/\log_{10}$ yr	2.16	2.29	2.21
	$\underline{y}$-intercept	g/cm^2	-5.53	-6.53	-5.48
	$\underline{r}^2$	.01 percent	.756	.742	.762
	$\underline{S}$	g/cm^2	1.22	1.26	1.21
Soil-development index (SDI).	Slope	$\log_{10}$ SDI/$\log_{10}$ yr	.751	.804	.767
	$\underline{y}$-intercept	$\log_{10}$ SDI	1.76	-2.14	-1.74
	$\underline{r}^2$	.01 percent	.914	.916	.922
	$\underline{S}$	$\log_{10}$ SDI	10.23	.23	.22

Ventura County, California: Santa Barbara, University of California, M.A. thesis, 152 p.

Dembroff, G.R., Johnson, D.L., Keller, E.A., and Rockwell, T.K., 1982, The soil geomorphology and neotectonics of the Ventura River and central Ventura basin, California: American Society of Agronomy-Soil Science Society of America-Geological Society of America annual meeting, Anaheim, Calif., 1982, field guide for soil-geomorphology tour, p. 285-298.

Deming, W.E., 1943, Statistical treatment of data: New York, John Wiley, 261 p.

Dethier, D.T., and Bethel, John, 1981, Surficial deposits along the Cowlitz River near Toledo, Lewis County, Washington: U.S. Geological Survey Open-File Report 81-1043, 10 p.

Harden, J.W., 1982, A quantitative index of soil development from field descriptions: Examples from a chronosequence in central California: Geoderma, v. 28, no. 1, p. 1-28.

----- in press, Soils developed in granitic alluvium near Merced, California: U.S. Geological Survey Bulletin 1590-A.

Harden, J.W., and Marchand, D.E., 1977, The soil chronosequence of the Merced River area [California], in Singer, M.J., ed., Soil development, geomorphology, and Cenozoic history of the northeastern San Joaquin Valley and adjacent areas, California, chap. 6 of American Society of Agronomy-Soil Science Society of America-Geological Society of America, joint field session, 1977, guidebook: Davis, Calif., American Society of Agronomy.

----- 1980, Quaternary stratigraphy and interpretation of soil data from the Auburn, Oroville, and Sonora areas along the Foothills fault system, western Sierra Nevada, California: U.S. Geological Survey Open-File Report 80-30, 57 p.

Harden, J.W., and Taylor, E.M., 1983, A quantitative comparison of soil development in four climatic regimes: Quaternary Research, v. 20, no. 3, p. 342-359.

Hingston, M.S., and Gailitis, V., 1976, The geographic variation of salt precipitated over western Australia: Australian Journal of Soil Science, v. 14, p. 319-335.

Jenny, Hans, 1979, The soil resource: Origin and behavior: New York, Springer-Verlag (Ecological Studies, v. 37), 377 p.

Kerr, P.F., Stroud, R.A., and Drew, I.M., 1971, Clay mobility in landslides, Ventura, California: American Association of Petroleum Geologists Bulletin, v. 55, no. 2, p. 267-291.

Lajoie, K.R., Kern, J.P., Wehmiller, J.F., Kennedy, G.L., Mathieson, S.A., Sarna-Wojcicki, A.M., Yerkes, R.F., and McCrory, P.F., 1979, Quaternary marine shorelines and crustal deformation, San Diego to Santa Barbara, California, in

Abbott, P.L., Geologic excursions in the southern California area: San Diego, Calif., San Diego State University, Department of Geological Sciences, p. 3-15.

Lajoie, K.R., Sarna-Wojcicki, A.M., and Yerkes, R.F., 1982, Quaternary chronology and rates of crustal deformation in the Ventura area, California, in Neotectonics of the Ventura basin, field trip 3 of Cooper, J.D., compiler, Neotectonics in southern California: Geological Society of America, Cordilleran Section annual meeting, 78th, Anaheim, Calif., volume and guidebook, p. 43-51.

Machette, M.N., 1983, Geologic map of the southwest quarter of the Beaver quadrangle, Beaver County, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1444, scale 1:24,000.

----- 1985, Calcic soils of the southwestern United States, in Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 11-22.

Machette, M.N., and Personius, S.F., 1984, Map of Quaternary and Pliocene faults in the eastern part of the Aztec 1^{o} by 2^{o} quadrangle and the western part of the Raton 1^{o} x 2^{o} quadrangle, northern New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-1465-B, 14 p., scale 1:250,000.

Machette, M.N., and Steven, T.A., 1983, Geologic map of the northwest quarter of the Beaver quadrangle, Beaver County: U.S. Geological Survey Miscellaneous Investigations Series Map I-1445, scale 1:24,000.

Machette, M.N., Steven, T.A., Cunningham, C.G., and Anderson, J.J., 1983, Geologic map of the Beaver quadrangle, Beaver and Piute Counties, Utah: U.S. Geological Survey Miscellaneous Investigations Series Map I-1520, scale 1:50,000.

Marchand, D.E., and Allwardt, Alan, 1981, Late Cenozoic stratigraphic units, northwestern San Joaquin Valley, California: U.S. Geological Survey Bulletin 1470, 70 p.

Mehra, O.P., and Jackson, M.L., 1960, Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate: Clays and Clay Minerals v. 7 , p. 317-327.

Meixner, R.E., and Singer, M.J., 1981, Use of field morphology rating system to evaluate soil formation and discontinuities: Soil Science, v. 131, no. 2, p. 114-123.

Merrill, G.P., 1921, Rocks, rock weathering, and soils: New York, Macmillan, 241 p.

Muhs, D.R., 1980, Quaternary stratigraphy and soil development, San Clemente Island, California: Boulder, University of Colorado, Ph.D. thesis, 255 p.

----- 1982, A soil chronosequence on Quaternary marine terraces, San Clemente Island, California: Geoderma, v. 28, no. 3-4, p. 257-283.

Natland, M.L., 1952, Pleistocene and Pliocene stratigraphy of southern California: Los Angeles, University of California, Ph.D. thesis, 165 p.

Palmer, L.A., 1967, Marine terraces of California, Oregon and Washington: Los Angeles, University of California, Ph.D. thesis, 308 p.

Putnam, W.C., 1942, Geomorphology of the Ventura region, California: Geological Society of America Bulletin, v. 53, no. 5, p. 691-754.

Quaide, W.L., 1957, Clay minerals from the Ventura Basin, California: Journal of Sedimentary Petrology, v. 27, no. 3, p. 336-341.

Reheis, M.C., 1984, Chronologic and climatic control on soil development, northeastern Bighorn Basin, Wyoming and Montana: Boulder, University of Colorado, Ph.D. thesis, 293 p.

----- in press, Gypsic soils on the Kane alluvial fans, Big Horn County, Wyoming: U.S. Geological Survey Bulletin 1590-C.

Rockwell, T.K., 1983, Soil chronology, geology, and neotectonics of the north central Ventura basin, California: Santa Barbara, University of California, Ph.D. thesis, 522 p.

Sarna-Wojcicki, A.M., Bowman, H.R., Meyer, C.E., Russell, P.C., Asaro, Frank, Michael, Helen, Rowe, J.J., Baedecker, P.A., and McCoy, Gail, 1980, Chemical analysis, correlations, and ages of late Cenozoic tephra units of east-central and southern California: U.S. Geological Survey Open-File Report 80-231, 53 p.

Sarna-Wojcicki, A.M., Williams, K.M., and Yerkes, R.F., 1976, Geology of the Ventura fault, Ventura County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-781, scale 1:6,000, 3 sheets.

Singer, M.J., and Janitzky, Peter, eds., 1986, Field and laboratory procedures used in a soil chronosequence study: U.S. Geological Survey Bulletin 1648, 49 p.

Soil Survey staff, 1975, Soil taxonomy--a basic system of soil classification for making and interpreting soil surveys: U.S. Department of Agriculture Handbook 436, 154 p.

Walker, A.L., 1983, The effects of magnetite on oxalate- and dithonite-extractable iron: Soil Science Society of America Journal, v. 47, no. 5, p. 1022-1026.

Wild, A., 1961, Loss of zirconium from 12 soils derived from granite: Australian Journal of Agricultural Resources, v. 12, p. 230-305.

Yaalon, D.H., and Lomas, J., 1970, Factors controlling the supply and chemical composition of aerosols in a near-shore and coastal environment: Agricultural Metereology, v. 7, p. 443-454.

Yeats, R.S., 1977, High rates of vertical crustal movement near Ventura, California: Science, v. 196, no. 4287, p. 295-298.

Yerkes, R.F., and Lee, W.H.K., 1979, Late Quaternary deformation in the western Transverse Ranges, California: U.S. Geological Survey Circular 799-B, p. 27-37.

Yerkes, R.F., Sarna-Wojcicki, A.M., and Lajoie, K.R., in press, Geology and Quaternary deformation of the Ventura area, Ventura County, California: U.S. Geological Survey Professional Paper 1339.

SUPPLEMENTARY TABLES

[See Singer and Janitzky (1986) for analytical methods]

Supplementary Table 1. Field descriptions

EXPLANATION

(see Soil Survey staff, 1975)

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
		abk, 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

Supplementary Table 1. Field descriptions—Continued

[Analyst: J.W. Harden, U.S. Geological Survey; and others]

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
								Alluvium, 0.7 Ka									
1	V2	A	5	c,w	10YR3/3	--	SL	1 m gr	--	fr	ss,po	3m,2f	2m tub	0	7.4	SL	so,po
2		2C1	39	c,s	2.5Y3.5/4	--	SL	m	--	fr	ss,ps	3m,2f, 1co	--	0	7.6	SL	so,po
3		3C2	60+	--	2.5Y6/4	--	SL	m-sg	--	fr	so,po	1m	--	0	7.6	SL	so,po
	V7	spoil	14	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4		A11	55	diff	--	--	LS	sg	--	lo	so,po	--	--	0	7.6	LS	so,po
5		A12	74	a	--	--	LS	sg	--	lo	so,po	--	--	0	7.8	LS	so,po
		2C	100	--	--	--	cobC	--	--	--	--	--	3f,3vf tub	0	--	--	so,po
								Alluvium, 2 Ka									
6	V1	A11	17	diff	10YR3/1	10YR4/2	SCL	2m gr, 1 f sbk	sh	lo	ss,po	2m,2f	2m, 1f tub	0	7.2	SCL	ss,po
7		A12	53	g,w	10YR3/1	10YR5/2	SCL	2 m gr, 1 m sbk	--	lo	ss,po	2m,2f, 1co	2m,2f, tub	0	6.8 7.0	SCL	ss,po
8		A13	82	g,i-w	10YR3/2 10YR4/3	2.5Y6/4	SL	m,1 m sbk	--	lo	ss,po	2m,2f, 1co	2m,2f, 1vf tub	0	--	SL	ss,po
9		A+C	120	g,w	2.5Y5/4	--	SL	m	--	lo	ss,po	1co, 1m	2m,2f, 1vf tub	0	--	SL	ss,po
10		C1ca	140	s,a	2.5Y5/4	2.5Y7/4	SL	m	--	lo	ss,po	--	2vf tub	0	8.2	SL	ss,po
		2C2ca	160	--	--	--	SL	--	--	--	--	--	--	0	8.2	SL	ss,po
11	V6	A11	50	g,w	10YR2/1	10YR3/2	L	2 m gr, 1 m sbk	sh	lo	ss,po	3f,3vf, 2m	3f, 2mtub	0	7.3	L	ss,po
12		A12	60	g,w	10YR2/1	10YR3/2	L	--	lo	lo	ss,po	1f,1vf, 3vf	2f,2vf tub	0	7.5	L	ss,po
13		C1ca	100	--	2.5Y4/2	2.5Y6/4	SL	--	--	lo	ss,po	--	3vf, 2ftub	0	8.2	SL	ss,po
14		2C2ca	115+	--	2.5Y5/4	2.5Y7/4	L	--	--	--	s,ps	--	--	0	8.2	L	ss,po
								Alluvium, 40 Ka									
15	V4	A11	20	d,w	--	--	CL	2 m pr, 1f sbk	vh	vfi	vs,pv	3vf, 2f	2f,2vf tub	0	--	CL	vs,pv
16		A12	53	gr,w	--	--	CL	m pr	vh	vfi	vs,pv	3vf, 2f	1f,1vf tub	0	--	CL	vs,pv
17		A13	83	c,w	--	--	CL	1 m abk	--	fi	vs,pv	1f, 1vf	1f,1vf tub	0	--	CL	vs,pv
18		2B2t	115	c,s	--	--	CL	1 m abk	--	--	vs,pv	2f	2-3f, 1vftub	2nbrw	--	CL	vs,pv
19		3B31t	131	c,s	--	--	SCL	m	--	fi	s,p	1-2f	3f, 2mtub	2mkbrw, 2mkpo	--	SL	ss,po
20		4B32t	141	c,s	--	--	SCL	--	--	lo	ss,po		1ftub	0	--	SL	ss,po
21		5B33t	158	--	--	--	CL	--	--	--	s,ps	--	3ftub	2nbr, 2npo, 1mkbrw	--	SL	ss,po
		6C	300	--	--	--	SL	--	--	--	--	--	--	0	--	SL	ss,po
22		7C	310	--	--	--	L	--	--	--	--	--	--	0	--	L	ss,po
23	V5	A11	17	c,w	10YR3/1	10YR4/2	L	2 f pr	vh	fi	s,p	1f, 1vf	1v,1vf, 1mtub	0	--	L	s,p
24		A12	51	c,w	10YR3/1	10YR4/2	L	2 f sbk	sh	fr	s,p	2f,1m	3m 2ftub 1vfint	0	--	L	s,p
25		A3	60	a,i	10YR3/3	10YR4/3	SL	1 f sbk	sh	fr	s,p	2f,1m	3m, 3ftub	0	--	SL	ss,po
26		2B1	79	c,w	7.5YR5/4	10YR6/4	SL	m, 1 f abk	--	fr	ss,po	--	3f, 2mtub	1npo, 1nbrw	--	SL	ss,po
27		2B21t	98	c,w	7.5YR5/4	7.5YR6/4	SCL	m, 1 f abk	--	fr	ss,ps	1f	3f,2m tub	1mkbrw, 1npo, 2nbrw	--	SL	ss,po
28		3B22t	106	c,w	--	--	SL	m, 1 f abk	--	fr	ss,po	1f	2vfint, 1ftub	2nbrw	--	SL	ss,po
29		4B23t	118	c,w	--	--	SCL	m, 1 f abk	--	fr	s,p	--	2f,1m tub	2mkbr, 2mkpo, 1kbrw			
30		5B31	129	c,w	--	--	SCL	m, 1 f abk	--	--	ss,po	--	2vfint, 1f tub	0	--	SL	ss,po
30		6B32	134	c,w	--	--	SCL	m, 1 f abk	--	--	s,p	--	2f,1m tub	0	--	SL	ss,po
30		7B33	149	c,w	--	--	SCL	m, 1 f abk	--	--	ss,po	--	2vfint, 1ftub	3nbr	--	SL	ss,po
31		8C	155	--	--	--	L	--	--	--	--	--	--	0	--	L	ss,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
Alluvium over Marine Terrace, 80 ka																	
36	V8	A11	2.5	c,w	10YR3/1	10YR5/3	L	2 m g r	h	fi	s,po	3f,3vf	--	0	--	L	s,po
		A12	17	c,w	10YR3/1	10YR5/3	L	2 c sbk	vh	vfi	s,po	2f,2vt	2f,2vf, 1mtub	0	--	L	s,po
37		2A3	54	g,w	7.5YR3/2	--	C	1 m pr, 1 m sbk	vh	vfi	vs,pv	1f,1vf 1vf	1f 1mtub	0	--	L	s,po
38		3B21t	9D	g,w	7.5YR4/4 7.5YR5/4 7.5YR3/2	--	CL	1 f pr	vh	vfi	vs,pv		1f, 1vftub	1nbrw, 1nbrpo	--	L	s,po
39		4B22tca	152	c,w	7.5YR4/4	7.5YR5/4	CL	2 f pr	vh	vfi	vs,pv	1f	1f,1vf tub	3mkpf	--	L	s,po
40		5B31ca	183	c,w	7.5YR4/4 7.5YR5/6	7.5YR5/4	SiCL	2 f pr	h	fi	vs,pv	1vf	3f,2m tub	3mkbr, 3mkbf, 3mkpo	--	L	ss,po
41		6B32ca	190	c,w	10YR4/4	10YR5/6	L	1 f sbk	sh	fi	s,ps	1vf	3f,2m tub	1nbrw	--	L	ss,po
42		7B33ca	200	c,w	7.5YR4/4	7.5YR5/4	SiCL	1 f pr	vh	vfi	vs,pv	1vf	3f,2m tub	1nbrw, 3mkpf	--	L	ss,po
43		8B34ca buried?	217	c,w	10YR4/4 7.5YR4/4	10YR6/6	SiCL	m	vh	fi	ss,po	1vf	3f,2m tub	1--2mkpo, 1--2mkbrw	--	L	ss,po
44		9C1ca buried?	269		10YR4/4	10YR6/4	L	m	h	fi	ss,po	--	1-2f tub	1nbrw	--	L	ss,po
45		10C2ca buried?	300	--	--	--	L	--	--	--	--	--	--	0	--	L	ss,po
46	V9	A1	13	g,w	10YR3/2	10YR5/3	L	2 m sbk	vh	fi	ss,po	2f,2vf	3f,1vf, tub	0	6.6	L	ss,po
47		2A3	47	g,w	7.5YR3/2	7.5YR5/3	CL	2 m pr	vh	fi	so,pv	1-2f, 1-2vf vf	2f,2 vfi, 1mtub	0	7.6	L	ss,po
48		2B21t	68	g,w	7.5YR4/4	--	C	2 m pr	vh	fi	so,pv	1f,1vf	1m,1f, 1vftub	1nbrw	7.6	L	ss,po
49		3B22t	100	g,w	10YR4/4	10YR5/4	SiC	2 m pr	vh	fr	--	1vf	2f, 2 vf, 1mtub	2mkbrw	--	L	ss,po
50		4B31t	157	g,w	10YR4/4 2.5Y4/4	10YR6/6 10YR5/4	SiC	1 f pr	vh	fi	vs,pv	1vf	1f,1vf tub	3mkbr 2kpf	--	L	ss,po
51		5B32t	201	--	10YR4/4	10YR6/6	SL	1 f pr	sh	fr	ss,po	--	3f,2m tub	1nbrw	--	L	ss,po
52		5B33ca	266	--	10YR5/4	10YR6/6	L	c sbk	--	--	--	--	3m,2co tub	1nbrw, 1npo	--	L	ss,po
53		6Cca	311	--	2.5Y5/4	2.5Y7/4	L	sg	--	--	--	--	--	0	--	L	ss,po
Alluvium, 80 ka																	
54	V3	A11	7	c,w	10YR3/2	10YR5/3	SL	3 m gr	sh	fr	so,po	3vf, 2m	2vftub	0	--	SL	so,po
55		A12	25	g,	10YR3/2	10YR5/3	SL	2 m sbk	sh	fr	so,po	2vf, 2f,2m	3vf, 2mtub	0	--	SL	so,po
56		A31	33	g,w	10YR3/3	10YR4/3	SL	1f m sbk	sh	fi	ss,ps	2vf, 1f,1m	2vf, 2f,2mtub	0	--	SL	so,po
56		A32	58	c,w	7.5YR4/2	--	SCL	1f m sbk	sh	fi	ss,ps	2vf, 1m	2-3vf, 2f,1m tub	0	--	SL	so,po
57		2B2t	112	g,w	5YR4/6	--	SCL	m,1 m sbk	--	fr-fi	s,p	1vf	3vf, 2ftuh	4mkbr, 3kbrw	--	SL	so,po
58		2B31t	147	g,w	5YR4/6 7.5YR5/6	--	SCL	m,1 m sbk	--	lo	s,p	--	3vf, 2ftub	3n-mkbr, 1mkhrw	--	SL	so,po
59		3B32t	182	--	5YR4/4 7.5YR5/6	--	SCL	sg	--	lo	ss,po	--	1ftub	3nbr, 1kbrw	--	SL	so,po
60		3Cox	272	--	7.5YR5/6	--	SL	sg	--	lo	so,po	--	--	--	--	SL	so,po
61		4C2ox	280	--	7.5YR5/6	--	SL	sg	--	lo		--	--	--	--	SL	so,po
62	V10	A11	6	c,w	--	--	SL	m	--	--	--	--	--	--		SL	--, --
63		A12	62	c,w	--	--	SL	m	--	--	--	--	--	--	--	SL	--, --
64		B1t	88	d,i	--	--	SL	m	--	--	--	--	--	--	--	SL	--, --
65		2B21t	152	g,w	--	--	SL	m, m-c pr	--	--	--	--	--	--	--	SL	--, --
66		3B31t	260	g,w	--	--	SL	m	--	--	--	--	--	--	--	SL	--, --
67		4B32t	300+	--	--	--	SL	m	--	--	--	--	--	--	--	SL	--, --

Supplementary Table 2. Physical properties

[Analysts: J.Baker, R. Johnson, J. Lindsay, B. McCall, H.G. Rose, G. Sellers, J.Taggert, J.S. Wahlberg]

					Percentage of <2-mm fraction								
No.	Sample	Horizon	Basal depth (cm)	>2 mm	Total sand	vco sand	co sand	m sand	fi+vfi sand	Silt	<2-µm clay	<1-µm clay	Bulk density (g/cm^3)
						Alluvium, 0.7 ka							
1	V2	A	5	0	63.1	1.9	6.2	7.3	47.6	18.8	18.1	15.1	1.34
2	V2	2C1	39	0	61.9	2.9	6.7	8.3	44.0	21.7	16.3	13.1	1.65
3	V2	3C2	60+	0	74.8	2.2	14.2	14.4	44.1	13.4	11.B	9.4	1.63
4	V7	A11	55	0	86.1	0.6	5.7	28.3	51.5	7.4	6.5	6.2	1.71
5	V7	A12	74	0	B7.8	1.0	6.3	28.3	52.2	6.7	5.5	4.8	1.54
						Alluvium, 2 ka							
6	V1	A11	17	0	53.1	1.6	4.9	6.6	40.0	26.5	20.4	16.6	1.40
7	V1	A12	53	0	57.4	1.3	5.2	7.0	44.0	22.0	20.6	17.3	1.40
8	V1	A13	82	0	62.5	1.0	5.0	7.4	49.0	18.8	18.7	15.1	1.38
9	V1	A+C	120	0	65.7	0.8	5.4	8.0	51.6	17.8	16.5	13.7	1.32
10	V1	C1ca	160	0	63.8	0.3	1.8	4.2	57.6	18.2	18.0	14.1	1.52
11	V6	A11	50	0	44.3	2.2	4.6	5.1	32.4	34.1	21.5	17.6	1.35
12	V6	A12	60	0	50.9	2.4	5.6	6.9	36.1	29.5	19.6	16.9	1.44
13	V6	C1ca	100	0	61.6	9.3	12.2	8.3	31.8	22.2	16.2	13.7	1.74
14	V6	2C2ca	115	0	50.9	4.6	7.1	5.9	33.3	28.9	20.2	16.4	1.15
						Alluvium, 40 ka							
15	V4	A11	20	0	31.3	0.1	0.2	0.4	30.7	31.1	37.5	32.8	1.74
16	V4	A12	53	0	33.7	0.1	0.1	0.4	33.0	27.4	38.9	33.6	1.76
17	V4	A13	83	0	25.4	0.2	0.2	0.4	24.7	34.7	39.9	34.3	1.84
18	V4	2B2t	115	0	31.5	0.1	0.3	0.5	30.5	29.8	38.7	33.6	1.63
19	V4	3B31t	131	5-10	47.3	1.2	1.3	1.4	43.4	25.3	27.4	22.1	1.56
20	V4	4B32t	141	5	50.1	0.3	0.7	1.1	55.0	22.8	20.1	16.4	1.64
21	V4	5B33t	158	5-10	23.7	0.4	0.4	0.4	22.6	39.2	37.1	29.7	1.58
22	V4	7C only	310	0	37.2	0.0	0.3	0.4	36.5	41.3	21.5	16.6	1.42
23	V5	A11	17	0	50.4	0.3	2.3	5.4	42.4	28.0	21.6	17.5	1.54
24	V5	A12	51	0	48.0	0.4	2.4	5.3	34.9	30.5	21.5	17.6	1.48
25	V5	A3	60	0	54.4	0.3	2.6	5.9	45.6	26.1	19.5	15.5	1.60
26	V5	2B1	79	5	64.2	0.9	5.1	8.1	50.0	20.3	15.5	12.2	1.72
27	V5	2B21t	98	5	57.7	1.2	4.2	6.9	45.4	22.1	20.2	16.9	1.72
28	V5	3B22t	106	1-2	67.5	0.9	2.9	5.7	57.9	17.3	15.2	12.1	1.72
29	V5	4B23t	118	0	56.9	0.8	2.6	4.7	40.6	19.8	23.3	18.6	1.78
30	V5	5B31-7B33	149	0	56.8	1.5	4.6	9.1	41.6	26.9	16.3	13.8	1.73
31	V5	8C	155+	0	37.9	0.1	0.6	2.3	35.0	47.0	15.1	10.2	1.92
32	V5N	A11	23	0	46.0	0.5	2.7	4.8	37.9	33.0	21.0	18.9	1.50
33	V5N	B21t	54	0	36.5	0.2	2.1	3.9	30.2	32.3	31.2	28.8	1.78
34	V5N	B3	89	0	31.2	0.1	1.3	2.7	27.1	37.1	31.7	27.6	1.76
35	V5N	2C1ox	100+	0	54.8	0.2	4.3	7.5	42.8	31.0	14.2	11.7	1.74

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-µm clay	<1-µm clay	Bulk density (g/cm^3)
					Alluvium over Marine Terrace, 80 ka								
36	V8	A11	2.5	5-10	37.8	0.3	0.7	1.4	35.3	45.3	16.9	14.8	1.53
37	V8	2A3 only	54	0	31.2	0.2	1.5	2.5	27.1	27.5	41.3	39.0	1.84
38	V8	3B21t	90	0	45.2	1.9	5.2	6.2	31.9	25.8	29.0	26.6	1.86
39	V8	4B22tca	152	0	22.1	0.1	0.9	1.8	19.3	46.3	31.6	28.0	1.81
40	V8	5B31ca	183	0	10.4	0.0	0.2	0.3	9.9	54.8	34.7	29.2	1.70
41	V8	6B32ca	190	0	34.8	0.0	0.0	0.1	34.6	46.6	18.7	16.1	1.64
42	V8	7B33ca buried?	200	0	9.9	0.0	0.0	0.1	9.8	52.3	37.7	30.9	1.64
43	V8	BB34ca buried?	217	0	18.5	0.0	0.1	0.2	18.2	53.4	28.1	23.4	1.56
44	V8	9C1ca buried?	269	0	34.0	0.3	0.7	1.4	31.6	45.6	20.4	16.8	1.58
45	V8	10C2ca buried?	300	0	27.9	1.0	1.1	1.2	24.5	47.1	25.0	20.3	1.55
46	V9	A1	13	0	39.8	0.6	1.4	2.1	35.5	42.5	17.7	14.6	1.60
47	V9	2A3	47	--	30.0	0.4	1.4	2.5	25.7	33.2	36.7	33.2	1.87
48	V9	2B21t	68	--	25.9	0.3	1.2	2.4	22.0	33.5	40.6	36.8	1.86
49	V9	3B22t	100	--	13.5	0.0	0.4	0.9	12.2	44.7	41.8	35.9	1.85
50	V9	4B31t	157	--	16.6	0.1	0.3	0.7	15.6	4B.3	35.1	31.2	1.60
51	V9	5B32t	201	--	28.2	0.2	0.4	1.0	26.7	46.9	24.9	20.7	1.56
52	V9	5B33ca	266	--	27.4	0.7	0.5	0.6	35.6	47.7	24.9	20.2	1.52
53	V9	6Cca	311	--	46.3	0.2	0.5	0.7	44.7	39.1	14.6	11.9	1.52
					Alluvium, 80 ka								
54	V3	A11	7	5	64.0	2.6	6.1	6.7	48.5	23.8	12.2	9.1	1.34
55	V3	A12	25	60	55.5	1.9	5.4	6.4	41.7	30.2	14.3	10.8	1.44
56	V3	A31&A32	58	60	57.6	2.6	6.7	6.6	41.8	25.0	17.4	13.9	1.48
57	V3	2B2t	112	5	60.7	6.5	13.8	10.2	30.2	15.7	23.6	20.8	1.84
58	V3	2B31t	147	5	67.6	11.8	21.7	14.2	20.0	13.2	19.2	16.3	1.80
59	V3	3B32t	182	55	67.3	16.8	18.7	11.2	20.6	13.8	18.9	16.1	1.72
60	V3	3Cox	272	65	73.4	18.8	19.9	13.2	21.5	11.8	14.8	12.6	1.82
61	V3	4C2ox	280	5	77.2	7.5	29.5	21.2	19.1	12.4	10.4	8.0	1.57
62	V10	A11	6	50	67.8	1.6	5.8	8.0	52.3	21.5	10.7	8.3	1.33
63	V10	A12	62	50	63.4	1.1	5.4	7.6	49.2	24.2	12.4	9.6	1.47
64	V10	B1t	88	50	59.1	3.6	8.5	7.4	39.5	26.1	14.9	11.6	1.88
65	V10	2B21t	152	25	54.7	4.4	11.4	7.5	31.4	17.3	28.0	25.6	1.94
66	V10	3B31t	260	70	60.4	9.2	15.6	9.6	25.9	16.5	23.1	20.7	1.88
67	V10	4B32t	300+	50	65.9	8.8	14.8	10.0	32.3	17.6	16.5	14.4	2.06

Supplementary Table 3. Extractive chemical analyses

[CEC, cation-exchange capacity. Analysts: P. Janitzky, R. Meikner under M.J. Singer, University of California, Davis]

No.	Sample	Horizon	Basal depth (cm)	Percentage of <2-mm: Total N	Percentage of <2-mm: Organic C	meq/100g soil: Exchange Na	meq/100g soil: Exchange K	meq/100g soil: Exchange Ca	meq/100g soil: Exchange Mg	meq/100g soil: Exchange H	meq/100g soil: CEC	pH 1:1 H_2O	Percentage of <2-mm: Fe_d	Percentage of <2-mm: Al_d
							Alluvium, 0.7 ka							
1	V2	A	5	--	2.74	1.42	2.01	17.35	2.80	0.48	20.10	6.96	0.79	--
2	V2	2C1	39	--	0.37	1.33	0.86	10.70	1.40	--	9.95	7.78	0.82	--
3	V2	3C2	60+	--	0.22	1.37	0.57	8.48	1.07	--	6.77	7.79	0.67	--
4	V7	A11	55	--	0.66	0.00	0.45	6.91	1.75	0.48	9.54	7.72	8.38	--
5	V7	A12	74	--	0.44	0.06	0.28	5.36	2.22	0.84	7.52	7.36	0.34	--
							Alluvium, 2 ka							
6	V1	A11	17	--	2.32	1.12	1.63	14.47	3.62	2.25	24.24	6.80	0.87	--
7	V1	A12	53	--	1.17	1.37	1.08	12.01	3.64	2.13	20.35	6.81	0.90	--
8	V1	A13	82	--	0.61	1.01	0.52	11.08	3.60	1.37	17.07	7.09	0.87	--
9	V1	A+C	120	--	0.45	1.06	0.52	11.26	2.57	0.08	12.47	7.82	0.83	--
10	V1	C1ca	160	--	0.24	0.97	0.52	12.01	3.43	--	11.06	8.24	0.79	--
11	V6	A11	50	--	3.22	0.11	1.52	22.33	3.87	4.06	31.51	6.69	0.99	--
12	V6	A12	60	--	1.50	0.00	1.02	19.22	2.41	1.29	21.36	7.45	0.93	--
13	V6	C1ca	100	--	0.52	0.11	0.53	14.52	1.60	--	10.96	8.36	0.79	--
14	V6	2C2ca	115	--	0.36	1.14	0.77	14.16	2.14	--	10.76	8.63	0.91	--
							Alluvium, 40 ka							
15	V4	A11	20	--	1.82	0.69	1.27	18.41	8.79	4.66	35.49	6.18	0.56	--
16	V4	A12	53	--	1.08	1.74	0.65	20.89	10.16	2.98	36.92	6.56	0.54	--
17	V4	A13	83	--	0.86	3.65	0.51	19.30	10.45	1.89	36.81	7.12	0.55	--
18	V4	2B2t	115	--	0.30	6.09	0.48	16.59	9.35	1.25	32.17	7.16	0.85	--
19	V4	3B31t	131	--	0.12	5.38	0.43	11.08	6.95	2.05	23.18	6.31	1.07	--
20	V4	4B32t	141	--	0.10	3.76	0.43	9.59	5.26	2.01	19.14	6.37	0.89	--
21	V4	5B33t	158	--	0.10	6.09	0.48	15.23	8.90	2.53	31.16	6.31	1.15	--
22	V4	7C only	310	--	0.08	3.70	0.29	11.93	5.47	0.88	20.60	6.80	0.96	--
23	V5	A11	17	--	1.71	0.38	1.02	15.36	2.73	2.01	23.79	7.03	0.76	--
24	V5	A12	51	--	1.26	1.01	0.82	15.62	3.04	0.45	22.52	7.21	0.74	--
25	V5	A3	60	--	0.78	0.87	0.40	14.27	2.94	1.77	19.70	7.48	0.70	--
26	V5	2B1	79	--	0.24	1.07	0.36	9.59	2.51	1.00	14.80	7.36	0.68	--
27	V5	2B21t	98	--	0.22	0.87	0.40	14.08	3.76	0.80	19.75	7.62	0.92	--
28	V5	3B22t	106	--	0.18	0.87	0.56	9.78	2.82	0.32	14.49	7.92	0.72	--
29	V5	4B23t	118	--	0.17	1.22	0.40	15.23	5.12	0.48	22.07	8.10	1.02	--
30	V5	5B31-7B33	149	--	0.10	1.22	0.36	10.33	3.56	--	11.56	8.35	0.75	--
31	V5	8C	155+	--	0.09	1.42	0.27	8.31	1.75	--	4.19	8.67	0.37	--
32	V5N	A11	23	--	2.46	0.11	1.18	16.68	3.62	3.34	24.29	6.68	0.80	--
33	V5N	B21t	54	--	0.74	0.62	0.37	18.66	7.96	2.53	30.45	7.11	1.23	--
34	V5N	B3	89	--	0.43	2.47	0.37	16.92	8.90	1.21	29.24	7.69	1.37	--
35	V5N	2C1ox	100+	--	0.11	1.14	0.29	5.44	3.43	0.40	11.01	8.34	0.68	--
							Alluvium over Marine Terrace, 80 ka							
36	V8	A11	2.5	--	1.56	0.00	0.86	8.00	3.41	4.10	17.12	6.31	0.80	--
37	V8	2A3 only	54	--	0.71	2.52	0.28	19.90	7.90	3.10	34.44	7.16	1.61	--
38	V8	3B21t	90	--	0.27	3.96	0.12	14.30	5.37	0.88	24.39	8.07	1.75	--
39	V8	4B22tca	152	--	0.14	5.13	0.20	17.24	5.96	0.56	29.69	8.08	1.13	--
40	V8	5B31ca	183	--	0.09	6.33	0.36	16.62	5.82	0.48	30.25	7.85	1.05	--
41	V8	6B32ca	190	--	0.08	3.38	0.20	9.47	3.60	0.52	17.93	7.78	0.79	--
42	V8	7B33ca buried?	200	--	0.13	4.83	0.45	17.91	6.44	1.04	31.76	7.53	1.09	--
43	V8	8B34ca buried?	217	--	0.07	4.83	0.36	15.14	5.06	--	22.07	7.93	0.91	--
44	V8	9C1ca buried?	269	--	0.06	2.81	0.20	13.10	3.66	--	15.45	8.09	0.87	--
45	V8	10C2ca buried?	300	--	0.09	2.81	0.36	14.81	4.01	--	17.12	7.95	1.09	--
46	V9	A1	13	--	1.63	0.00	0.36	8.62	3.86	4.06	18.13	6.29	0.87	--
47	V9	2A3	47	--	0.86	1.97	0.36	16.44	7.07	5.63	31.51	6.69	1.57	--
48	V9	2B21t	68	--	0.67	2.80	0.29	18.82	8.14	7.00	34.64	7.25	1.57	--
49	V9	3B22t	100	--	0.30	6.02	0.36	20.62	9.03	3.38	34.86	7.89	1.29	--
50	V9	4B31t	157	--	0.15	6.37	0.56	15.98	7.61	2.49	30.86	7.87	1.29	--
51	V9	5B32t	201	--	0.10	5.78	0.56	11.85	5.06	0.24	20.60	8.00	1.08	--
52	V9	5B33ca	266	--	0.10	4.64	0.56	13.37	5.08	--	18.33	8.06	1.04	--
53	V9	6Cca	311	--	0.06	2.74	0.56	9.31	3.25	--	11.51	8.14	0.87	--

Supplementary Table 3. Extractive chemical analyses—Continued

No.	Sample	Horizon	Basal depth (cm)	Percentage of <2-mm Total N	Percentage of <2-mm Organic C	meq/100g soil Exchange Na	meq/100g soil Exchange K	meq/100g soil Exchange Ca	meq/100g soil Exchange Mg	meq/100g soil Exchange H	CEC	pH 1:1 H_2O	Percentage of <2-mm Fe_d	Percentage of <2-mm Al_d
						Alluvium, 80 ka								
54	V3	A11	7	--	4.00	0.73	1.63	11.64	2.18	5.87	24.79	6.14	0.87	--
55	V3	A12	25	--	1.66	0.97	1.68	7.57	1.54	4.22	15.55	6.10	0.95	--
56	V3	A31&A32	58	--	1.36	1.01	1.40	7.76	2.41	3.38	15.76	6.16	1.05	--
57	V3	2B2t	112	--	0.37	1.01	0.57	9.22	7.01	2.49	18.99	6.72	1.54	--
58	V3	2B31t	147	--	0.17	0.76	0.26	8.64	6.70	1.89	16.26	7.25	1.51	--
59	V3	3B32t	182	--	0.13	0.83	0.22	8.64	6.91	1.73	15.55	7.34	1.46	--
60	V3	3Cox	272	--	0.11	0.97	0.22	7.57	6.02	1.69	15.60	7.36	1.43	--
61	V3	4C2ox	280	--	0.08	1.05	0.22	6.77	5.09	1.29	12.07	7.47	1.25	--
62	V10	A11	6	--	1.72	0.70	1.02	6.55	2.16	4.30	13.43	5.99	0.92	--
63	V10	A12	62	--	0.83	0.00	0.56	6.09	2.63	3.58	13.13	6.30	0.99	--
64	V10	B1t	88	--	0.42	1.20	0.34	5.61	4.79	2.98	14.85	6.72	1.12	--
65	V10	2B21t	152	--	0.35	4.93	0.49	7.50	8.86	3.62	24.80	6.52	1.68	--
66	V10	3B31t	260	--	0.13	10.41	0.49	6.14	8.55	1.69	19.95	7.24	1.66	--
67	V10	4B32t	300+	--	0.09	7.26	0.34	4.63	6.68	2.53	16.64	6.65	1.58	--

Supplementary Table 4. Clay mineralogy

[Analyst: A.L. Walker, U.S. Geological Survey]

No.	Sample	Horizon	Basal depth (cm)	Kaolinite	Chlorite	Vermiculite	Illite	Montmorillonite
				Alluvium, 0.7 ka				
2	V2	2C1	39	+	--	--	++	+++
3	V2	3C2	60+	+	--	--	++	+++
				Alluvium, 2 ka				
9	V1	A+C	120	+	--	--	++	+++
10	V1	C1ca	160	+	--	--	++	+++
13	V6	C1ca	100	+	--	--	++	+++
14	V6	2C2ca	115	+	--	--	++	+++
				Alluvium, 40 ka				
20	V4	4B32t	141	+	--	--	++	+++
29	V5	4B23t	118	+	--	--	++	+++
				Alluvium over Marine Terrace, 80 ka				
39	V8	4B22tca	152	+	--	--	++	+++
50	V9	4B31t	157	+	--	--	++	+++
				Alluvium, 80 ka				
57	V3	2B2t	112	+	--	--	++	--

+, trace constituent ++, minor constituent +++, major constituent --, not detected

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

[Zr in parts per million; all others in weight percent. Analysts: J. Baker, J. Budahn, R. Knight, J. Taggert, 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	Zr
						Alluvium, 0.7 ka								
1	V2	A	5	56.5	14.7	5.59	2.30	2.80	2.3	2.90	0.75	0.30	0.05	200
2	V2	2C1	39	57.0	15.0	5.96	2.50	3.13	2.3	2.73	0.78	0.30	0.05	208
3	V2	3C2	60+	58.2	15.1	5.62	2.40	3.38	2.5	2.70	0.79	0.30	0.05	276
4	V7	A11	55	--	--	--	--	--	--	--	--	--	--	--
5	V7	A12	74	54.2	14.3	6.05	2.60	2.37	1.8	2.86	0.73	0.54	0.04	143
						Alluvium, 2 ka								
6	V1	A11	17	--	--	--	--	--	--	--	--	--	--	--
7	V1	A12	53	57.7	14.7	5.82	2.00	1.84	2.2	2.81	0.76	0.30	0.04	211
8	V1	A13	82	--	--	--	--	--	--	--	--	--	--	--
9	V1	A+C	120	58.6	15.0	5.64	2.10	2.90	2.6	2.66	0.78	0.30	0.05	247
10	V1	C1ca	160	56.9	14.5	5.03	2.10	5.38	2.5	2.58	0.76	0.30	0.03	252
11	V6	A11	50	--	--	--	--	--	--	--	--	--	--	--
12	V6	A12	60	54.2	15.2	6.39	2.40	2.80	2.3	2.88	0.78	0.50	0.05	170
13	V6	C1ca	100	51.9	14.6	6.08	2.40	6.69	2.1	2.62	0.74	0.30	0.05	173
14	V6	2C2ca	115	51.5	14.3	5.94	2.50	7.80	2.2	2.59	0.75	0.30	0.04	157
						Alluvium, 40 ka								
15	V4	A11	20	--	--	--	--	--	--	--	--	--	--	--
16	V4	A12	53	62.5	14.1	4.63	1.30	1.67	2.3	1.70	0.67	0.20	0.03	208
17	V4	A13	83	--	--	--	--	--	--	--	--	--	--	--
18	V4	2B2t	115	--	--	--	--	--	--	--	--	--	--	--
19	V4	3B31t	131	60.5	14.5	6.03	2.00	1.90	2.0	2.01	0.72	0.58	0.04	276
20	V4	4B32t	141	--	--	--	--	--	--	--	--	--	--	--
21	V4	5B33t	158	61.5	14.3	5.55	2.10	1.95	2.2	2.18	0.71	0.57	0.03	196
22	V4	7C only	310	63.7	14.0	4.52	1.60	2.30	2.8	2.22	0.65	0.61	0.02	246
23	V5	A11	17	--	--	--	--	--	--	--	--	--	--	--
24	V5	A12	51	60.8	14.1	4.57	1.50	1.74	2.3	2.91	0.58	0.20	0.04	159
25	V5	A3	60	--	--	--	--	--	--	--	--	--	--	--
26	V5	2B1	79	--	--	--	--	--	--	--	--	--	--	--
27	V5	2B21t	98	--	--	--	--	--	--	--	--	--	--	--
28	V5	3B22t	106	--	--	--	--	--	--	--	--	--	--	--
29	V5	4B23t	118	59.2	15.4	6.05	2.20	2.00	2.2	2.34	0.77	0.40	0.04	208
30	V5	5B31-7B33	149	--	--	--	--	--	--	--	--	--	--	--
31	V5	8C	155+	62.6	11.8	1.60	0.93	8.26	2.7	3.44	0.23	0.30	0.02	97
32	V5N	A11	23	--	--	--	--	--	--	--	--	--	--	--
33	V5N	B21t	54	--	--	--	--	--	--	--	--	--	--	--
34	V5N	B3	89	--	--	--	--	--	--	--	--	--	--	--
35	V5N	2C1ox	100+	--	--	--	--	--	--	--	--	--	--	--

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	Zr
						Alluvium over Marine Terrace, 80 ka								
36	V8	A11	2.5	64.1	14.7	4.00	1.10	1.56	2.9	2.80	0.85	0.10	0.05	352
37	V8	2A3 only	54	--	--	--	--	--	--	--	--	--	--	--
38	V8	3B21t	90	--	--	--	--	--	--	--	--	--	--	--
39	V8	4B22tca	152	58.1	16.7	6.87	2.40	1.63	2.3	2.51	0.88	0.10	0.03	178
40	V8	5B31ca	183	--	--	--	--	--	--	--	--	--	--	--
41	V8	6B32ca	190	--	--	--	--	--	--	--	--	--	--	--
42	V8	7B33ca buried?	200	58.4	16.5	6.35	2.40	1.72	2.5	2.80	0.85	0.20	0.04	164
43	V8	8B34ca buried?	217	--	--	--	--	--	--	--	--	--	--	--
44	V8	9C1ca buried?	269	--	--	--	--	--	--	--	--	--	--	--
45	V8	10C2ca buried?	300	58.5	15.8	5.90	2.20	3.27	2.6	2.88	0.84	0.30	0.04	402
46	V9	A1	13	63.1	14.8	4.34	1.20	1.52	2.9	2.71	0.89	0.10	0.06	235
47	V9	2A3	47	--	--	--	--	--	--	--	--	--	--	--
48	V9	2B21t	68	--	--	--	--	--	--	--	--	--	--	--
49	V9	3B22t	100	--	--	--	--	--	--	--	--	--	--	--
50	V9	4B31t	157	57.8	16.3	6.83	2.50	1.66	2.4	2.65	0.87	0.20	0.05	202
51	V9	5B32t	201	--	--	--	--	--	--	--	--	--	--	--
52	V9	5B33ca	266	--	--	--	--	--	--	--	--	--	--	--
53	V9	6Cca	311	62.3	15.3	4.88	1.80	2.82	3.1	2.85	0.86	0.30	0.04	427
						Alluvium, 80 ka								
54	V3	A11	7	--	--	--	--	--	--	--	--	--	--	--
55	V3	A12	25	61.1	14.9	4.68	1.20	1.33	2.7	3.06	0.81	0.20	0.07	283
56	V3	A31&A32	58	--	--	--	--	--	--	--	--	--	--	--
57	V3	2B2t	112	52.3	19.4	8.16	1.90	0.99	1.5	2.30	0.85	0.10	0.06	153
58	V3	2B31t	147	--	--	--	--	--	--	--	--	--	--	--
59	V3	3B32t	182	--	--	--	--	--	--	--	--	--	--	--
60	V3	3Cox	272	--	--	--	--	--	--	--	--	--	--	--
61	V3	4C2ox	280	53.0	18.4	8.61	2.10	0.93	1.5	2.27	0.78	0.20	0.05	156
62	V10	A11	6	--	--	--	--	--	--	--	--	--	--	--
63	V10	A12	62	59.4	15.7	5.81	1.40	1.14	2.6	2.75	0.85	0.20	0.05	303
64	V10	B1t	88	--	--	--	--	--	--	--	--	--	--	--
65	V10	2B21t	152	--	--	--	--	--	--	--	--	--	--	--
66	V10	3B31t	260	50.5	18.8	9.22	2.00	0.74	1.9	1.81	0.75	0.30	0.06	152
67	V10	4B32t	300+	52.8	18.0	9.67	1.90	0.68	2.3	2.11	0.76	0.30	0.13	307

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

[Zr in parts per million; all others in weight percent. Analysts: A.J. Barter, K. Dennen, R. Johnson, J.R. Lindsay, B. Scott, K. Stewart, J. Taggert]

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	Zr
Alluvium, 0.7 ka														
1	V2	A	5	65.2	12.3	2.92	1.19	2.34	2.50	3.03	0.43	0.24	0.02	186
2	V2	2C1	39	68.6	12.9	3.06	1.21	2.57	2.65	3.09	0.49	0.21	0.02	177
3	V2	3C2	60+	70.6	12.8	2.55	0.99	2.33	2.77	3.23	0.41	0.18	0.02	198
4	V7	A11	55	--	--	--	--	--	--	--	--	--	--	--
5	V7	A12	74	80.2	9.00	1.26	0.48	0.95	1.92	2.94	0.20	0.24	0.02	117
Alluvium, 2 ka														
6	V1	A11	17	--	--	--	--	--	--	--	--	--	--	--
7	V1	A12	53	68.8	12.8	3.35	1.11	1.46	2.49	3.09	0.48	0.20	0.03	215
8	V1	A13	82	--	--	--	--	--	--	--	--	--	--	--
9	V1	A+C	120	68.7	12.8	3.12	1.15	2.07	2.60	3.03	0.48	0.21	0.03	239
10	V1	C1ca	160	65.0	13.1	3.39	1.39	4.01	2.65	2.92	0.51	0.23	0.02	207
11	V6	A11	50	--	--	--	--	--	--	--	--	--	--	--
12	V6	A12	60	66.3	13.0	3.50	1.23	2.13	2.45	3.08	0.51	0.34	0.04	251
13	V6	C1ca	100	65.9	12.9	3.33	1.18	3.74	2.60	3.07	0.50	0.22	0.03	238
14	V6	2C2ca	115	64.0	12.8	3.45	1.34	4.70	2.46	3.00	0.47	0.20	0.03	197
Alluvium, 40 ka														
15	V4	A11	20	--	--	--	--	--	--	--	--	--	--	--
16	V4	A12	53	65.6	13.1	3.69	1.01	1.63	2.41	1.89	0.57	0.18	0.04	251
17	V4	A13	83	--	--	--	--	--	--	--	--	--	--	--
18	V4	2B2t	115	--	--	--	--	--	--	--	--	--	--	--
19	V4	3B31t	131	66.8	13.0	4.01	1.30	2.12	2.63	2.26	0.53	0.71	0.03	220
20	V4	4B32t	141	--	--	--	--	--	--	--	--	--	--	--
21	V4	5B33t	158	63.6	13.7	4.75	1.76	1.98	2.36	2.25	0.62	0.58	0.04	177
22	V4	7C only	310	66.9	13.3	3.63	1.25	2.35	2.84	2.37	0.52	0.64	0.03	220
23	V5	A11	17	--	--	--	--	--	--	--	--	--	--	--
24	V5	A12	51	71.5	11.2	2.58	0.86	1.20	2.14	2.92	0.37	0.13	0.03	173
25	V5	A3	60	--	--	--	--	--	--	--	--	--	--	--
26	V5	2B1	79	--	--	--	--	--	--	--	--	--	--	--
27	V5	2B21t	98	--	--	--	--	--	--	--	--	--	--	--
28	V5	3B22t	106	--	--	--	--	--	--	--	--	--	--	--
29	V5	4B23t	118	68.1	12.9	3.64	1.31	1.49	2.28	2.79	0.51	0.26	0.03	213
30	V5	5B31-7B33	149	--	--	--	--	--	--	--	--	--	--	--
31	V5	8C	155+	70.6	9.83	1.10	0.59	5.95	2.30	3.05	0.19	0.23	0.03	138
32	V5N	A11	23	--	--	--	--	--	--	--	--	--	--	--
33	V5N	B21t	54	--	--	--	--	--	--	--	--	--	--	--
34	V5N	B3	89	--	--	--	--	--	--	--	--	--	--	--
35	V5N	2C1ox	100+	--	--	--	--	--	--	--	--	--	--	--

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	P_2O_5	MnO	Zr
						Alluvium over Marine Terrace, 80 ka								
36	V8	A11	2.5	67.8	13.5	3.08	0.78	1.42	2.86	2.85	0.65	0.08	0.04	358
37	V8	2A3 only	54	--	--	--	--	--	--	--	--	--	--	--
38	V8	3B21t	90	--	--	--	--	--	--	--	--	--	--	--
39	V8	4B22tca	152	62.1	15.3	5.33	1.82	1.64	2.56	2.55	0.72	0.13	0.04	223
40	V8	5B31ca	183	--	--	--	--	--	--	--	--	--	--	--
41	V8	6B32ca	190	--	--	--	--	--	--	--	--	--	--	--
42	V8	7B33ca buried?	200	59.7	16.0	5.77	2.16	1.69	2.43	2.79	0.76	0.23	0.04	163
43	V8	8B34ca buried?	217	--	--	--	--	--	--	--	--	--	--	--
44	V8	9C1ca buried?	269	--	--	--	--	--	--	--	--	--	--	--
45	V8	10C2ca buried?	300	61.4	14.5	4.78	1.69	3.62	2.59	2.84	0.68	0.25	0.04	241
46	V9	A1	13	67.6	13.3	3.27	0.77	1.36	2.78	2.79	0.65	0.08	0.04	424
47	V9	2A3	47	--	--	--	--	--	--	--	--	--	--	--
48	V9	2B21t	68	--	--	--	--	--	--	--	--	--	--	--
49	V9	3B22t	100	--	--	--	--	--	--	--	--	--	--	--
50	V9	4B31t	157	61.0	15.6	5.54	2.09	1.65	2.62	2.67	0.75	0.22	0.04	194
51	V9	5B32t	201	--	--	--	--	--	--	--	--	--	--	--
52	V9	5B33ca	266	--	--	--	--	--	--	--	--	--	--	--
53	V9	6Cca	311	66.5	14.2	3.57	1.31	2.72	3.12	2.93	0.62	0.22	0.03	316
						Alluvium, 80 ka								
54	V3	A11	7	--	--	--	--	--	--	--	--	--	--	--
55	V3	A12	25	70.6	12.5	3.00	0.70	0.99	2.63	3.03	0.51	0.10	0.05	318
56	V3	A31&A32	58	--	--	--	--	--	--	--	--	--	--	--
57	V3	2B2t	112	68.1	13.5	4.83	1.08	0.71	2.05	2.51	0.49	0.09	0.04	161
58	V3	2B31t	147	--	--	--	--	--	--	--	--	--	--	--
59	V3	3B32t	182	--	--	--	--	--	--	--	--	--	--	--
60	V3	3Cox	272	--	--	--	--	--	--	--	--	--	--	--
61	V3	4C2ox	280	73.5	11.7	3.83	0.91	0.64	2.11	2.64	0.38	0.08	0.02	141
62	V10	A11	6	--	--	--	--	--	--	--	--	--	--	--
63	V10	A12	62	68.9	13.7	3.52	0.84	0.94	2.93	2.87	0.56	0.09	0.05	300
64	V10	B1t	88	--	--	--	--	--	--	--	--	--	--	--
65	V10	2B21t	152	--	--	--	--	--	--	--	--	--	--	--
66	V10	3B31t	260	66.9	13.9	5.22	1.22	0.62	2.41	2.34	0.49	0.17	0.03	154
67	V10	4B32t	300+	68.9	13.2	4.52	1.04	0.59	2.75	2.40	0.45	0.14	0.05	177

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

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

No.	Sample	Horizon	Basal depth (cm)	Ba	Ce	Co	Cr	Cs	Dy	Eu	Fe	Gd	Hf	K	La	Lu	Mn
Alluvium, 0.7 ka																	
1	V2	A	5	614	76.5	10.4	88.3	5.31	5.63	1.37	3.56	5.85	5.96	2.27	40.2	0.462	369
2	V2	2C1	39	721	79.4	12.8	104	6.41	5.66	1.38	4.35	5.93	5.24	2.27	41.2	0.450	455
3	V2	3C2	60+	755	82.5	11.7	98.4	5.67	5.45	1.38	4.04	5.95	6.36	2.17	42.2	0.476	427
4	V7	A11	55	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	V7	A12	74	632	65.0	11.5	114	6.67	4.68	1.13	4.32	4.50	3.36	2.51	33.0	0.365	427
Alluvium, 2 ka																	
6	V1	A11	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	V1	A12	53	717	71.1	10.5	98.2	5.84	5.30	1.38	4.17	6.15	4.78	2.41	38.8	0.454	420
8	V1	A13	82	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	V1	A+C	120	729	78.5	11.0	93.8	5.54	6.07	1.36	3.88	6.07	5.99	2.33	40.5	0.478	448
10	V1	C1ca	160	714	69.6	11.1	92.3	5.70	5.08	1.25	3.86	5.11	4.64	2.31	36.6	0.394	430
11	V6	A11	50	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	V6	A12	60	616	74.1	12.3	91.9	6.17	5.36	1.31	4.47	5.44	3.96	2.48	39.1	0.430	451
13	V6	C1ca	100	586	76.4	12.5	87.8	5.75	5.50	1.37	4.35	6.1	4.14	2.50	39.4	0.420	449
14	V6	2C2ca	115	578	70.5	11.4	83.1	5.38	5.11	1.29	4.020	--	3.79	2.22	37.7	0.397	417
Alluvium, 40 ka																	
15	V4	A11	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	V4	A12	53	715	62.8	8.98	127	5.29	5.50	1.32	3.19	5.95	5.29	1.51	33.4	0.460	352
17	V4	A13	83	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	V4	2B2t	115	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	V4	3B31t	131	621	57.5	8.75	148	6.28	4.80	1.13	4.08	5.20	5.35	1.76	32.4	0.400	381
20	V4	4B32t	141	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	V4	5B33t	158	642	56.3	8.12	137	7.54	4.60	1.14	3.89	5.00	4.04	2.03	33.5	0.400	326
22	V4	7C only	310	667	53.8	6.29	122	4.56	4.30	1.04	3.02	4.50	5.91	1.91	29.1	0.385	252
23	V5	A11	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	V5	A12	51	838	56.8	9.47	108	4.85	4.40	1.17	3.20	4.5	3.56	2.53	30.9	0.363	416
25	V5	A3	60	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	V5	2B1	79	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	V5	2B21t	98	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	V5	3B22t	106	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	V5	4B23t	118	99	69.1	10.9	126	6.37	5.50	1.32	4.12	5.51	4.67	1.95	36.8	0.490	422
30	V5	5B31-7B33	149	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	V5	8C	155+	1060	33.1	4.08	64.6	2.10	2.54	0.722	1.19	2.80	2.07	3.13	17.7	0.205	268
32	V5N	A11	23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
33	V5N	B21t	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--
34	V5N	B3	89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	V5N	2C1ox	100+	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Alluvium over Marine Terrace, 80 ka																	
36	V8	A11	2.5	752	81.8	10.6	74.1	4.39	5.77	1.46	2.80	5.83	9.47	2.45	40.6	0.514	461
37	V8	2A3 only	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--
38	V8	3B21t	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--
39	V8	4B22tca	152	609	80.6	10.7	91.2	7.11	6.91	1.77	4.80	7.10	4.34	2.23	47.4	0.535	346
40	V8	5B31ca	183	--	--	--	--	--	--	--	--	--	--	--	--	--	--
41	V8	6B32ca	190	--	--	--	--	--	--	--	--	--	--	--	--	--	--
42	V8	7B33ca buried?	200	740	79.6	11.9	88.2	7.36	5.38	1.49	4.45	5.98	3.82	2.42	43.0	0.442	400
43	V8	8B34ca buried?	217	--	--	--	--	--	--	--	--	--	--	--	--	--	--
44	V8	9C1ca buried?	269	--	--	--	--	--	--	--	--	--	--	--	--	--	--
45	V8	10C2ca buried?	300	692	82.1	11.6	84.6	6.17	5.67	1.47	4.14	6.54	6.10	2.49	41.6	0.464	416
46	V9	A1	13	718	82.9	10.9	73.9	4.43	6.19	1.45	2.80	--	9.61	2.15	43.5	0.555	496
47	V9	2A3	47	--	--	--	--	--	--	--	--	--	--	--	--	--	--
48	V9	2B21t	68	--	--	--	--	--	--	--	--	--	--	--	--	--	--
49	V9	3B22t	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--
50	V9	4B31t	157	645	83.3	11.1	84.2	7.08	7.11	1.63	4.32	--	4.56	2.21	47.2	0.567	398
51	V9	5B32t	201	--	--	--	--	--	--	--	--	--	--	--	--	--	--
52	V9	5B33ca	266	--	--	--	--	--	--	--	--	--	--	--	--	--	--
53	V9	6Cca	311	692	83.4	9.27	83.6	4.62	6.31	1.44	3.17	--	10.6	2.22	43.7	0.548	388

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
									Alluvium, 80 ka								
54	V3	A11	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--
55	V3	A12	25	797	81.6	10.3	78.8	5.11	5.69	1.37	3.27	5.51	6.76	2.52	42.6	0.475	597
56	V3	A31&A32	58	--	--	--	--	--	--	--	--	--	--	--	--	--	--
57	V3	2B2t	112	753	83.0	9.07	96.7	7.04	4.73	1.27	5.77	5.45	3.72	1.93	46.9	0.389	413
58	V3	2B31t	147	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59	V3	3B32t	182	--	--	--	--	--	--	--	--	--	--	--	--	--	--
60	V3	3Cox	272	--	--	--	--	--	--	--	--	--	--	--	--	--	--
61	V3	4C2ox	280	757	110	9.84	110	7.72	10.3	2.86	5.92	12.1	3.25	2.19	60.5	0.630	493
62	V10	A11	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
63	V10	A12	62	788	91.8	7.73	82.5	4.78	6.47	1.58	3.85	--	7.13	2.30	49.9	0.505	464
64	V10	B1t	88	--	--	--	--	--	--	--	--	--	--	--	--	--	--
65	V10	2B21t	152	--	--	--	--	--	--	--	--	--	--	--	--	--	--
66	V10	3B31t	260	1380	183	9.64	106	5.40	13.9	3.79	6.00	--	3.24	1.58	97.0	0.800	494
67	V10	4B32t	300+	1070	255	35.40	99.9	5.22	20.3	5.28	6.42	--	3.79	1.81	139.0	1.220	983

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

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

No.	Sample	Horizon	Basal depth (cm)	Na	Nd	Rb	Sb	Sc	Sm	Sr	Ta	Tb	Th	Tm	U	Yb	Zr
									Alluvium, 0.7 ka								
1	V2	A	5	1.94	35.9	108	1.15	12.0	6.77	298	1.17	0.868	13.2	0.500	4.04	3.03	218
2	V2	2C1	39	1.74	38.6	118	1.77	13.8	7.05	258	1.17	0.900	14.1	0.500	5.57	3.07	177
3	V2	3C2	60+	1.83	36.1	113	1.36	13.3	6.96	246	1.17	0.886	14.2	0.480	5.20	2.92	255
4	V7	A11	55	--	--	--	--	--	--	--	--	--	--	--	--	--	--
5	V7	A12	74	1.47	29.0	121	0.962	14.5	5.73	206	1.08	0.746	12.4	0.390	4.90	2.38	119
									Alluvium, 2 ka								
6	V1	A11	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
7	V1	A12	53	1.61	37.4	117	1.17	13.3	6.71	191	1.09	0.894	13.4	0.510	3.99	3.01	180
8	V1	A13	82	--	--	--	--	--	--	--	--	--	--	--	--	--	--
9	V1	A+C	120	1.86	35.8	109	1.32	12.8	6.96	225	1.20	0.912	13.4	0.510	3.89	3.10	239
10	V1	C1ca	160	1.77	33.8	109	1.51	12.2	6.17	253	1.06	0.807	12.4	--	4.13	2.77	170
11	V6	A11	50	--	--	--	--	--	--	--	--	--	--	--	--	--	--
12	V6	A12	60	1.60	33.1	120	1.31	14.2	6.51	217	1.10	0.859	13.6	0.470	3.23	2.72	148
13	V6	C1ca	100	1.60	36.1	110	1.25	13.5	6.8	261	1.10	0.889	13.5	0.480	3.22	2.68	160
14	V6	2C2ca	115	1.67	31.1	101	1.08	12.7	6.38	262	1.04	0.832	12.6	0.420	3.34	2.58	127

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
								Alluvium, 40 ka									
15	V4	A11	20	--	--	--	--	--	--	--	--	--	--	--	--	--	--
16	V4	A12	53	1.79	30.6	81.3	1.32	11.2	6.25	218	0.970	0.893	10.9	0.534	6.29	2.96	182
17	V4	A13	83	--	--	--	--	--	--	--	--	--	--	--	--	--	--
18	V4	2B2t	115	--	--	--	--	--	--	--	--	--	--	--	--	--	--
19	V4	3B31t	131	1.58	28.9	93.5	1.34	13.2	5.61	195	0.962	0.760	11.8	0.420	5.81	2.49	164
20	V4	4B32t	141	--	--	--	--	--	--	--	--	--	--	--	--	--	--
21	V4	5B33t	158	1.73	28.7	91.7	1.46	13.4	5.75	215	0.966	0.783	11.0	0.470	5.61	2.57	120
22	V4	7C only	310	2.06	24.2	84.4	1.19	10.1	5.05	218	0.916	0.699	9.85	0.410	4.48	2.49	215
23	V5	A11	17	--	--	--	--	--	--	--	--	--	--	--	--	--	--
24	V5	A12	51	1.80	29.6	105	1.09	10.9	5.56	204	0.914	0.701	10.3	0.370	3.00	2.41	154
25	V5	A3	60	--	--	--	--	--	--	--	--	--	--	--	--	--	--
26	V5	2B1	79	--	--	--	--	--	--	--	--	--	--	--	--	--	--
27	V5	2B21t	98	--	--	--	--	--	--	--	--	--	--	--	--	--	--
28	V5	3B22t	106	--	--	--	--	--	--	--	--	--	--	--	--	--	--
29	V5	4B23t	118	1.59	34.4	96.5	1.64	13.9	6.71	198	1.09	0.880	12.9	0.480	3.88	3.06	174
30	V5	5B31-7B33	149	--	--	--	--	--	--	--	--	--	--	--	--	--	--
31	V5	8C	155+	2.07	16.1	93.7	0.659	4.44	3.07	307	0.460	0.421	5.01	0.239	2.39	1.35	84.4
32	V5N	A11	23	--	--	--	--	--	--	--	--	--	--	--	--	--	--
33	V5N	B21t	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--
34	V5N	B3	89	--	--	--	--	--	--	--	--	--	--	--	--	--	--
35	V5N	2C1ox	100+	--	--	--	--	--	--	--	--	--	--	--	--	--	--
								Alluvium over Marine Terrace, 80 ka									
36	V8	A11	2.5	2.29	37.4	112	0.988	10.4	7.04	260	1.33	0.954	12.7	0.590	3.92	3.48	333
37	V8	2A3 only	54	--	--	--	--	--	--	--	--	--	--	--	--	--	--
38	V8	3B21t	90	--	--	--	--	--	--	--	--	--	--	--	--	--	--
39	V8	4B22tca	152	1.76	46.8	112	1.30	15.3	8.58	188	1.20	1.13	15.0	0.567	3.48	3.52	154
40	V8	5B31ca	183	--	--	--	--	--	--	--	--	--	--	--	--	--	--
41	V8	6B32ca	190	--	--	--	--	--	--	--	--	--	--	--	--	--	--
42	V8	7B33ca buried?	200	1.80	37.7	123	1.13	15.0	7.58	207	1.22	0.959	14.4	0.490	3.44	2.89	143
43	V8	8B34ca buried?	217	--	--	--	--	--	--	--	--	--	--	--	--	--	--
44	V8	9C1ca buried?	269	--	--	--	--	--	--	--	--	--	--	--	--	--	--
45	V8	10C2ca buried?	300	1.97	37.5	127	1.12	13.5	7.2	225	1.25	0.955	14.3	0.540	3.62	3.05	224
46	V9	A1	13	2.13	38.5	107	1.00	10.2	6.95	242	1.28	0.963	13.1	--	3.99	3.41	357
47	V9	2A3	47	--	--	--	--	--	--	--	--	--	--	--	--	--	--
48	V9	2B21t	68	--	--	--	--	--	--	--	--	--	--	--	--	--	--
49	V9	3B22t	100	--	--	--	--	--	--	--	--	--	--	--	--	--	--
50	V9	4B31t	157	1.79	42.1	116	1.03	14.4	8.1	215	1.21	1.11	14.4	--	3.48	3.39	168
51	V9	5B32t	201	--	--	--	--	--	--	--	--	--	--	--	--	--	--
52	V9	5B33ca	266	--	--	--	--	--	--	--	--	--	--	--	--	--	--
53	V9	6Cca	311	2.28	37.1	106	0.865	11.0	6.87	251	1.21	0.993	13.9	--	3.62	3.49	425
								Alluvium, 80 ka									
54	V3	A11	7	--	--	--	--	--	--	--	--	--	--	--	--	--	--
55	V3	A12	25	1.95	37.8	134	0.948	11.5	6.92	182	1.34	0.899	13.1	0.510	4.87	2.99	247
56	V3	A31&A32	58	--	--	--	--	--	--	--	--	--	--	--	--	--	--
57	V3	2B2t	112	1.16	37.7	107	1.37	17.3	6.67	110	1.22	0.790	16.5	0.420	4.29	2.51	156
58	V3	2B31t	147	--	--	--	--	--	--	--	--	--	--	--	--	--	--
59	V3	3B32t	182	--	--	--	--	--	--	--	--	--	--	--	--	--	--
60	V3	3Cox	272	--	--	--	--	--	--	--	--	--	--	--	--	--	--
61	V3	4C2ox	280	1.13	68.8	125	1.30	18.2	14.2	170	1.04	1.77	14.7	0.736	4.15	4.33	149
62	V10	A11	6	--	--	--	--	--	--	--	--	--	--	--	--	--	--
63	V10	A12	62	1.97	42.0	115	1.04	12.8	7.7	213	1.27	1.04	14.5	--	4.25	3.23	270
64	V10	B1t	88	--	--	--	--	--	--	--	--	--	--	--	--	--	--
65	V10	2B21t	152	--	--	--	--	--	--	--	--	--	--	--	--	--	--
66	V10	3B31t	260	1.38	88.4	94.8	1.24	19.3	17.9	131	0.920	2.31	18.3	--	4.20	5.44	174
67	V10	4B32t	300+	1.72	118	97.8	1.30	17.5	22.6	150	1.04	3.40	18.0	--	4.08	8.11	239

Supplementary Table 8. Methods used in laboratory analyses

Analysis	Method	Most recent references
Sample preparation	Crushing, sieving, sonication.	Busacca and Singer (1984), Singer and Janitzky (in press).
Particle size	Sieving, pipet	Singer and Janitzky (in press).
Bulk density	Clod	Do.
Exchangeable cations (cation-exchange capacity).	BaCl	Do.
Total acidity	BaCl-triethanolamine	Do.
Total N	Kjeldahl	Do.
Organic carbon	Walkley-Black	Do.
Dithionite-extractable Al and Fe.	Citrate-bicarbonate-dithionite.	Do.
Oxalate-extractable Al and Fe.	Sodium oxalate	Walker (1984).
Clay mineralogy	Glycolation, heating	
X-ray fluorescence		
Instrumental neutron activation.		

GPO 785-048/48014

U.S. DEPARTMENT OF THE INTERIOR

March 3, 1849