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LATE CENOZOIC STRATIGRAPHIC UNITS
NORTHEASTERN SAN JOAQUIN VALLEY, CALIFORNIA

By

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Late Cenozoic stratigraphic units, northeastern San Joaquin Valley, California

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Abstract

Recent mapping of late Tertiary and Quaternary deposits in the northeastern San Joaquin Valley has shown the need for clarification, revision, and subdivision of some of the previously mapped stratigraphic units. We propose a uniform nomenclature for deposits younger than the Mehrten Formation in this region. The Laguna Formation (late Pliocene) is now recognized as far south as the Merced area, where it is overlain by the North Merced Gravel (Pliocene or Pleistocene). The China Hat pediment of Hudson (1960, p. 1552) is interpreted as the uppermost gravel member of the Laguna Formation and is believed to represent an old fan deposit rather than a pediment. The Laguna, Turlock Lake, Riverbank, and Modesto Formations are lithologically similar but may be distinguished and subdivided on the basis of soil profile development, topographic position and expression, local lithologic differences, unconformities, and associated buried soils. The Turlock Lake Formation is subdivided into two units (lower, upper) and the Riverbank Formation into three units (lower, middle, upper), separated by unconformities and well-developed buried soils. The Modesto Formation is subdivided into two informally designated members, separated by a minor unconformity and weakly developed buried soil.

The lower (oldest) member of the Modesto is in places associated with two geomorphic surfaces, and as many as four terraces showing slightly different soil development are associated with deposits of the upper (youngest) member. Post-Modesto deposits are informally subdivided into four stratigraphic units, designated Post-Modesto I, II, III, and IV. Most of the stratigraphic units discussed are believed to represent separate alluvial episodes, recorded by fill terraces opening westward onto alluvial fans. Substantial time intervals between periods of aggradation are represented by buried paleosols. Some of the properties of relict and buried paleosols are summarized and their relations to the proposed stratigraphic units are described.

INTRODUCTION

A thick sequence of late Cenozoic surficial deposits that underlies the entire San Joaquin Valley of California has been studied in detail only in the northeastern San Joaquin Valley. The first important differentiation of late Cenozoic units in the northeastern part of the valley was by Gale, Piper, and Thomas (1939), who distinguished three major deposits in the Mokelumne area: The Laguna Formation, the Arroyo Seco Gravel, and the Victor Formation. Subsequently Arkley (1954, 1962a) reported a sequence of major Pleistocene alluvial deposits in the vicinity of the Merced River. Being a soil scientist, he made no attempt to assign formational names to the deposits in the earlier report. Davis and Hall (1959), after consulting Arkley's work, designated three of these deposits the Turlock Lake, Riverbank, and Modesto Formations. More recently, late Cenozoic deposits have been studied in some detail along the upper San Joaquin River by Janda (1965, 1966), along the Chowchilla River by Helley (1967), and along the Mokelumne and American River drainages by Shlemon (1967a, 1967b, 1971, 1972). Detailed soil survey mapping has been completed over the entire area (Arkley, 1954, 1962b, 1964; Ulrich and Stromberg, 1962, Huntington, 1971). The high quality of soil survey mapping has permitted the differentiation and detailed mapping of many Quaternary units (Marchand, 1976a-f) that would otherwise have been lumped together with other units. The spatial distribution of and stratigraphic relations between these units have in turn allowed a more complete reconstruction of the Quaternary depositional, tectonic, and climatic history of central California (Marchand, 1976g; 1977).

Recent geologic mapping in the northeastern San Joaquin Valley has shown the need to clarify, revise, and subdivide some previously named stratigraphic units. This report proposes a uniform stratigraphic nomenclature for continental deposits younger than the Mehrten Formation in the northeastern San Joaquin Valley (fig. 1). Its emphasis is

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Figure 1 near here

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therefore on description rather than interpretation. This report is based on studies in eastern Stanislaus, Merced, and Madera Counties and in northern Fresno County, but reconnaissance investigations suggest that the proposed stratigraphic units apply, with some local modification, throughout most of the eastern San Joaquin Valley and southeastern Sacramento Valley. The Laguna Formation and the North Merced Gravel are described as they occur in the study area. Type sections of the Turlock Lake, Riverbank, and Modesto Formations are redescribed, some additional reference sections are provided, and post-Modesto deposits are discussed. The relation of proposed stratigraphic units to those previously used is shown in figure 1. Table 1 summarizes

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TABLE 1 NEAR HERE

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the regional strike, thickness, and depositional surface gradients of some Cenozoic units in the northeastern San Joaquin Valley; these data are discussed below and in the final section of this report.

Figure 1. Relation of proposed stratigraphic units to those previously used in the northeastern San Joaquin Valley.

Table 1.--Comparison of approximate regional gradient[1], strike[1], and thickness of some Cenozoic units, northeastern San Joaquin Valley

Age	Stratigraphic unit	Gradient along Merced River (m/km)	Gradient along San Joaquin River (m/km)	Regional strike	Mean thickness on Merced River fan	Range of thickness Chowchilla River area[5]
Modern	Present San Joaquin River	0.72	0/83[3]	---	---	---
Late Holocene	Holocene II	0.88	---	N30W	20[2]	---
	Modesto Formation					
	Upper member	1.2	0.95[3]	N30W	40[2]	0-23
	Lower Member	1.7-1.9	1.3[3]	N30W		
	Riverbank Formation					
	Upper unit	1.8-2.0	1.5[3]	N30W		
Pleistocene	Middle unit	2.2	1.9[3]	N30W	80[2]	0-23
	Lower unit	2.7	---	N30W		
	Turlock Lake Formation					
	Upper unit	3.2	2.8[3]	N30W	315[2]	17-70
	Lower unit	---	---	---	---	33-150[7]
Pliocene or Pleistocene	North Merced Gravel	3.5-8.0	---	N30-35W	2-4	---
Pliocene	Laguna Formation	---	---	---	15-70+	---
	China Hat Gravel Member	10.5	---	N40-45W	5-30	---
Miocene and Pliocene	Mehrten Formation	18.9[2]	---	N45W	470[2]	---
Miocene	Basalt of Table Mountain east of Friant	---	22-27[4]	N50W[4]	---	---
Oligocene and Miocene	Valley Springs Formation	17.7	---	N45-50W	106[2]	---
Eocene	Ione Formation	30.0	30.4[4]	N50W[4]	150[2]	---

1/ Based on generalized contours on reconstructed surface of unit.
2/ After Arkley, 1962a.
3/ After Janda, 1965, plate 5.
4/ N. King Huber, written commun., 1977.
5/ After Helley, 1967, fig. 39.
6/ Includes China Hat Gravel Member
7/ May also include Laguna Formation.

A secondary objective is to indicate some of the characteristics of stratigraphically important soils in this region and their use in the development of a Quaternary chronology. More detailed soil data and interpretations have been presented elsewhere (Marchand and Harden, 1976; Harden and Marchand, 1977). Soil nomenclature follows the Seventh Approximation System (Soil Survey Staff, 1975) as used by Birkeland (1974, p. 3-10), although Great Soil Group designations from the older system are given in parentheses. Some selected properties of age-diagnostic soils of stratigraphic importance are compared in table 2.

TABLE 2 NEAR HERE

Acknowledgments

We gratefully acknowledge the assistance of many geologists and soil scientists in providing valuable information and constructive criticism during the preparation of this report. In particular we appreciate the assistance of R. J. Arkley, J. A. Bartow, E. L. Begg, Jennifer Harden, E. J. Helley, N. K. Huber, G. L. Huntington, R. J. Janda, Ron Ollenberger, William Page, Steve Soenke, and Clyde Wahrhaftig. Steve Talco, Michael Doukas and Christine Hastorf drafted most of the illustrations.

	Geologic unit	Typical soil series	Depth (m) to fresh, loose parent material (Ca horizon)	Mean thickness of B horizon (cm)	Mean thickness of Bt horizon (cm)	Character of subsoil horizons	Most representative continuous moist color of subsoil (Munsell)*	Mean pH of all horizons	Maximum bulk density of subsoil horizon	Clay and iron oxides in best developed subsoil horizon	Character and thickness of hardpan
Increasing Soil Profile Development — Well Drained Soils Lacking Hardpans	China Hat Gravel Member	Corning, acid variant	> 5	400+	400+	Maximal argillic	10R 3/6-8m	4.5±0.5	2.1	Pores filled; thick, continuous coatings on large clasts and over ped surfaces to 300 cm or more	No hardpan
	Turlock Lake Formation Upper unit	Montpellier	> 5	350	200	do	2.5YR 4/6-8m	5.6±0.6	2.1	Pores filled; thick, continuous, coatings on large clasts; moderately thick, subcontinuous over ped faces	do
	Riverbank Formation Lower unit	Snelling, Ramona; strong variants	4.5-5.0	270	105	Very strong argillic	5YR-2.5YR 4/6m	5.9±0.6	2.0	Pores filled; moderately thick coatings on large clasts; thin to moderate, discontinuous coatings over ped faces	do
	Riverbank Formation Middle unit	Snelling, Ramona; normal variants	4	210	90	Strong argillic	7.5-5YR 4/4-6m	6.0±0.6	2.0	Pores filled, moderate to thin and discontinuous coatings on large clasts; a few thin coatings on major peds	do
	Riverbank Formation Upper unit	Snelling, Ramona; weak variants	3.5	170	70	Argillic	7.5YR 4/4m	6.3±0.6	2.0	Most pores filled; some thin, discontinuous coatings on large clasts	do
	Modesto Formation Lower member	Greenfield	2.5	110	40	Weak argillic	10YR-7.5YR 4/3-4m	6.6±0.7	1.9	Pores partially filled; some very thin, extremely discontinuous coatings on large clasts	do
	Modesto Formation Upper member, phase 1	Oakdale; Hanford, strong variant	1.8	50	20	Cambic	10YR-7.5YR 4/3-4m	6.8±0.8	1.8	Thin films along root holes, some partial filling of pores; usually no coatings on large clasts	do
	Modesto Formation Upper member, phase 2-3	Hanford, normal variant	1.6	0	0	AC	10YR 4/3m	6.9±0.8	1.7	Thin films along root holes and thin coatings on grains; no pore fillings	do
	Modesto Formation, Upper member, phase 4; Post-Modesto I	Hanford, weak variant	1.4	0	0	Thin AC	10YR 4/3m	7.0±0.8	1.6	Some very thin, extremely discontinuous coatings on grains and along root holes	do
	Post-Modesto II	Tujunga, Grangeville	0.8	0	0	Cox	10YR 4/3m	7.6±0.9	1.5	None evident	do
	Post-Modesto III	Tujunga, weak variant	0.4	0	0	Thin Cox	10YR 4-5/3m	7.8±1.0	1.4	do	do
	Post-Modesto IV	Riverwash	0	0	0	None	10YR 5-6/2m	7.9±1.0	1.3	do	do
Increasing Soil Profile Development — Soils with Hardpans+	China Hat Gravel Member	Redding, acid variant	> 4	400+	400+	Maximal argillic	10R 3/6-8m	4.5±	2.1	Pores filled; thick, continuous coatings on large clasts and over ped surfaces to 300 cm or more	Silica-iron, maximal; up to 100 cm
	North Merced Gravel	Redding	>4	30°	25°	do	2.5YR-10R 4/6-8m	5.0±0.5	2.1	do	do
	Riverbank Formation Lower unit	San Joaquin, strong variant	3.5-4.0	70	60	do	2.5YR 4/6m	5.9±0.6	2.0	do	do
	Riverbank Formation Middle unit	San Joaquin, normal variant Madera, strong variant	3.0-3.5	50	40	Very strong argillic	5YR-2.5YR 4/4-6m	6.0±0.6	2.0	Pores filled; moderately thick coatings on large clasts and over ped faces	Silica-iron, maximal; up to 50 cm
	Riverbank Formation Upper unit	Madera, normal variant San Joaquin, weak variant	2.5-3.0	40	35	Strong argillic	7.5YR-5YR 4/4m	6.2±0.6	2.0	Pores mostly filled; thin, discontinuous films on large clasts	Silica-iron, with $CaCO_3$ seams; strong; up to 40 cm
	Modesto Formation Lower unit	Fresno	1.5	35	25	Argillic	10YR 4/4m	8.5±0.7	1.9	Pores partially filled; thin coatings on grains	$CaCO_3$-silica; moderate; up to 35 cm

*Refers to relict soil formed on the geologic

•Films and coatings on clasts and ped surfaces may show redder hues and brighter chromas.

+Soils with cemented hardpans appear to have developed under impeded drainage during at least part of their history.

§Parent material contains locally derived detritus, in part from andesitic source.

°Affected by proximity of underlying unit, which controls position of hardpan.

Table 2.--Comparison of some stratigraphically significant relict soils in the northeastern San Joaquin Valley. Soils compared are formed on uneroded or very slightly eroded arkosic alluvial sand and have not been buried by younger deposits. All data and statements in this table represent typical values or approximate averages. Variation due to changes in parent material, climate, and organic influences is substantial. Underscoring indicates most typical value.

Diagnostic criteria

The post-Laguna stratigraphic units discussed in this report differ from conventional units in several respects. They are mappable lithostratigraphic units with clearly defined tops and bottoms but are defined only to a limited degree by lithology and superposition. Type sections are useful to some extent, but lateral and vertical lithologic variations within a single unit are frequently more pronounced than differences between units. The principal characteristics that serve to differentiate Quaternary deposits in the northeastern San Joaquin Valley are (1) truncation or incision of one alluvial fill by another, (2) relative elevation in a sequence of geomorphic surfaces, (3) degree of erosional dissection or preservation of depositional surfaces, (4) superposition and buried soils, and (5) contrasting soil development on uneroded and lithologically comparable parent material and under similar conditions of drainage and climate. Weathering and topographic features therefore become major distinguishing properties and are discussed below in some detail for each of the proposed stratigraphic units.

The Post-Mehrten alluvial deposits (excluding the North Merced Gravel) are similar in that they are predominantly arkosic[1/], except

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[1/]The term arkosic, as used in this report, refers specifically to a mineralogy dominated by quartz, sodium and potassium feldspar, and biotite with subordinate amounts of hornblende, magnetite, and other mafic or opaque minerals. This mineralogy contrasts with that of sediment derived from the andesitic Mehrten Formation along the foothills, which lacks biotite and contains much more calcic plagioclase, amphibole, and pyroxene and less sodium and potassium feldspar and quartz.

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where derived from local drainages that head in metamorphic or Tertiary volcanic and sedimentary rocks of the foothills. In interfluve areas relatively high on the major alluvial fans, almost all units, including the Laguna Formation, display an upward, frequently abrupt coarsening from well stratified fine sand, silt, or clay near the base to coarse pebbly sand or gravel near the top. Finer-grained, better stratified deposits are more common in fan interfluves and toward the west, on the alluvial fan toes. Local lacustrine deposits were laid down where rapid mainstream aggradation blocked preexisting tributary drainages.

Deposits younger than the Turlock Lake Formation occur as a series of nested terraces incised in older deposits near the Sierran Nevada foothills and opening westward onto alluvial fans. Each alluvial fan commonly spills out west of and over the next oldest fan, such that the youngest fans are found close to the lower San Joaquin River[2/], whereas

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[2/] The term 'lower San Joaquin River' refers to the part north of Mendota that flows north toward the Sacramento-San Joaquin estuary. Similarly, the term 'upper San Joaquin River' refers to the west-flowing part east of Mendota between Fresno and Madera.

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the oldest fans head near the foothills to the east (pl. 2). Geomorphic evidence of relative age is thus most useful near the mountains, where cut-and-fill relations are often seen, but westward toward the basin the depositional surfaces converge (compare gradients in table 1) so that soils and superposition of deposits separated by buried soils become the primary distinguishing criteria. These buried soils, where they occur within soil auger depth (about 1.7 m) are often recognized as separate soil map units - for example, Foster over Temple soils, Grangeville over alkali hardpan,

Grangeville over Traver soils, and Ramona, hard substratum phase (Ulrich and Stromberg, 1962; Huntington, 1971). Unconformities and buried soils have not been traced in the subsurface across the axis of the San Joaquin Valley (Janda and Croft, 1967; Croft, 1972), so basin deposition may well have been nearly continuous, although fluctuating in rate, throughout late Cenozoic time.

Most of the Post-Mehrten units, subunits, and members recognized in this report represent separate alluvial fills as opposed to strath surfaces cut in preexisting alluvium. Criteria for recognition of fills include: (1) more than 2 m of nongravelly sediment superposed over older units, (2) local lithologic contrasts, either in grain size or provenance, between deposits, (3) opening of terraces westward onto alluvial fans, (4) closed depressions at the mouths of sidestream gullies along the back edges of terraces or the margins of alluvial fans, caused by blockage of tributaries by rapid mainstream aggradation. Using these criteria, the following units clearly represent separate alluvial fills: both units of the Laguna, both units of the Turlock Lake, all three units of the Riverbank, both members of the Modesto, Post-Modesto II deposits, and probably Post-Modesto III and IV deposits as well. The North Merced Gravel is a lag deposit over an erosional surface; no evidence to date demonstrates local alluvial filling. Present evidence is insufficient to determine whether Post-Modesto I deposits and the various phases of the lower and upper members of the Modesto represent separate alluvial fills.

Description of stratigraphic units

Pre-Laguna Tertiary units

A series of predominantly nonmarine Tertiary clastic deposits rest on granitic and metamorphic basement along the northeastern margin of the San Joaquin Valley (pl. 2) and on Cretaceous sedimentary rocks beneath the valley floor. They dip gently southwestward (table 1) beneath the Quaternary alluvial deposits which cover most of the valley bottom. These Tertiary formations are not of primary concern to this paper and will therefore be described only cursorily except for the Laguna Formation. More detailed accounts may be found in Allen (1929), Gale, Piper, and Thomas (1939), and Gillam (1974).

The oldest of these, the Ione Formation (Eocene), consists primarily of light brown, tan, and gray to pinkish or yellowish quartz sandstone with interbedded kaolinitic clay, usually near the base. The sandstone becomes conglomeratic and very strongly cemented near the top, where it locally contains marine fossils. In many places these cemented beds form resistant westward sloping (table 1) cuestas over basement outcrops along the eastern margin of the San Joaquin Valley and in the westernmost foothills of the Sierra Nevada. The Ione appears to have been deposited in a fluctuating swamp and deltaic environment close to the marine shoreline (Gillam, 1974). Lateritic soils containing crystalline iron oxides and abundant kaolinite (oxisols in the 7th approximation classification) formed on, beneath, and perhaps within the Ione, together with plant macrofossils, indicate a tropical or subtropical climate prior to, during, and after Ione deposition. Ely, Grant, and McCleary (1977) have discussed some aspects of lateritic crust remnants on the buried and exhumed Ione surface in eastern Stanislaus and Merced Counties.

The Valley Springs Formation (Oligocene and Miocene), a sequence of rhyolitic sandstone, siltstone, claystone, and conglomerate that appears to have been deposited by streams flowing in post-Ione valleys having 30 m or more of local relief, overlies the Ione from Merced County northward. The Valley Springs Formation crops out at slightly lower elevations than the Ione, either in valleys between exposures of the Ione or to the west of them where the Ione dips valleyward beneath the surface. The Valley Springs also contains thick ledge-forming altered zones that are often pisolitic and that may represent diagenetically altered paleosols formed under climatic conditions much wetter and perhaps warmer than present.

Overlying the Valley Springs and cropping out in the band west of it is the Mehrten Formation of Miocene to late Pliocene age (Dalrymple, 1963, 1964), consisting in this area of conglomerate, sandstone, siltstone, and claystone derived from andesitic source material. A general decrease in mean grain size within the Mehrten can be seen southward from the Stanislaus to the Fresno River, where Mehrten exposures cease. The Mehrten in the northeastern San Joaquin Valley was apparently laid down by southwest-trending streams carrying andesitic debris from the central and northern Sierra Nevada. Like the Ione and Valley Springs, the Mehrten also dips southwestward but at a somewhat gentler gradient than the Valley Springs. Arkley (1962a) gives an approximate slope of 18.9 m/km for the reconstructed Mehrten depositional surface near Merced (table 1). In this area the Mehrten is much thicker than the older Tertiary units, and consequently it crops out much more extensively. Near Friant, in Madera and Fresno Counties, Janda (1966) has recognized a sequence of tuffaceous silt, sand, and gravel deposits younger than the Ione Formation and older than the Turlock Lake Formation. These deposits, described by Janda (1966) and earlier mapped by MacDonald (1941), lie beneath the andesite of Kennedy Table Mountain just east of Friant. Dalrymple (1963, 1964) dated a basalt in the Jose Basin about 16 km east of Friant at 9.5 ± 0.3 m.y. and correlated it with the andesite of Kennedy Table Mountain. New K-Ar dates on the basalt of approximately 10 m.y. and of about 11 m.y. on tuff pebbles interbedded with fluvial sediment beneath the basalt indicate that the Kennedy Table Mountain deposits are older than the Jose Basin basalt (Huber, 1977).

Laguna Formation

The Laguna Formation was named by Gale, Piper, and Thomas (1939) for arkosic alluvial deposits in the vicinity of Laguna Creek, San Joaquin County, overlying the Mehrten Formation and truncated by the Arroyo Seco Gravel, which was thought by those authors to be a pediment veneer. Although the Laguna is not continuously exposed south of the Mokelumne River, in Merced County it occupies a similar stratigraphic position above the Mehrten and truncated by the North Merced Gravel (Arkley, 1962a) and consists of granitic alluvium ranging from gravel to fine silt. Consequently, the formation name is here geographically extended to include similar deposits in Merced and Stanislaus Counties. Thick deposits of this approximate age also occur near the mouth or the Kings River (Huber, 1977, p. 31-32). The Mehrten-Laguna contact in the Mokelumne River area has been described as transitional (Gale and others, 1939), but in Merced County the Laguna is channeled into the Mehrten, and a regional angular unconformity is indicated by the data of table 1. A substantial thickness of alternating arkosic beds and beds of andesitic detritus reworked from the Mehrten crop out at the base of the Laguna in many places. We place the bottom of the Laguna Formation at the base of the lowest arkosic detritus, a practice that seems consistent with the original definition of Gale, Piper, and Thomas (1939). The development of the Warnerville Pediment of McCleary and Grant (1977), which truncates the Mehrten Formation between the Stanislaus and Tuolumne Rivers, may correspond in time to deposition of the Laguna Formation to the north and south.

In the region south of its type section, the Laguna is best exposed south of the Merced River. This outcrop area extends nearly to the Chowchilla River as a series of isolated outcrops, in most places within or slightly west of the belt of Mehrten exposures (pl. 2). The Laguna may stand either as a topographic high, where the gravelly facies in its upper part are exposed, or in sideslopes and valley bottoms, where erosion has exposed the finer grained part of the formation.

In the vicinity of the type section and in Stanislaus and Merced Counties the Laguna is characterized by beds of alluvial gravel, sand, and silt. Pebbles and cobbles of quartz and metamorphic fragments dominate the gravelly units, but the matrix of the gravel and the Laguna's finer grained sediments are invariably arkosic, in contrast to the andesitic deposits of the underlying Mehrten and the darker colored, locally derived matrix within the overlying North Merced Gravel. The Laguna normally shows a moderate to strong degree of compaction, slightly greater than the Turlock Lake Formation, but sand bodies at depth are in places as fresh and unconsolidated as modern channel deposits (see reference section below, unit 1 of landfill exposure). Cementation is not common below the hardpan[3/] of the surface

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[3/] The term 'hardpan' in this report refers only to a pedogenic horizon formed through cementation of parent materials by iron oxides, silica, or calcium carbonate.

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soil. As Gale, Piper, and Thomas (1939) have pointed out, it is often impossible to distinguish the Laguna Formation from younger granitic alluvium by lithology. Such a distinction can usually be made only through stratigraphic relations to the pediment gravels, weathering and soil development (see p. 58-59 below), or topographic setting.

The Laguna Formation consists of at least two upward coarsening units, separated by a strong buried soil and here designated the lower and upper units (fig. 1). Coarse gravel beds cap both units underlain by sand, and by stratified silt and fine sand beds at the base, which make up the bulk of both units.

The Laguna is well exposed at the new Merced County landfill site, about 11 km north of Merced and just east of Oakdale Road. The upper and lower units appear to be lithologically similar in this area, except for the thick China Hat Gravel Member (see below) near the top of the upper unit. Two exposures are described below as a composite reference section for the lower unit of the Laguna Formation in this area.

Reference Section A, lower unit of Laguna Formation

Location: series of roadcuts proceeding westward along access road into Merced County landfill site, about 11 km north of Merced, just east of Oakdale Road NW1/4NW1/4 Sec. 25, T. 6 S., R. 13 E., Winton and Yosemite Lake 7-1/2 quadrangles, Merced County

unit	thickness m	thickness cm
Top of roadcut, crest of hill		
North Merced Gravel	1.0	
9. Gravel; weathered dark red to dark reddish brown; abundant pebbles and cobbles up to 13-15 cm maximum diameter in sandy matrix, extensively but not thoroughly weathered; pebbles predominantly metamorphic with some quartz; rests on Laguna Formation with pronounced erosional unconformity; cf. description below under North Merced Gravel		

	m	cm
Unconformity		
Lower unit of Laguna Formation--		
8. Coarse granitic sand with infrequent scattered pebble and cobble lenses; weathered reddish-brown to yellowish-brown; relatively massive, but original stratification extensively modified by pedogenesis; strongly cemented with iron and silica (hardpan of Redding soil)		90
7. Coarse gravel with minor interstratified sand; weathered reddish-brown to yellowish-brown; pebbles up to 10 cm similar to those of North Merced gravels, but matrix is granitic; not well imbricated or stratified; strongly cemented by iron and silica in upper part becoming less cemented at depth		98
6. Sand with cobbly beds and lenses; weathered reddish-brown to yellowish-brown; moderately well indurated but not cemented.		90-120

	m	cm
5. Coarse gravel similar to unit 3; weathered reddish brown in upper part tending toward buff or gray at depth or where soil profile has been eroded; includes prominent sandy beds; moderately well indurated		variable --up to 90-120
4. Coarse sand with scattered pebbles; weathered reddish brown to pale reddish brown and buff; moderately well indurated		90-120
3. Coarse sand with more pebbles than 6 above; weathered reddish brown to buff; moderately well indurated		60
2. Sand; weathered pale reddish brown; uniform and massive; moderately indurated	2.4-3.1	
1. Sand; buff; massive irregular zone containing some pebbly lenses; moderately indurated but some zones show little evidence of weathering; base not exposed		90-120
Total thickness	≃10 m	

(note: probable fault contact on west side, bringing uppermost Laguna [unit 7?] up against unit 1 on the east. Fault appears to offset Redding soil formed on North Merced Gravel. The gravel beds tend to be lenticular, so thicknesses of units 5-9 are approximate.)

No pronounced unconformities other than channels were found within the Laguna in these outcrops. The coarse sand and gravels of units 2-5 above may correspond to the coarse upper material of unit 6 in the landfill exposure described below. Units 5 through 8 of the roadcut exposures apparently represent deposits removed by erosion at the location of the landfill exposure.

Reference section B, lower unit of Laguna Formation

Location: in exposures in Merced County landfill site NE-1/4NW-1/2 section 25, T 6 S, R 1 3 E, Yosemite Lake 7-1/2 quadrangle, Merced County

unit	thickness m	thickness cm
Upper surface bulldozed, original pediment veneer removed by excavation		
Lower unit of Laguna Formation--		
6. Pebbly coarse sand; weathered reddish brown and reddish yellow; some less weathered lenses are grayish brown to olive brown; moderately well indurated but not cemented; maximum observed pebble size 6-8 cm diameter; prominent fluvial crossbedding and channels; minor(?) unconformity locally present at base of unit	1.0	

	m	cm
5. Silty sand; predominantly light gray to light buff with irregular mottles of yellow-orange to yellow-brown; fine-grained; contains very few pebbles moderately well indurated; upper 6-8 cm shows fairly strong platy structure and upper 5 cm are more oxidized (probably pedogenic and related to the unconformity above); as a whole, the unit is not well stratified and tends to be relatively massive		
4. Silt and very fine sand; light gray; well indurated; massive		64
3. Very fine sand; buff to light gray with orangish mottles; massive; well indurated; lenticular, cannot be traced laterally; typical of thin zones within the two overlying units		55

The Laguna includes at least one major hiatus, as shown by a buried soil in exposures along the east and north sides of the landfill site. This soil has a reddish-brown, clay-rich Bt horizon similar to that of the strongly developed Corning series, normally formed on the North Merced Gravel or the China Hat Gravel Member of the Laguna Formation; it lacks an iron-silica hardpan. We have informally designated that part of the Laguna below the buried soil as the lower unit and that above it as the upper unit (fig. 1). Exposures of the upper unit in the landfill are too sparse to warrant a detailed description, but the deposit appears to be arkosic, fine- to coarse-grained sand and pebble gravel similar to that of the lower unit. R. J. Janda (oral commun., 1976) and Marchand have noted similar soils in deposits akin to the Laguna south of Fresno. Ira Klein (written commun., 1975) has recognized three paleosolic zones in the eastern San Joaquin Valley subsurface beneath the Corcoran Clay Member of the Turlock Lake Formation. The oldest (lowest) of these soils may correspond to the buried soil in the Laguna Formation. Marchand has also found three very strong buried soils beneath the Corcoran Clay Member of the Tulare Formation in U.S. Bureau of Reclamation cores from the 18-Mile Pumping Plant on the west side of the San Joaquin Valley.

A thick section is well displayed in the Main Canal cut about 13 km north of Merced and 1.6 km east of Oakdale Road where the canal cuts through the most prominent ridge of the China Hat (pl. 1 and 2). About 18.2 m of interstratified arkosic silt, sand, and gravel is exposed in the canal cut. A number of erosional surfaces and oxidized zones can be found within this section, but these do not necessarily represent long time intervals. The China Hat is the stratigraphically highest unit present in this exposure and is the thickest of several gravel units in this section (elsewhere the China Hat reaches apparent thicknesses of 15 m or more, but here the upper gravel is only a few meters thick.) The China Hat in the canal cut rests on arkosic sediment within the Laguna Formation, which is much finer grained at the contact than the overlying gravel but which itself contains the gravel units noted above. There seems to be little lithologic difference between gravel of the China Hat and the gravel beds lower in the canal section except that the China Hat is the youngest and thickest gravel. In the west side of this canal cut we found no unequivocal evidence of a strong buried soil, indicative of a major time hiatus, at the base of the China Hat. The matrix of the China Hat is arkosic, a characteristic that distinguishes the Laguna Formation from the locally derived North Merced Gravel. The North Merced Gravel and the iron-silica-cemented hardpan of an eroded Redding soil, where the veneer of North Merced Gravel has been stripped, truncate the Laguna and its China Hat Gravel Member along the north and south sides of the canal cut.

We conclude from the evidence presented above that the China Hat Gravel Member is not a pediment, but rather a remnant of a late Laguna gravelly fan deposit near its apex, now prominently exposed through topographic inversion. Consequently, we here designate Arkley's (1962) China Hat as a local, uppermost member of the upper unit of the Laguna Formation rather than as a separate formation. We retain the term "China Hat", even though the deposit is not laterally continuous from one drainage to the next and is here reduced to member status, because it has such topographic prominence and can be readily mapped.

The thickness of the Laguna Formation in Stanislaus and Merced Counties is uncertain because its basal contact with the Mehrten is exposed in few places, and subsurface records have not been studied. The Laguna is much thinner here than in the Mokelumne River area, where Gale, Piper, and Thomas (1939) estimate up to 122 m of section. A probable thickness of about 15-70 m seems reasonable for northeastern Merced County. The formation thins rapidly toward the south and does not crop out between the Chowchilla River and the San Joaquin River.

Several soils have formed on the Laguna during and since its deposition. Erosion has in many places stripped away parts of the post-Laguna soils and hence they are often not entirely age diagnostic. Acid variants of the Redding (iron-silica hardpan) and Corning (no hardpan) soils (table 2) have formed on the China Hat Gravel Member. A Corning soil, acid variant, formed at a relatively uneroded site on the China Hat, exposed in a 4-m soil pit excavated by Woodward Clyde Consultants and made available to us by William Page, is described below as a representative post-China Hat soil (slightly eroded).

Deposits that may be in part correlative with the Laguna Formation crop out along the margins of the Sacramento and San Joaquin Valley. Unnamed sandy, arkosic deposits similar to the Laguna occur near the mouths of the Kings and Kaweah Rivers and of Poso Creek. Some coarse Laguna-like gravel and sand deposits occur in the upper part of the Kern River Formation of Anderson (1911) east and north of Bakersfield (Bartow and Doukas, 1976). The older silty varicolored deposits of the lower part of the Kern River Formation, however, were deposited by meandering streams, in contrast with the overloaded, braided fluvial environment suggested by much of the Laguna. The lower Kern River interfingers westward with the marine Etchegoin and San Joaquin Formations (Foss, 1972; Dibblee, 1973) of early and late Pliocene age. The Laguna could be correlative with older parts of the Red Bluff Formation of the Sacramento Valley, is probably correlative with the older part of the Tulare Formation along the west side of the San Joaquin Valley, and perhaps with arkosic gravels and part of the Tuscan Formation near Oroville and Chico.

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Corning Soil series, acid variant, formed on China Hat Gravel Member[4/]

[[4/] Soil description by Jennifer W. Harden, 12/1/76 in backhoe pit in NE 1/4, NW 1/4, sec. 2, T. 6 S., R. 14 E., Yosemite Lake 7 1/2' quadrangle, Merced County.]

0-12 cm	A1	Gravelly silt loam; reddish yellow (7.5 YR 6/6d) and yellowish brown (10 YR 5/4m) to dark brown (7.5 YR 4/4m); weak, fine angular to subangular blocky structure, slightly hard (dry), slightly sticky, slightly plastic (wet); common medium and coarse pores; plentiful fine and medium roots; gravels are siliceous; medium acid (6.0); boundary is gradual and wavy.
12-53 cm	A+B	Gravelly silty clay loam; reddish yellow (7.5 YR 6/6d) and dark brown (7.5 YR 4/4m); structure and consistence and reaction as above in A1; common medium and coarse pores; plentiful fine and medium roots; common, thin pore fillings; clay films are common. thin bridging grains; gravels are siliceous; medium acid (6.0); boundary is abrupt and wavy.

53-140 cm	IIB21t(b)	Extremely cobbly clay loam; yellowish red (5 YR 5/6 d), and dark red (2.5 YR 3/6 m); structure appears moderately strong, medium subangular blocky (cobbles interfere); extremely hard (dry), very sticky, very plastic (wet); common, medium pores; few, medium roots to 88 cm; cobbles are more cohesive at top of horizon; cobble and gravel size clasts; manganese oxide coatings very common on clasts from 53-88 cm; strongly acid (5.5); boundary gradual, wavy.
140-234 m	IIB22t(b?)	Very cobbly clay; red (2.5 YR 4/8 d), red (10 R 4/7 m); structure similar to IIB21t(b?); extremely hard (dry), very sticky, very plastic (wet); common medium pores; clay films are continuous, extremely thick everywhere, with colors of 10 R 3/6 m, 2.5 YR 4/8 m; all non-siliceous cobbles fall apart ('ghosts'); no manganese oxides; extremely acid (4.0-4.5); boundary is gradual and irregular.

234-310 cm	IIB31t(b?)	Very cobbly, coarse sandy clay loam; red (2.5 YR 4/8 d), and dark red (10 R 4/8 m); weak, medium subangular blocky structure; very sticky, very plastic (wet); few, medium pores; common, moderately thick clay films bridging grains, lining pores, and coating clasts; cobbles are disintegrated; extremely acid (4.0); boundary is gradual and irregular.
310 + cm	IIB32t(b?)	Very cobbly, coarse sandy clay loam; dark red (2.5 YR 3/6 d), and dark red (10 R 3/6 m); same as above but clay skins are few, moderately thick over grains and cobbles; gravel and cobble size clasts.

A discontinuous hardpan (Bsim horizon) occurs about 1 m below the surface and is up to 0.7 m thick. Continuous red (10R 4/6-8m) clay films extend to 4 m depth, far below the hardpan, indicating that the pan on the China Hat Gravel Member is a younger pedogenic feature superimposed on a very old soil. The presence of a thick maximal argillic horizon in the Laguna Formation beneath the North Merced Gravel and associated Redding hardpan indicates that much of the weathering that produced the soils on the Laguna Formation and China Hat Gravel Member occurred prior to North Merced time. The depth of translocated clay coatings in the post-China Hat soil suggests deeper penetration of water than could occur under present climatic conditions. The Hopeton and less frequently the Montpellier soil is mapped in sandy Laguna on sideslopes where the overlying China Hat Gravel Member has been removed. Some of these soil profiles, although eroded, have strong red argillic B horizons extending more than 180 cm beneath the present land surface; oxidation may extend to more than 4.5 m. In a few localities, the Hopeton soils have been removed by erosion, and soil series typical of the Turlock Lake Formation (Whitney, Rocklin) have been mapped on the finer grained and stratigraphically lower parts of the Laguna Formation. The buried soil exposed at one location within the Merced County landfill (p. 23) represents at least one long time interval of weathering and landscape stability during deposition of the Laguna.

The China Hat surface is characterized by very pronounced hog-wallow or mima mound microrelief (up to 2 m or more of relief), which in many areas extends down dissected slopes as steep as 10 percent. Evidence of substantial burrowing and rodent disturbance in soil pits in the China Hat Gravel Member strongly supports the rodent burrow origin of the mounds as originally suggested by Arkley and Brown (1954).

The age of the Laguna Formation is presumably late Pliocene. We draw this conclusion from the following considerations: (1) the Laguna overlies the Mehrten Formation, whose upper part is younger than the 8.8-9.0m.y. Tuolumne Table Mountain Latite of Dalrymple (1963) and which at Turlock Lake State Park contains a vertebrate fauna of latest Hemphillian age, possibly transitional into Blancan (Hugh Wagner, 1976 and oral commun., 1976), (2) the Laguna is truncated by the North Merced pediment, believed to be latest Pliocene or early Pleistocene in age (see below), and (3) subsurface deposits in the type area, believed to be Laguna, contain <u>Neohipparion</u> teeth (Gale, Piper, and Thomas, 1939, p. 60-61), suggesting a late Pliocene age.

North Merced Gravel

The North Merced Gravel, named by Arkley (1962a, p. 29), represents a thin veneer of gravel over an erosional surface of regional extent in the northeastern San Joaquin Valley. The geomorphic surface called the North Merced pediment by Arkley meets criteria for a pediment in that (1) it is an erosional surface of low relief cut across a variety of rock types and having regional extent, (2) it is covered by a thin lag deposit of coarse locally derived gravel, and (3) it appears to have developed in a semiarid climate similar to that of the present[5/].

[5/] The Redding and Corning soils characteristically formed on the North Merced Gravel are xeralfs (Noncalcic Brown Soils) similar to those presently forming on Quaternary deposits of the region.

Remnants of the North Merced pediment are best preserved in the Snelling, Merced Falls, Yosemite Lake, and Haystack Mountain 7 1/2' quadrangles of northeastern Merced County (plate 3; Marchand, 1967a, sheets 6 and 7) but may be traced at least as far south as the San Joaquin River. The gravel veneer may be correlative with part of the Arroyo Seco Gravel of Gale, Piper and Thomas (1939) to the north (Arkley, 1962a).

The North Merced Gravel truncates, in general westward progression, Mesozoic granitic and metamorphic rocks, and the Ione, Valley Springs, Mehrten, and Laguna Formations. The lower unit of the Turlock Lake Formation and younger Quaternary deposits were deposited on topography incised into the North Merced surface.

The pediment is associated with a discontinuous, gently sloping topographic surface between the Sierra Nevada foothills and the Quaternary alluvial fans. A reconstructed topographic surface on the highest smooth pediment remnants slopes steeply in places, especially near bedrock outcrops, but does not appear to have been significantly tilted to the west as do the depositional surfaces of the China Hat, Laguna, and older stratigraphic units. Instead, the North Merced pediment tends to conform to local topography and often displays local slopes in many directions, although the mean gradient is about 6 m/km toward the west southwest (table 1). A hogwallow microrelief or mima mound topography less pronounced than that associated with the China Hat Gravel Member (Nikiforoff, 1941; Arkley and Brown, 1954) has developed almost everywhere on the pediment surface. The hardpan of the Redding soil creates a perched water table and the undrained hogwallow depressions frequently hold water during the winter rainy season.

Detailed mapping in the Merced area has shown that what has been called the North Merced pediment is actually at least two or more erosional surfaces of significantly different ages. The fully developed Redding soil, with a 2.5YR-10R 4/6-8m Bt horizon containing 50-60 percent clay above a maximally developed silica-iron cemented hardpan (table 2) is found only on topographic flats or benches. Soils on gravel-veneered sideslopes having gradients up to 5-10 percent do not have the intense development of the Redding and are more akin to the weak or normal variant of the San Joaquin or Yokohl series (table 2) although they may be mapped as Redding, Corning, Rocklin, or Keyes. In many areas, especially along Hornitos and Snelling Roads in the Yosemite Lake 7 1/2' quadrangle northeast of Merced, these younger slopes merge into smooth surfaces lying significantly below the level of the North Merced benches (Marchand, 1976a, sheet 6). These lower surfaces in turn merge with surfaces underlain by the upper unit of the Riverbank Formation--for example, northwest of Fahrens Creek, Yosemite Lake quadrangle. The North Merced pediment therefore appears to have undergone at least one period of extensive dissection and regrading during late Riverbank time. Slopes bearing weakly developed soils such as cobbly variants of the Pentz and Peters series, formed on lag gravel overlying nongravelly Tertiary or older rocks, may represent surfaces regraded during Modesto time.

The North Merced Gravel is rarely more than 1-2 m thick, although thicknesses of 3-4 m are occasionally observed. Pebbles and cobbles reach 15 cm or more in maximum diameter and are predominantly of quartz-vein or mixed metamorphic source. Granitic pebbles and cobbles are conspicuously absent. The gravel matrix is locally derived, but intense weathering has converted most of the weatherable grains to pedogenic clay.

The most characteristic soil developed on the North Merced Gravel is the Redding series, an acid (pH 5.1 ± 0.6), red (hues 2.5YR to 10R, chromas 6 to 8), montmorillonitic soil with a maximal argillic B horizon and well developed iron-silica hardpan more than 0.5 m thick (table 2). The hardpan has in most places formed along the unconformity underlying the pediment gravels and its vertical position within the soil profile commonly appears to be controlled by the change in parent material or the presence of a buried argillic horizon. The Corning soil series is locally mapped where the hardpan is absent.

The North Merced Gravel and the Redding soil that has formed on it are difficult to describe separately because the post-pediment soil is strongly developed and extends through the gravel into the underlying material. The Redding soil series and its parent material are described below as exposed above the Laguna Formation along the Merced County landfill access road. Arkley (1962a) did not designate a type section, but this exposure serves that purpose.

Type section, North Merced Gravel

Location: access road to Merced County landfill site, NE 1/4, NW 1/4, sec. 25, T. 6 S., R. 13 E., Yosemite Lake 7 1/2' quadrangle, Merced County

Redding soil series, formed on North Merced Gravel (description by Jennifer W. Harden in backhoe pit just north of road on low ridge crest)

0-5 cm	Ap	Gravelly loam; dark brown (7.5 YR 4/4d) and strong brown (7.5 YR 3/4m); friable (moist), slightly sticky, slightly plastic (wet); roots common, fine; slightly acid (6.5); boundary clear and smooth.
5-19 cm	B11	Gravelly heavy loam; dark brown (7.5 YR 4/4 d), and dark reddish brown (5 YR 3/4 m); firm (moist), sticky, plastic (wet); roots common, fine; thin clay films on gravels; medium acid (6.0); boundary clear and wavy.
19-36 cm	B12	Gravelly heavy loam; yellowish red (5 YR 5/6 d), and dark red (2.5 YR 3/6 m); medium subangular blocky structure; hard (dry), sticky, plastic (wet); few, fine roots; common, fine pores; few thin clay films bridging grains and coating gravels; medium acid (6.0); boundary is clear.

36-47 cm	B21t	Cobbly clay loam; yellowish red (5 YR 5/6 d), and dark red (2.5 YR 3/6 m); medium subangular blocky structure, very hard (dry), very sticky, very plastic (wet); few, fine pores; pore fillings are common, moderately thick; moderately thick clay films are bridging grains and coating cobbles;contains cobble and gravel size clasts; strongly acid (5.5); boundary is gradual.
47-71 cm	B22t	Cobbly heavy clay loam; dark red (2.5 YR 3/6 d) with 5 YR 4/6 d skins, same colors moist; medium subangular blocky structure, very hard (dry), very sticky, very plastic (wet); pores are common fine to medium; many thick pore fillings; clay films are common to many, coating ped faces and cobbles; contains cobble and gravel size clasts; medium acid (6.0); boundary is abrupt and irregular.
71 + cm	IIBsimb	Cobbly sandy matrix; yellowish red (5 YR 6/6 d), and yellowish red (5 YR 5/8 m); extremely hard (dry); cementation is strong to indurated but is found to be quite variable horizontally and in thickness; thick clay coating is common just on top of pan, and on imbedded cobbles; strongly acid (5.5).

Unweathered North Merced parent material is not present but appears to have been coarse gravel containing pebbles and cobbles up to 15 cm in maximum diameter in a matrix of coarse sand, primarily derived from andesitic and metamorphic rocks of the foothills. Large metamorphic clasts that are not quartzose display thin to moderate weathering rinds, but are internally fresh and coherent. Clasts are more weathered and decomposed within the B horizon of the Redding soil but nowhere as much as nonquartzose clasts in the China Hat Gravel Member. Smectite contents of up to 50 percent of the less-than-2 micron fraction in the post-North Merced soil are indicative of locally derived andesitic sediment from the Mehrten Formation in the North Merced parent material. The silica-iron hardpan of the Redding soil has formed here on Laguna parent material underlying the North Merced Gravel. Red clay films evident in the outcrop and oriented clay visible in thin sections well below the zone of cementation indicate that the Redding hardpan formed on a pre-North Merced argillic B horizon in the Laguna Formation (intra-Laguna soil, exposed in nearby landfill cuts?).

The North Merced Gravel is also well exposed in cuts along Snelling Road in the SW 1/4, sec. 9, T. 6 S., R. 14 E., Yosemite Lake 7 1/2' quadrangle, Merced County and in a streambank cut just west of Snelling Road in the extreme south-central part of sec. 4, of the same township and quadrangle. Here the coarse locally derived gravel of the North Merced, bearing the fully developed Redding soil, contrasts sharply with the fine-grained arkosic sediment of the underlying Laguna Formation (lower part of upper unit).

The age of the North Merced Gravel is somewhat uncertain but is suggested by indirect evidence. The gravel is separated from the underlying Laguna Formation by a very strongly developed soil indicative of a long time hiatus. It is older than the paleomagnetically reversed lower unit of the Turlock Lake Formation. The North Merced pediment appears to mark a period of tectonic stability after the last major uplift of the Sierra Nevada block and is possibly related in time to the final stages of canyon cutting. Dalrymple (1963, 1964) has dated basaltic flows near the bottom of the Kern and San Joaquin River canyons at about 3.0-3.5 m.y., indicating that canyon cutting in the southern Sierra Nevada was nearly completed by that time. The age of the North Merced pediment, using a 1.8 m.y. age for the Tertiary-Quaternary boundary (Bandy and Wilcoxon, 1970; Berggren, 1972), is presumably early latest Pliocene or Pleistocene, perhaps about 1-2 m.y. Such an age would be consistent with the antiquity implied by the very strongly developed post-pediment soil.

Turlock Lake Formation

The Turlock Lake Formation includes arkosic alluvium and related deposits in the stratigraphic interval between the North Merced Gravel and the Riverbank Formation. Both its lower and upper contacts are unconformable along the eastern edge of the San Joaquin Valley, showing erosional relief of up to 30 m or more. The formation was first recognized by Arkley (1954) and named by Davis and Hall (1959) for arkosic silt, sand, and gravel overlying the Mehrten Formation and underlying the Riverbank Formation in eastern Stanislaus and northern Merced Counties. Although the sediments of the Turlock Lake are commonly indistinguishable from those of the older Laguna Formation or of the younger Riverbank and Modesto Formations, they bear a suite of distinctive, strongly developed haploxeralfs (Noncalcic Brown soils) and underlie a topography much more dissected than that associated with younger deposits. The formation is widely recognizable and mappable throughout the northeastern San Joaquin Valley (for example, cf. Janda, 1965, 1966; Helley, 1967; Janda and Croft, 1967; Marchand, 1976a-f).

A buried soil at least as well developed as the soil formed on the lower unit of the Riverbank (see p. 74, 78) separates the Turlock Lake Formation into two units in the northeastern San Joaquin Valley. This soil is recognizable in both surface exposures and subsurface records. The Fair Oaks Formation of Shlemon (1967a, b), exposed along the north bluff of the American River east of Sacramento, is probably correlative with the Turlock Lake Formation. At the Sunrise Boulevard Bridge the Fair Oaks contains three units separated by strong buried soils comparable to Ramona soils formed on the lower or middle units of the Riverbank Formation. If the thick upper and lower units of the Fair Oaks at the Sunset Boulevard Bridge section correlate with the thick upper and lower units of the Turlock Lake Formation to the south, the middle unit of the Fair Oaks appears to lack a southern counterpart, due either to erosion or nondeposition. Such correlations, however, are extremely tenuous and await results from paleomagnetic or other dating and correlation techniques.

The Turlock Lake Formation consists primarily of arkosic alluvium, mostly fine sand, silt, and some clay at the base grading upward into coarse sand and occasional coarse pebbly sand or gravel. The pebbles are of granitic as well as metamorphic, volcanic, and quartz-vein rocks and are in most places not as large nor as abundant as those in the China Hat Gravel Member and North Merced Gravel. The gravel and sand beds are frequently lenticular, crossbedded and difficult to trace laterally. The beds of finer grained sediment are commonly well sorted, well stratified, and internally laminated and in many places contain virtually unweathered grains of micas, feldspars, and mafic minerals. Some of these beds may be of local lacustrine origin.

The Turlock Lake commonly stands topographically above the younger fans and terraces throughout the northeastern San Joaquin Valley in a broad band between the Mehrten, Laguna, and pediment outcrops to the east and the younger Riverbank and Modesto alluvial fans to the west (pl. 2). It slopes west beneath these younger alluvial deposits at a very gentle gradient, generally about 3 m/km (table 1). Outcrops of Turlock Lake are widespread but discontinuous, especially near the mouths of major river canyons where incision and dissection have removed much of the older sediments. Erosion has modified the upper surface of the Turlock Lake so that little if any of the original depositional surface remains, and fan forms are not clearly evident from topography or present outcrop pattern. The closest approximation to an original fan surface in the areas mapped to date is probably those parts of the extensive outcrop areas between the Merced and Tuolumne Rivers south of Turlock Lake State Park, especially those areas where the Montpellier soil series has been mapped. The original fan apexes were probably in or close to the foothills, but their position can be only approximately determined. Present topographic relief is up to 30 m or more. Hogwallow microrelief characterizes those areas of eroded Turlock Lake where the Rocklin hardpan soils have formed.

The thickness of the Turlock Lake is variable and appears to increase toward the valley. Davis and Hall give an estimate of 90-260 m for eastern Stanislaus County. Arkley (1962a) estimates about 315 m for northern Merced County, and Helley (1967, fig. 39) shows a range of about 17-70 m for the upper unit and 33-150 m for the lower unit[6/] in the Chowchilla area (table 1).

[6/] This latter figure represents the total thickness of arkosic sediment below the buried paleosol believed to be the intra-Turlock Lake soil and above the Mehrten Formation. The thickness may therefore include the Laguna Formation as well as the lower unit of the Turlock Lake.

The type section of the Turlock Lake Formation is exposed in roadcuts on a hill within Turlock Lake State Park between the lake and the Tuolumne River. Several new roadcut exposures in the surrounding area show the type section to include at least two units separated by an unconformity and well developed buried soil, locally exhumed by post-Turlock Lake erosion. This finding is consistent with the observations of Arkley (1962a), Janda (1966), Janda and Croft (1967) and Helley (1967), who noted the presence of a major buried soil within the Turlock Lake Formation at widespread localities. Because the unconformity and buried soil were not mentioned in the original description, because new exposures in the type area now exist, and because we did not find a stratigraphic sequence which corresponded in all respects to that previously described, the type section is redescribed below.

Type section, Turlock Lake Formation

Location: Series of roadcuts along Lake Road in E 1/2SW 1/4, sec. 31, T. 3 S., R. 13 E., proceeding eastward down the hill southwest of park headquarters, Turlock Lake State Park, Cooperstown 7 1/2' quadrangle, Stanislaus County (pl. 1)

unit	thickness m	cm
Top of hill; topographic surface with up to 25-30 m of local relief		
Turlock Lake Formation--		
Upper unit		
10. Sand; weathered brown to light brown; very poorly exposed at crest of hill	0.1	
9. Silt; not well exposed; probably similar to unit 8 below	2.3	
8. Silt; light gray to white, reddish yellow to brown mottles in sandy zones and along laminae; contains interstratified very fine sand; crenulated bedding with amplitude of 2-5 cm	4.9	

	m	cm
7. Fine sand; light gray to light brown with abundant reddish yellow mottles; contains scattered small pebbles up to 1.5 cm maximum diameter; poorly sorted; relatively massive with some general indication of thick bedding; upper part grades laterally into overlying silt toward west	1.1-1.5	
6. Sand; light brown to brown; medium to coarse grained, pebbly; very friable; little weathered	1.4	
Total exposed thickness of upper unit	9.8-10.2 m	

	m	cm
Erosional unconformity with up to 4 m of local relief		
Lower unit (?)		
5. Sand; light brown with reddish yellow mottles; medium to fine grained; massive with faint horizontal stratification; scattered small pebbles; appears to lens out toward east and is covered by upper unit silts to west; these beds appear west of 4 and directly underlie the unconformity at that position; they appear to stratigraphically overlie 3, but exposures between the two outcrops are poor	4.0 minimum (base not exposed)	
4. Poorly exposed zone of contact between upper and lower units; medium sand with scattered cobbles, weathered reddish yellow to reddish brown; presumably part of lower unit	0.9	

Lower unit	m	cm
3. Gravel; strongly weathered reddish brown to red; red clay coatings around fragments; contains coarse interstitial sand and interstratified sand beds; gravels contain up to 50 percent of clasts as large as 10 cm in maximum diameter; buried soil Bt horizon passes down through this unit into unit 2 without break; thick bedding, somewhat obscured by soil development; not well exposed	7.0	

	m	cm
2. Coarse sand with prominent gravel; weathered to uniform reddish brown to red; many decomposed pebbles; massive; about 25 percent gravel with clasts up to 10 cm in diameter (mode about 2.5 cm); poorly exposed; contains fragments of underlying units; subcontinuous pedogenic clay films around clasts indicate very deep weathering; soil peds are coarse subangular blocky and strong in upper part of unit becoming weaker with depth and eventually disappearing; this stratigraphic unit appears to fall within the stripped B2t and upper C horizon of the buried post-lower unit, pre-upper unit soil	3.8	

		m
1.	Silt; gray becoming purplish toward base; with interstratified fine sand; well stratified; relatively unweathered; not well exposed; color is inherited from underlying Mehrten Formation. Contact with Mehrten is not well exposed	3.8

Total exposed thickness of lower unit 19.5 m

Total exposed thickness of Turlock Lake Formation 29.3-29.7 m

Unconformity

Mehrten Formation: andesitic sandstone and siltstone; base not exposed

Bottom of hill (east side)

A relatively new roadcut just west of the campground access road junction provides a much better exposure of the lower unit in the type area. This section is described below

Reference section A, Turlock Lake Formation

Location: roadcut in NE 1/4SW 1/4, sec. 31, T. 3 S., R. 13 E. along new highway just west of junction with campground access road, Turlock Lake State Park, Cooperstown 7 1/2' quadrangle, Stanislaus County (pl. 1)

unit	thickness m	cm
Flat area at top of roadcut		
Turlock Lake Formation:		
Lower unit		
7. Gravel; very strongly weathered to red and reddish brown (mapped as Corning soil series); contains interstitial coarse sand, not well exposed, expecially at top; overlain unconformably by basal silts of upper member at top of hill (see type section)	2.4 minimum	
6. Coarse to medium sand; weathered reddish brown; fairly massive but bedding is affected by soil formation; contains a few scattered pebbles; B horizon of exhumed buried soil extends down about 2.1-2.4 m within unit, Clox horizon to about 3.4 m	4.0	

	m	cm
5. Medium-grained sand; yellowish-brown to light brown with strong brown mottles along bedding planes; contains a few thin pebble lenses and beds, all pebbles small; fairly massive but some laminae are evident; well consolidated but not appreciably weathered	4.9	
4. Medium sand becoming finer near base; light brown; fairly massive but shows some poorly defined beds 25-30 cm thick	1.8	
3. Silt and silty clay; gray to light gray; very well stratified and internally laminated; very well sorted; contains some interstratified fine sand beds; internal parallel laminae especially well developed near base, in beds 3-5 cm thick; moderately well consolidated; possibly lacustrine	5.2	

	m	cm
2. Transition zone: silt; somewhat purplish; very well stratified; generally similar to 5 above except for color		60-90
Total thickness of lower unit	≈19 m	

Unconformity

Mehrten Formation:

1. Andesitic sandstone with some pebbles and cobbles and well-developed large-scale cross-bedding

Base of roadcut

The second roadcut west of this location reveals very strongly weathered gravels with a large proportion of decomposed cobbles and pebbles at an elevation below the basal silt and clay of the lower unit. These gravels may be Laguna or, alternatively, they might represent a still older alluvial phase of the Turlock Lake Formation. As noted above, Ira Klein (written commun., 1975) has recognized three strongly developed paleosols above the marine Tertiary and beneath the Corcoran Clay Member of the Turlock Lake. These paleosols occur in U. S. Bureau of Reclamation cores from northeast of Madera to a point about 16 km southwest of Madera, indicating at least three periods of prolonged or intense weathering prior to upper Turlock Lake time. The soils cannot be traced further westward across the valley axis.

Sandstone and claystone of the Mehrten Formation crop out down the steep bluff to the campground beneath the described exposure. To the east, down the access road to the campground, arkosic sediment which may be part of either the Laguna or Turlock Lake overlies the Mehrten at a much lower elevation than the Mehrten-Turlock Lake contact at the roadcut, indicating that the unconformity at the top of the Mehrten has a minimum relief of 10 m at this location.

The Turlock Lake Formation in its type area, Turlock Lake and vicinity, includes both the lower and upper units of the formation and provides a reasonably good representation of typical lithologic units. Neither the type section nor the reference section, however, clearly exposes the contact between the two members. Therefore an additional reference section is included below to supplement the type section.

Reference section B, Turlock Lake Formation

Location: series of roadcuts leading up Negro Hill, SW 1/4NW 1/4 sec. 4, T. 5 S., R. 14 E., about 0.8 km north of Snelling, Snelling 7 1/2' quadrangle, Merced County (pls. 1 and 3)

unit	thickness m	cm
Summit of hill south of the road; dissected topography with up to 20 m of local relief		
Turlock Lake Formation:		
Upper unit		
4. Not exposed; mapped as Montpellier soil series; presumably coarse sand similar to units 5 and 6 of Reference section A, judging from nearby roadcuts at the same elevation	11.6	
3. Silt and sand grading upward into medium and coarse sand; light gray becoming buff to pale red-brown upward	4.2	
Total thickness upper member	15.8 m	

	m	cm
Erosional unconformity with several meters of local relief		
Lower unit		
2. Coarse silt and very fine sand; weathered red-brown to buff; massive; contains scattered pebbles up to 2.5 cm maximum diameter; silt grades upward into very fine sand; iron-silica hardpan (Rocklin soil series) developed in this material is a stripped Bsim horizon of a buried paleosol formed on the lower unit prior to deposition of upper member; this soil extends into the underlying gravels and forms a prominent topographic bench about halfway up the hillslopes in this area marking the contact between the two units (pl. 3)	1.5	
1. Gravel; weathered buff to light reddish brown; fragments up to 30 cm in diameter; mean diameter 2.5-4 cm; contains interstitial sand; well indurated; base not exposed	7.3	
Bottom of hill		
Total exposed thickness of lower unit	8.8 m	
Total exposed thickness of Turlock Lake Formation	24.6 m	

Grain size tends to coarsen upward in both units of the Turlock Lake. The lower unit in reference section A clearly shows this pattern, but the coarse upper part of the upper unit has been stripped by erosion in the type area. However, the coarse-over-fine stratigraphic sequence is seen in alluvium derived from all major glaciated river basins draining to the northeastern San Joaquin Valley (Janda, 1966; Janda and Croft, 1967; Arkley, 1962a). Parts of the sequence may be seen at many locations. Some of the best exposures are along Turlock and Oakdale Roads in sections 22, 23, 26, 27 and 35, T. 5 S., R. 2 E. Cressey and Winton 7 1/2' quadrangles, Merced County. Thick well-bedded fine sand, silt, and clay along the base of the bluffs of Dry Creek progressively pass into sand and coarse pebbly sand at higher elevations to the west along both of these roads. Coarse uppermost alluvium is well exposed in roadcuts just east of the Hall Road-East Avenue intersection, secs. 14 and 23, T. 5 S., R. 11 E., Cressey 7 1/2' quadrangle, Merced County, where the well developed Montpellier soil formed on the coarser material appears to have been only slightly eroded. Soil survey map units in much of eastern Stanislaus, Merced, Madera, and Fresno Counties serve to distinguish the uppermost coarse alluvium in both units (Montpellier or Cometa soil series; occasionally Rocklin) from underlying fine sand and silt (Whitney, Rocklin, Trigo, Pollasky) (pl. 3, fig. 2).

The Turlock Lake Formation is not easily distinguished from the underlying Laguna Formation, especially where the intervening North Merced Gravel is absent or where its relation to the deposit in question is not clear. Our experience indicates that the following criteria are useful means of differentiating the two formations, although such differentiation is not everywhere possible:

1) Gravel beds (China Hat Gravel Member and underlying beds) in the upper part of the Laguna Formation tend to be thicker, coarser, and less sandy than comparable beds in both units of the Turlock Lake Formation.

2) Clasts of nonquartzose rock in the China Hat and Laguna tend to show thick weathering rinds and are often partially to thoroughly decomposed, so that they can be cut through with a knife. Clasts in the Turlock Lake are normally fresher, except within the A and B horizons of the soil zone.

3) Feldspar in the Laguna tends to be white and chalky, and biotite tends to be altered or bleached. In contrast, feldspar and biotite in the Turlock Lake Formation beneath the B horizon are frequently fresh or nearly so.

4) The silty or fine sand beds of the Laguna tend to be slightly more compact and better consolidated than do similar beds in the Turlock Lake.

5) The pH of the Laguna and China Hat soils is very low, usually 4.5 or less; pH in Turlock Lake soils goes down to about 5.2 but not below (table 2)

6) Laguna soils, where not severely eroded, have hues of 10R; most Turlock Lake soils give 2.5 YR hues, or, where eroded, 5 YR hues.

7) Clay coatings over ped surfaces extend down more than 4 m in the China Hat soils, but rarely more than 2 m in fully developed Turlock Lake soils.

The weathering and soil criteria must be used with particular caution, since these parameters vary with depth and virtually all post-Turlock Lake and post-Laguna soils are eroded, in places deeply.

Lower unit

The lower unit of the Turlock Lake Formation appears to be everywhere overlain by the upper unit. Consequently it crops out only in very small areas near major river valleys such as those of the Stanislaus, Tuolumne, Merced, and San Joaquin where erosion has removed the upper unit. The resistant nature of the buried soil, commonly stripped to an iron-silica hardpan or thick argillic horizon, has locally allowed partial exhumation of the lower unit. We have found that the lower unit can be identified and separately mapped where well exposed. It has been recognized over broad areas in U. S. Bureau of Reclamation cores and drillers logs (Arkley, 1962a; Janda, 1965; Helley, 1967) and may represent more than one period of aggradation.

The lower unit includes a sequence of gravel and coarse sand that overlies finer sand, silt, and clay of possible lacustrine origin. The clay, silt, and fine sand are well sorted and occur in thin well defined horizontally laminated beds near the base of the unit. The Montpellier and Rocklin soil series have been mapped on the exhumed surface of the lower unit. The Whitney soil is also mapped on the lower unit, especially on sideslopes where erosion has exposed the finer sediment underlying the gravels and sand near the top of the lower unit. In a few places where gravels occur within the lower unit, usually near the top, the Corning soil series has been mapped--for example, at the type area of the Turlock Lake Formation.

The age of the lower unit must substantially exceed 600,000 years, judging from the strong development of the buried intra-Turlock Lake soil (see below). The unit in reference section A is paleomagnetically reversed and may include a normal interval, according to preliminary results from sampling by Duane Packer (oral commun., 1976). If the normal event is confirmed by further sampling, it might represent the Jaramillo normal polarity event (0.89-0.95 m.y.), making the lower unit of the Turlock Lake about 900,000 years old.

Upper unit

The upper unit of the Turlock Lake Formation underlies a rolling topography having up to 30 m or more of local relief. It caps the lower unit and older deposits along the base of the foothills, where it stands above the highest exposures of the Riverbank Formation.

The upper unit records a single major episode of alluviation. In the Merced River area it appears to include only sand and silt, except in terraces upstream from Merced Falls. Gravel beds, however, occur in the upper unit in the Fresno and San Joaquin River fans. Like the lower unit, the upper unit contains well stratified internally laminated silt and fine sand that may be lacustrine in origin. These deposits make up a relatively large proportion of the upper unit, especially in the middle and basal parts of the section. They are probably correlative, at least in a general sense, with the Corcoran Clay Member of the Turlock Lake and Tulare Formations, a prominent aquiclude in the subsurface of the San Joaquin Valley (Frink and Kues, 1954; Janda and Croft, 1967; Croft, 1972).

The age of the upper unit appears to be about 600,000 years. This estimate is based on stratigraphic relations on and beneath the upper San Joaquin River fan (Janda, 1965, 1966; Janda and Croft, 1967). The Friant Pumice Member occurs within and near the base of the upper unit of the Turlock Lake Formation in that area and has been dated by potassium-argon at 600,000 years old (Janda, 1965, 1966). In the subsurface the Friant Pumice Member is believed to rest conformably on the Corcoran Clay Member of the Tulare Formation (Janda and Croft, 1967), making the Corcoran a member of the Turlock Lake Formation in the eastern San Joaquin Valley (fig. 2) as well as a member of the Tulare Formation on the west side of the San Joaquin Valley. The strong degree of post-Turlock Lake soil development is consistent with the radiometric age of the Friant Pumice Member. Vertebrate fossils indicating an Irvingtonian age have been recovered from several localities within the upper unit (Janda, 1965, 1966).

Where the upper unit surface is relatively uneroded and not buried by younger deposits, the Montpellier soil series (table 2) has developed on sandy alluvium at the top of the upper unit of the Turlock Lake Formation. This soil has the following general characteristics:

Montpellier Soil Series (generalized description)

(1) An A horizon 20-60 cm thick; strong brown hues 7.5YR to 5YR, moist chromas 3 to 4, pH 5.7 ± 0.5

(2) A massive, compact B horizon up to 1.5 m or more thick; red-brown to red, hues usually 2.5YR, moist chromas 6 to 8; pH similar to A horizon or slightly higher; strong, coarse, sub-angular blocky peds tending toward prismatic; moderately thick, continuous clay films on ped faces, around clasts, and filling pore spaces, becoming thinner and less continuous with depth

(3) Somewhat consolidated sand at 2.4-3.0 m with some clay formed in place, but otherwise not strongly weathered; fresh parent material usually more than 5 m.

These traits persist to a considerable extent even in locations where the Turlock Lake soil has been covered by early Riverbank (lower unit) alluvium. The degree of post-Turlock Lake, pre-Riverbank erosional dissection also indicates a substantial time interval between the youngest Turlock Lake and oldest Riverbank alluvial episodes. If the climate during this interval was not significantly different than that during post-Riverbank time, this period appears to have been longer than post-Riverbank time.

Riverbank Formation

Deposits now known as the Riverbank Formation were first recognized in the Merced River area by Arkley (1954) and later named in eastern Stanislaus and northern Merced Counties by Davis and Hall (1959). The term has subsequently been extended to deposits on the upper San Joaquin River fan (Janda, 1965, 1966; Janda and Croft, 1967, Huntington, 1971), the Chowchilla River fan (Helley, 1967) and in the Mokelumne and American River drainages (Shlemon, 1967a, 1967b, 1971, 1972). We have subdivided the Riverbank Formation into three informally designated units (table 3) on the basis of superposition, paleosols (table 2) and

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TABLE 3 NEAR HERE

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buried soils, and on geomorphic evidence (fig. 2. pl. 3). Helley (oral commun., 1977) tentatively recognizes three Riverbank units in the eastern Sacramento Valley. All of these units appear to coarsen upward, like those of the Turlock Lake Formation.

Figure 2 near here

Figure 2. Schematic geologic cross section across the Merced River near Snelling, Merced County, showing relation of soils to stratigraphic units and geomorphic surfaces.

Table 3.--Comparison of some characteristics of three units in the Riverbank Formation

Unit	Lower	Middle	Upper
Relative age	Oldest	Intermediate	Youngest
Areal distribution	A few scattered remnants on San Joaquin, Merced, and Stanislaus Rivers	Widely distributed remnants associated with all major rivers and some smaller rivers (Fresno, Chowchilla)	Confined to modern drainageways, including small streams heading in the foothills; not commonly seen on major rivers, probably owing to Modesto channel erosion
Preservation of depositional surface (estimated)	20 percent or less	30 - 60 percent	75 - 100 percent
Local relief of present surface	15 - 25' (5-8 m)	5-15' (2-5 m)	0-5' (0-2 m)
Fan apex position of unit relative to overall alluvial fan	Indeterminate, but close to fan head	Less than 2-3 km from fan head	Usually 10-20 km from fan head
Characteristic soils[1]			
Arkosic, sandy parent material; no hardpan	Snelling, Ramona, strong variant	Snelling, Ramona, normal variant	Snelling, Ramona weak variant
Arkosic, sandy parent material; hardpan	San Joaquin, strong variant	San Joaquin, normal variant Madera, strong variant	San Joaquin, weak variant Madera, normal variant
Nonarkosic, sandy parent material; no hardpan	Not recognized	Academy	Not recognized; Snelling, Ramona mapped in areas of mixed source area
Nonarkosic, sandy parent material; hardpan	Not recognized	Yokohl, strong variant	Yokohl, normal variant

[1] See table 2 for soil properties.

The Riverbank Formation consists primarily of arkosic sediment derived mainly from the interior of the Sierra Nevada, underlying at least three sets of high terraces and coalescing alluvial fans along most of the eastern San Joaquin Valley (pl. 2). The formation is also used here to include locally derived sediment from small drainage basins along the foothills. The Riverbank terraces and fans truncate or are cut into Turlock Lake alluvium or fill post-Turlock Lake gulleys and ravines, and in turn they are cut and filled near the foothills by terraces of the lower member of the Modesto Formation. They slope gently to the west (table 1) beneath interdistributary and fan deposits of early Modesto (lower member) age. The Riverbank as exposed in the northeastern San Joaquin Valley is primarily sand containing some scattered pebbles, gravel lenses, and some interbedded fine sand and silt. Some of the finer grained deposits are well stratified and may have been deposited in local ponds. Well sorted sandy deposits bearing Snelling and Ramona soils may be eolian in some places. In surface exposures, however, lacustrine and eolian deposits are relatively minor. Fine-grained alluvium is not as extensively exposed as in the Turlock Lake and Modesto Formations.

The type section is located on the south bluff of the Stanislaus River in the town of Riverbank. Our stratigraphic notes at this section (where it was described) correspond fairly closely to the description of Davis and Hall (1959, p. 16-17), but because the upper 4.3-4.9 m is the Modesto rather than the Riverbank Formation (see also Janda, 1966, p. 247-248), and because the Riverbank consists of two alluvial bodies separated by a conspicuous buried soil in a fresher bluff exposure just east of the type section, the type section is redescribed below.

Type section, Riverbank Formation

Location: exposures in south bluff of Stanislaus River in NW 1/4 NE 1/4, sec. 26, T. 2 S., R. 9 E., just north of intersection of Jackson and Topeka Streets in Riverbank, Riverbank 7 1/2' quadrangle, Stanislaus County (pl. 1)

unit	thickness m	cm
Top of bluff, about 10 m above river level; subdued dunal topography		
Modesto Formation:		
Upper(?) member		
4. Disturbed material; probably sandy alluvium and eolian sand (Delhi soil series is correctly mapped elsewhere in the vicinity); lower contact not well exposed	1.2	
Unconformity(?)		
Lower(?) member		
3. Sand; medium to fine-grained; buff; massive; well sorted; becomes coarser toward base; may be either eolian or fluvial	2.1-2.4	

	m	cm
2. Silt; light gray; coarser lenses weathered yellowish brown; variable in thickness; well stratified, showing prominent cross stratification and internal cross lamination; includes three or more distinct sandy and pebbly lenses, as much as, 10 cm thick, the lowest of which is predominantly gravel (2.5 cm maximum diameter); eastward along outcrops silty beds up to 76 cm thick crop out beneath the lowest gravel lens; overlies clearly visible unconformity	0.76-1.2	

Unconformity

Riverbank Formation:

Upper unit

1. Pebbly sand, equivalent to unit 3 of Davis and Hall (1959), underlain by deposits as described by these authors except that their unit 8 (silt or clay) is locally much thicker than 30 cm (1 ft)	12.3	

A buried soil with incipient hardpan (similar to the Madera, normal variant, but with a structural and textural B horizon more like the Snelling, weak variant), developed on the Riverbank sediments, is briefly described below:

0 to 15-30 cm	B2b	weak, argillic horizon; no evidence of translocated clay; some weak cementation by silica, iron, and calcium carbonate in lower part; surface has been somewhat eroded
30-46 cm	BCb	transition zone showing less aggregation
46-114 cm	C1b	orangish-brown zone of oxidation
114-about 190 cm	C2b	yellowish-brown zone of oxidation, less well aggregated; base not clearly exposed
over 190 cm	Cnb	fresh, unweathered, loose sand and silt

An excellent exposure just east of the type section, located directly beneath a convalescent home on the bluff, shows that the Riverbank consists of at least two units, and reveals a clear unconformity between the Riverbank and overlying early Modesto deposits. This section, described briefly below, also demonstrates a definite upward coarsening within the upper unit of the Riverbank and the presence of relatively coarse material at the top of the lower(?) Riverbank unit. The tentative assignment of the lower 7.6 m of this section to the lower unit is based on the characteristics of the buried Snelling (strong variant)[7/] soil (table 2), which is more strongly developed, even where buried here by the upper unit, than the normal Snelling formed on the middle unit of the Riverbank. This soil, however, is much shallower (thinner Bt, B3, Cox) than any post-Turlock Lake soil seen in this region, even where the Turlock Lake has been buried by the middle unit of the Riverbank Formation, a common occurrence throughout the northeastern San Joaquin Valley, especially in eastern Madera County.

[7/] The soil variants used here are our informal categories for soil taxadjuncts that may be taxonomically outside the defined range of properties for a given soil series. They represent differences in soil profile development that are recognizable in the field and have been verified by laboratory data (Marchand and Harden, 1976; Harden and Marchand, 1977).

Reference section A, Riverbank Formation

Location: about 30 m to the east of the type section

Unit	thickness m	cm
Top of bluff		
Modesto Formation:		
Upper member (bearing Hanford soil)		
6. Fine to medium sand with scattered pebbles and occasional cobbles; upper part is disturbed in many places; weathered pale brown; relatively massive; pinches out to east under convalescent home	0-2.0	
Unconformity		
Lower member (bearing Dinuba soil, eroded)		
5. Coarse pebbly sand in channel bottom grading rapidly upward into fairly well stratified very fine sand and silt; gray to pale gray-brown becoming browner upward. Soil on silty beds, buried to west by unit 6, is analogous to a Dinuba soil with recognizable Bt horizon	0-3.5	
Total thickness of Modesto Formation	1.5-5.5	

Unconformity

Riverbank Formation

Upper unit (bears Madera soil, eroded; to the east this unit is truncated by the early Modesto channel deposit)

	m	cm
4. Coarse pebbly sand; weathered strong brown to light reddish brown becoming light brown near base; in thick (up to 1 m), massive beds with thin interstratified beds of silt and fine to medium sand; pebbles up to 3 cm maximum diameter	up to 2.5	
3. Very fine sand and sandy silt; grayish brown to gray, fairly well stratified in beds 2-6 cm thick, beds coarser toward the top; transitional into overlying unit; red zone at base may be result of ground-water movement along top of underlying buried soil, or could be an eroded remnant of the middle unit	up to 2.5	

Unconformity

	m	cm
Lower(?) unit (bears Snelling, strong variant soil, eroded)		
2. Medium to coarse sand; weathered red-brown at top, gray to buff near base of exposure; contains a few scattered pebbles up to 2 cm diameter; the strongly developed buried soil developed on this material appears to be a Snelling, strong variant; B^2 horizon is red (2.5YR 4/4 m), 12-20 cm thick, and shows thick continuous clay films on ped surfaces; B^3 horizon gives way at about 1-1.5 m to oxidized C horizon, which in turn is underlain by nearly fresh, very slightly consolidated sand. Relatively unweathered silt beneath the sand has been exposed in orchard excavations near the bluff edge. To the east this unit is truncated by the upper unit channel	3.7	

	m	cm
1. Covered interval	3.9	

Base of bluff; terrace underlain by Post-Modesto II deposits

Total thickness of Riverbank Formation	up to 12.6 m

The Riverbank Formation comprises at least three distinct and mappable alluvial units in Stanislaus, Merced, Madera, and Fresno Counties (table 3). The type section and reference section A, as indicated above, provide good exposures of the uppermost unit and the upper part of the lower unit. The Riverbank Formation at its type section, however, is truncated by the Modesto Formation so that the characteristic Riverbank topography and soils are not present. Supplementary reference sections are described below.

The age of the Riverbank Formation is uncertain. From pedological evidence it appears to be significantly younger than the Turlock Lake Formation yet older than the last (Sangamon) interglaciation. Hansen and Begg (1970) have reported open-system uranium-series ages of 103,000±6,000 on bone material from the Riverbank Formation. These dates appear too young to us but might well represent a minimum age if the bones have gained young uranium. The Rancholabrean vertebrate fauna associated with the Riverbank (Janda, 1965, 1966) indicates an Illinoian or Wisconsinan age. We suggest an age of about 130,000 to 450,000 years, which would be consistent with the degree of pre- and post-Riverbank erosional dissection and soil development and would allow for deposition of the three units as distinct alluvial episodes, separated by two substantial periods of weathering and incision.

Like the Turlock Lake Formation, the Riverbank shows a variable thickness that tends to increase basinward. Davis and Hall (1959) indicate an approximate thickness of 45-60 m in northern Merced and eastern Stanislaus Counties. Arkley (1962a) suggests a thickness of about 80 m along the Merced River and Helley (1967, fig. 39) shows about 20 m along the Chowchilla River (table 1).

Lower unit

The lower unit of the Riverbank Formation is the least extensive of the three units in its present outcrops (table 3), although its original extent could have been as great as either of the later Riverbank fans. The lower unit is here defined to encompass all deposits older than the middle unit of the Riverbank and younger than the Turlock Lake Formation; it may include deposits from more than one aggradational cycle. It is now preserved only in a few locations on the Stanislaus, Merced, and San Joaquin Rivers (pl. 2). One of the best exposures lies immediately north of the Merced River in the Snelling and Turlock Lake 7 1/2' quadrangles (pl. 3, fig. 2). Most of the original alluvial surface here has been removed, but remnants can be seen standing 5-10 m above the middle Riverbank alluvial surface at an elevation of about 95 m (290 ft) where the westward trend of remnants crosses Cox Ferry Road (N 1/2 secs. 11 and 12, T. 5 S., R. 13 E., Turlock Lake and Snelling 7 1/2' quadrangles).

The soil developed on these remnants is mapped as the Snelling series but is much more strongly developed than the typical Snelling (normal variant) formed on the middle Riverbank alluvium nearby. The relict soil on the lower unit, here termed the Snelling, strong variant, displays a thick reddish-brown (2.5 YR 4/4m) Bt horizon with distinct and semicontinuous clay films over ped surfaces (table 2; see also description below of normal variant exposed in nearby roadcuts). The strong variant of the Snelling could also be considered a weak variant of the Montpellier soil series. Similarly, the strong variant of the Ramona soil, a relict soil on the lower unit of the Riverbank on both sides of the San Joaquin River near Friant (pl.2; Marchand, 1976g, sheet 7) could be considered a weak variant of the Cometa soil.

Soils formed on the lower unit differ from soils formed on the Turlock Lake Formation primarily in the thickness of the Bt, B3, and Cox horizons and depth to fresh, loose parent material (table 2). Lower Riverbank gravelly alluvium containing some locally derived detritus and bearing a Snelling, strong variant soil, overlies a buried Rocklin soil developed on somewhat finer grained, arkosic upper Turlock Lake alluvium in a roadcut several kilometers to the west (SE 1/4 NE 1/4 sec. 28, T. 5 S., R. 12 E., Cressey 7 1/2' quadrangle. Northeast of Cressey and south of the Merced River (W 1/2 SW 1/4 Sec. 9, T. 6 S., R. 21 E.), a buried strongly developed soil (San Joaquin, strong variant) (table 2), stripped to the hardpan, occurs in river bluff exposures in arkosic alluvium about 1 m below a normal variant San Joaquin soil (stripped hardpan and underlying Cox horizon), formed on the middle unit. Another surface occurrence of the lower unit is along Buhach Road between sections 17 and 18, T. 6 S., R. 13 E., Winton 7 1/2' quadrangle, where the lower unit of the Riverbank again overlies eroded Turlock Lake deposits.

An isolated lower unit remnant may also be present east of Oakdale on the south side of the Stanislaus River in sections 7 and 8, T. 2 S., R. 11 E. Here it stands as an island surrounded by Modesto channel deposits, about 10 m higher than the middle unit terrace, which forms a low bluff south of Oakdale. Other examples include the western part of section 26, T. 11 S., R. 30 E., Lanes Bridge 7 1/2' quadrangle, Madera County, where an early Riverbank surface bearing San Joaquin and Ramona soils stands 5-10 m above the well exposed middle unit alluvial surface just north of the San Joaquin River (Marchand, 1976g, sheet 6). The scattered occurrence of the lower unit suggests that it was not as extensive as the Turlock Lake Formation or that it was deposited as a very thin unit and was subsequently eroded over large areas.

Middle unit

The middle unit of the Riverbank Formation is associated with a broad alluvial surface, commonly consisting of thin (1-4 m) but westward thickening sandy alluvium over eroded Turlock Lake Formation. It represents a single aggradational unit. The alluvial surface, unlike that of the lower unit, is extensively preserved and is associated with the Chowchilla and Fresno River basins as well as the major rivers draining the glaciated interior of the Sierra Nevada (table 3). On the fan surfaces near the foothills the middle unit surface stands 5-10 m below remnants of the early Riverbank surface and about 10-15 m above the inset terraces of late Riverbank age (pl. 3, fig. 2).

The deposits of the middle unit and their characteristic Snelling (normal variant) and San Joaquin (normal variant) soils (table 2) are described in the supplementary reference sections below.

Reference section B, Riverbank Formation

Location: Exposures along both sides of Cox Ferry Road on N 1/4 of line between secs. 1 and 2, T. 5 S., R. 13 E., about 0.4 km south of Keyes Road and about 5.5 km west of Snelling, Turlock Lake 7 1/2' quadrangle, Merced County (pls. 1 and 3).

Unit	Thickness m	Thickness cm
Top of roadcut; slightly dissected topography about 30 m above Merced River level		
Riverbank Formation:		
Middle unit		
1. Coarse sand; weathered tan to buff; contains scattered subangular to subrounded pebbles up to 3-4 mm maximum diameter; moderately compact becoming less so toward base; unconformably overlies lower member in which a silica-iron hardpan has developed		

	m	cm
Unconformity with 1-2 m of relief; buried hardpan underlain by somewhat loose, relatively unweathered arkosic sand beneath		
Lower(?) unit		
2. Medium to coarse sand, weathered pale red-brown to pale orange-brown in upper part becoming mottled buff and gray toward base; similar to upper member at this location but contains no pebbles; lower 1-1.2 m are only slightly consolidated; massive with slight suggestion of coarse primary stratification; most of the observed vertical variation is pedogenic.	2.5	
Base not exposed		
Base of roadcut		
Total thickness of exposed Riverbank Formation	6.0 m	

The exposed section of the middle unit described above is thin and contains only sand but is one of the few places where the unit may be seen superposed over the lower unit (see p. 79 for another location).

Reference section C, middle unit of Riverbank Formation

Location: north bluff of the Merced River in second gully west of Cox Ferry Road (below road running westward along the tip of the bluff), NW 1/4 SW 1/4 sec. 11, T. 5 S., R. 13 E., Turlock Lake 7 1/2' quadrangle, Merced County, (pls. 1 and 3)

unit	thickness m	cm
Top of bluff; smooth, relatively undissected surface about 8-9 m below remnants of upper unit to the north and about 20 m above river level		
Riverbank Formation		
Middle unit		
4. Coarse sand; weathered buff to light brown; uniform and massive; contains a few scattered pebbles and granules; any original stratification destroyed by pedogenesis	2.3	
3. Coarse sand; weathered light brown to pale reddish brown; similar to unit 4 above but contains isolated pebbles and layers of cobbles up to 10 cm in maximum diameter; grades laterally into material like unit 1; crude horizontal stratification is apparent at a distance	1.5	

	m	cm
2. Coarse sand; laminae oxidized in upper part but otherwise only slightly weathered; well stratified with fairly abundant pebbles; oxidation becomes less prominent toward base; moderately indurated at top becoming very slightly indurated at base	2.1	
1. Coarse sand; virtually unweathered but some cross laminae marked by minor oxidation; unconsolidated; shows well developed festoon cross stratification and internal cross lamination; many pebbly lenses containing fragments up to 8 cm in diameter become more common toward base; base not exposed	9.1	

bottom of bluff, top of Holocene II terrace

Total thickness of exposed Riverbank Formation 15.0 m

The Snelling soil, normal variant, developed on the reference section sediments, is described below.

Soil description, Snelling series, normal variant

(0-350 cm described by Jennifer W. Harden in backhoe pit close to edge of bluff; soil below 350 cm described by Denis Marchand in natural bluff exposure)

0-46 cm	A1	Sandy loam; pale brown (10 YR 6/3d) and dark brown (10 YR 3/3m); moderate, coarse subangular blocky structure; slightly hard (dry), non-sticky, non-plastic; roots are few medium; pores are abundant medium and common coarse; medium acid (6.0); boundary is clear and smooth
46-70 cm	B1	Heavy sandy loam; light yellowish brown (10 YR 6/4d) and dark brown (7.5 YR 4/4m); moderate to strong, coarse to very coarse prismatic structure; very hard, slightly sticky, slightly plastic; roots are very few; pores are common to abundant medium, and few coarse; clay films are common, thin bridging grains; medium acid (6.0); boundary is clear and wavy.

70-140 cm	B21t	Light sandy clay loam; reddish yellow (7.5 YR 6/6 d), and strong brown (7.5 YR 4/6 m) with reddish brown (5 YR 4/4 m) clay films; strong very coarse subangular blocky to prismatic structure; very hard (dry), slightly sticky, slightly plastic (wet); pores are few coarse and abundant medium; clay films are many, moderately thick, bridging the grains; mildly alkaline (7.5); boundary is gradual and irregular.
140-210 cm	B22t	Sandy clay loam; reddish yellow (7.5 YR 6/6 d), and strong brown (7.5 YR 4.6 m) with reddish brown (5 YR 4/4 m) clay films; prismatic structure breaking to strong, very coarse subangular blocky; extremely hard (dry), sticky and plastic (wet); pores are abundant medium and few coarse; many moderately thick and few extremely thick pore fillings; clay films occur as many moderately thick grain bridges, and as common, moderately thick coats on ped faces; moderately alkaline (8.0); boundary is gradual to diffuse and irregular.

210-386 cm	B3t	Sandy loam; brownish yellow (10 YR 6/6 d), and dark brown (7.5 YR 4/4 m); strong, very coarse subangular blocky structure, extremely hard (dry), slightly sticky (wet); common, moderately thick pore fillings; clay films are common , moderately thick bridging grains; moderately alkaline (8.0).

386-457	C1	Loamy sand; dark yellowish brown to yellowish brown (19YR 4/4m); massive to single grain; layers are platy when dry; nonsticky and nonplastic when wet; lower boundary gradational
457 cm	Cn	Sand with minor pebble lenses; unweathered; grayish-brown to brown (10YR 5/2 to 5/3m); single grain; nonsticky and nonplastic when wet

Reference section D, middle unit of Riverbank Formation

Location: old railroad grade cuts in NE 1/4 NW 1/4 sec. 36, T. 5 S., R. 13 E., just east of Highway 59 about 0.1 km south of Youd Road intersection and about 0.8 km south of the Merced River, Yosemite Lake 7 1/2' quadrangle, Merced County, (Pls. 1 and 2).

Unit	Thickness m	Thickness cm
Top of cut; slightly irregular fan surface about 25-30 m above Merced River		
Riverbank Formation:		
Middle unit		
1. Sand; weathered buff to pale reddish brown; massive; medium- to coarse-grained; very uniform; occasional scattered small pebbles; any primary stratification destroyed by soil development; base not exposed; top not obviously eroded, but other parts of the same topographic surface stand several meters higher	2.7	

Soil description: Snelling, normal variant

0-38 cm	Ap	Sandy loam; dark brown (10YR 3/3m); medium to fine subangular blocky peds, moderately strong; very slightly sticky to slightly sticky and nonplastic to very slightly plastic when wet; distinct lower boundary
38-51 cm	B1	Heavy sandy loam; dark brown (7.5YR 4/4m); medium subangular blocky, moderately strong peds (stronger than Ap); slightly sticky and very slightly plastic when wet; distinct lower boundary
51-99 cm	B21t	Sandy clay loam; dark brown (7.5YR 4/4m); medium to coarse angular blocky, strong peds; sticky and slightly plastic when wet; gradational lower boundary
99-183 cm	B22t	Sandy clay loam; strong brown (7.5YR 5/6m) to yellowish red (5YR 4/6m); moderately strong, coarse angular blocky, becoming weak when wet; some clay coatings on peds but not continuous or abundant; most of clay appears to have formed in place; gradational lower boundary

183-216 cm	B23	Sandy clay loam; dark yellowish brown (10 YR 4/4m); coarse angular blocky tending toward weak prismatic peds, decreasing in strength downward; sticky and slightly plastic when wet; gradational lower boundary not well exposed
216-250+ cm	Cox(?)	Slightly weathered sand, somewhat consolidated, not well exposed

Base of cut

The San Joaquin normal variant and Madera strong variant, soils (table 2) occur where silica-iron hardpans have developed on the middle unit, perhaps owing to impeded internal or external drainage during at least part of the soil development period. A typical San Joaquin normal variant profile, developed on uniform fine- to medium-grained sandy alluvium just north of the above reference section, is described below.

Soil description, San Joaquin, normal variant[8/] (same locality, a few meters to the north).

[8/] This soil is considered a variant of the San Joaquin soil series because the upper 50 cm of the argillic horizon is texturally coarser than the defined limits of the soil series (G. L. Huntington, oral commun., 1976).

0-20 cm	Ap	Sandy loam, dark yellowish brown (10YR 3/4m); medium to fine cloddy, breaking to medium to coarse granular fragments; slightly plastic when wet; clear lower boundary
20-30 cm	A3	Sandy loam; dark yellowish brown (10YR 4/4m); medium to fine subangular blocky peds, moderately strong; slightly sticky to sticky and slightly plastic to plastic when wet; gradational lower boundary
30-56 cm	B1	Heavy sandy loam; dark yellowish brown (10YR 4/4m); medium to fine subangular blocky peds, moderately strong; slightly sticky to sticky and slightly plastic to plastic when wet; distinct lower boundary, becoming gradational in places
56-86 cm	B21t	Sandy clay loam; light yellowish brown (10YR 6/4m); medium to coarse subangular blocky peds, very strong; some thin pore fillings and clay films; sticky and slightly plastic to plastic when wet (more plastic than B1); distinct lower boundary

86-198 cm	B22t	Sandy clay loam; brown (7.5YR 5/4m); coarse columnar breaking to coarse to medium subangular blocky peds, very strong; abundant, continuous clay films and coatings; somewhat friable when moist but generally firm, sticky and slightly plastic to plastic when wet; abrupt lower boundary
198-218 cm	Bsim	Sandy clay loam; yellowish-red (5YR 5/6m); silica-iron cemented hardpan, cementation very strong; tendency toward platy structure at top of pan; clear lower boundary
218-254	Clox	Sandy clay loam; yellowish-red (5YR 5/6m); weakly cemented tending toward coarse subangular blocky structure downward
254-315+ cm	C2ŏx	Sandy loam; yellowish-brown (10YR 5/4m); medium to coarse subangular blocky peds, moderately strong; slightly firm when moist; very slightly sticky and nonplastic when wet

Base of cut; fresh parent material not exposed

The hardpans formed on middle unit surfaces (San Joaquin, normal variant; Madera, strong variant) are thicker and more strongly cemented throughout compared with those of the variant formed on the upper unit. The middle unit pan soils show redder, more clay-rich B2t horizons above the pan than the post-upper unit pan soils (table 2). Completely fresh parent material generally occurs within 3 m of the surface (table 2).

Soils other than those discussed above also occur on the Riverbank Formation. In many areas on the middle unit, clay from the argillic horizons of Riverbank soils has accumulated over the hardpan in local depressions. The Alamo soil series (Typic Duraquoll; Humic Gley soil) is mapped in these locations and frequently displays narrow and sinuous patterns. Sidestream alluvial fans and terraces graded to the upper surface of the Riverbank's middle unit on the Merced, Tuolumne, Stanislaus, and other major rivers flowing from the Sierra Nevada normally bear the Academy, Yokohl (strong variant) Porterville, or Seville series, (table 2). These soils formed on locally derived alluvium from andesitic and metavolcanic source areas. The Yokohl strong variant soil has a strongly developed red argillic horizon underlain by a thick well cemented silica-iron hardpan. The Porterville and Seville are Vertisols (montmorillonitic self-churning soils showing little or no profile development) and are therefore not age diagnostic. Their high clay content, close association with the Yokohl series, and occurrence on surfaces graded to mainstream middle unit terraces and alluvial fans, however, indicate their soil stratigraphic and time equivalence with the Yokohl-San Joaquin-Madera-Snelling-Ramona soil association on the middle unit.

Upper unit

The upper unit of the Riverbank Formation also represents a single aggradational unit. It underlies smooth, nearly undissected terrace and alluvial fan surfaces (table 3) which are relatively low and confined to modern drainageways, including those of minor streams such as Dry Creek (Merced County), Bear Creek, Dutchman Creek, Deadman Creek, and Berenda Creek (pls. 2 and 3; fig. 2). In the east these terraces stand slightly above early Modesto terrace surfaces, but to the west they are overtopped by Modesto fan deposits. In like manner they are inset 10-15 m into older Riverbank or Turlock Lake deposits on the upper fans but open westward and spill out over the middle Riverbank and early Riverbank fans. In many locations the contact between middle and upper unit fan remnants is marked by a decrease in slope (table 1) and degree of dissection and a change from San Joaquin to Madera or Exeter soils.

The upper unit is separated from the middle unit by a moderately developed buried soil. Like the two older units it appears to consist of a coarsening upward sequence of alluvial silts and sands, with thin pebbly or cobbly lenses near the top of the sequence. At one location in Madera County (SE 1/4,SE 1/4, sec. 35, T. 9 S., R 17 E., Kismet 7 1/2' quadrangle) in roadcuts along Avenue 24 just west of the Road 26 intersection, the upper unit unconformably overlies the middle unit, on which a San Joaquin normal variant soil developed prior to burial (only the hardpan and underlying Cox horizons are now preserved). The middle unit in these exposures in turn overlies Turlock Lake, on which an eroded Cometa soil is preserved through burial. The upper unit of the Riverbank at this location underlies a smooth terrace surface higher than the early Modesto terrace at this location and slightly inset into the middle unit and the underlying Turlock Lake Formation. The upper unit, bearing a Madera soil, also overlies the middle unit, bearing a buried hardpan soil, along the south bluff of the San Joaquin River about 1 km west of U. S. 99 (NE 1/4, NE 1/4, sec. 6, T. 13 S., R. 19 E.; Herndon 7 1/2' quadrangle).

The characteristic Ramona[9] (weak variant) soil (table 2) is

[9]The Ramona soil series in Madera and Fresno Counties is a somewhat redder and browner, more alkaline counterpart of the Snelling series in Stanislaus and Merced Counties.

formed on the upper unit at the location noted above. It has a significantly thinner and less well developed Bt horizon than the normal variant Ramona or Snelling formed on the middle unit. The color of the B horizon is about the same, but the Bt peds are weaker; colloidal clay is restricted to pores and thin, discontinuous skins around fragments. These weak Ramona and Snelling soils are distinguishable from the Greenfield soil on the lower member of the Modesto by color, horizon thickness, and other properties as summarized in table 2. Where hardpan soils have developed on the upper unit (Madera, normal variant; San Joaquin, weak variant; Exeter), the Bt horizon above the pan is thin and contains much less pedogenic clay than the San Joaquin, normal variant soils on the middle unit (table 2). The pan itself is usually moderately cemented through only 20 cm or less, very weakly cemented in the 25 cm or so beneath the stronger pan, and then the profile passes rapidly into oxidized but otherwise unweathered parent material. Calcium carbonate seams are frequently observed within the hardpan along joint surfaces. In general all upper unit soils tend to be more nearly neutral than their slightly acid counterparts formed on the middle unit.

The area immediately north of the Merced River in the southeastern part of the Turlock Lake 7 1/2' quadrangle and the southwestern part of the adjacent Snelling 7 1/2' quadrangle, northeastern Merced County (pl. 3; fig. 2) is suggested as a reference area for the Riverbank Formation. All three Riverbank geomorphic surfaces are well displayed in proximity here and the lower and middle units are exposed in several roadcuts, in superposition at one location (see above).

Modesto Formation

The Modesto Formation is composed of mainstream arkosic sediments and associated deposits of local derivation laid down during the last major series of gradational events in the eastern San Joaquin Valley. Gravel, sand, and silt was deposited as a series of coalescing alluvial fans extending continuously from the Kern River drainage on the south to the Sacramento River tributaries in the north. They occur in a wide band immediately east of the San Joaquin Valley axis and to the west of the Riverbank and older fan remnants (pl. 2). Most of the prime agricultural land and many of the major cities of the eastern San Joaquin Valley are located on young alluvial soils associated with the undissected Modesto terrace and fan surfaces. Modesto deposits overlie late Riverbank alluvium and older units as well and are locally incised or covered along modern channels by Post-Modesto deposits.

Davis and Hall (1959) first used the term Modesto Formation for young fluvial deposits in eastern Stanislaus and northern Merced Counties, earlier recognized by Arkley (1954) on the basis of soils and landforms. The formation name has since been widely applied to deposits throughout the eastern San Joaquin Valley (Arkley, 1962a; Janda, 1965, 1966; Janda and Croft, 1967; Helley, 1967; Huntington, 1971; Shlemon, 1967a, 1967b, 1971, 1972). The term Victor Formation (fig. 2) was used by Gale Piper, and Thomas (1939) for deposits in the Mokelumne River area that have since been differentiated into the Turlock Lake, Riverbank, and Modesto Formations. Because the Victor Formation was never clearly defined and includes deposits of significantly different age, we suggest abandonment of the term.

The materials of the Modesto Formation are virtually identical to those of the Laguna, Turlock Lake, and Riverbank Formations, but their association with low terraces and young fans and their moderate to slight degree of erosional modification and soil profile development clearly differentiate them from older alluvium. Modesto deposits are significantly more weathered than Holocene deposits, except for its upper member eolian sand, which generally displays a very weak A/Cox/Cn soil profile. A Wisconsinan age for the Modesto is indicated by the basis of (1) the youthful topography, geomorphic position, and soils, (2) the fact that the Modesto postdates the Riverbank Formation and is separated from it by a major period of weathering that was probably interglacial in magnitude, (3) radiocarbon dating of subsurface deposits correlated with the Modesto Formation (Janda and Croft, 1967; Croft, 1972), indicating an age greater than 9,000 years, and (4) a 14,000-year carbon-14 date on wood beneath the Kern River alluvial fan (see below).

Davis and Hall (1959) give a total thickness of 15-30 m for the Modesto Formation in eastern Stanislaus County. Arkley (1962a) suggests a thickness of about 40 m along the Merced River, and Helley (1967, fig. 39) shows about 20 m on the Chowchilla River fan. These figures are consistent with presently available data, but the section appears to thicken toward the valley axis and toward the south. Much evidence indicates that thickness varies considerably, especially that of the upper member, and that local facies changes within the formation make specific stratigraphic descriptions almost meaningless. For example, the Modesto's type section resembles many exposures of the Modesto toward the basin but differs greatly from exposures above Oakdale along the Stanislaus River, where the Modesto is composed entirely of sand and gravel. Near the city of Merced, the Modesto consists entirely of andesitic detritus, whereas along the major, westward draining rivers, it is predominantly arkosic. Numerous channels within Modesto and older alluvium (Shlemon, 1971) create rapid lateral changes in texture that can often be traced only by means of subsurface information. Similar facies changes occur in the older Laguna, Turlock Lake, and Riverbank Formations but are less evident owing to lack of preservation.

We recognize two informally named members of the Modesto Formation on the basis of topographic expression and position and soil development. In places, these two members can be subdivided into two or more subunits using similar evidence (fig. 3, pl. 4). In some areas, these

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Figure 3 near here

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subunits are associated with mappable geomorphic surfaces (alluvial fans or terraces).

The type section of the Modesto Formation apparently includes both its lower and upper members. This section is redescribed below because much of the material originally identified as Modesto is actually Riverbank alluvium exposed beneath an eroded buried soil at about 4.9-5.2 m depth.

Figure 3. Schematic geologic cross section across the Merced River west of Stevenson, Merced County, showing relation of soils to Modesto and Post-Modesto deposits and geomorphic surfaces

Type section, Modesto Formation

Location: series of cuts exposed in private road in NW 1/4, SW 1/4 sec. 1, T. 4 S., R. 9 E., down south bluff of Tuolumne River, just east of Mitchell Road Bridge (note slightly different location from that of Davis and Hall, 1959, p. 20 which is west of the bridge and presently overgrown by brush) Ceres 7 1/2' quadrangle, Stanislaus County (pl. 1).

Unit	Thickness m	cm
Top of bluff; smooth surface of late Modesto alluvial fan about 17 m above river level; surface appears to be disturbed in most places		
Modesto Formation		
Upper member		
8. Fine- to medium-grained sand; contains scattered granules; light brown; appears massive but stratification may have been destroyed by soil development; abrupt basal contact marked by platy calcium carbonate several centimeters thick and thin lenses of fine gravel and sand with orangish oxidation, all within a 5-cm zone (unconformity?)	1.5	

	m	cm
Unconformity(?)		
Lower(?) member		
7. Coarse silt and interstratified fine sand somewhat more compact than unit 8 above; light gray to gray with yellow-brown and brown mottling throughout; oxidized, strongly calcareous root, crevice, and burrow(?) fillings; becomes sandier toward base except for 20-30 cm silt bed just above unit 3; moderately well stratified; silt beds show weak parallel lamination; upper part has calcium carbonate cement (probably pedogenic and related to stripped buried soil(?) formed on lower member); somewhat indurated	1.2	
6. Fine sand; light gray to buff with very prominent yellowish brown to reddish brown oxidation marking coarser beds and laminae; well stratified and internally laminated	30	

	m	cm
5. Silt with interstratified fine sand; similar to unit 2 above but lacks abundant root casts		66
4. Medium sand with interstratified fine sand; medium gray with some yellowish brown oxidation along laminae; fairly well stratified and cross laminated; appears to be lenticular		10
3. Silt with some fine sand; greenish-gray with brown to reddish brown mottling throughout, especially toward base, slightly indurated; generally massive with some cross stratification (30-cm beds); distinct boundary at base when viewed at a distance, but hard to pinpoint exactly on the outcrop owing to water table effects along unconformity	1.2	
Total thickness of Modesto Formation	5.0 m	

	m	cm
Unconformity		
Riverbank Formation		
Upper unit		
2. Interstratified sand and silt, as described by Davis and Hall (1959, p. 20-21, unit 10-21); upper 64 cm is stripped B2 horizon of buried soil similar to the Snelling, weak variant, but somewhat less well developed; in places there is a weak iron-silica hardpan about 35 cm thick underlain by a platy, 10-cm transitional zone to a 45-cm oxidized Clox horizon; at all locations this buried soil is less well developed than the unburied upper Riverbank paleosol but better developed than soils formed on the lower member of the Modesto	5.5	
1. Silt and sand; not well exposed; base of river bluff; surface of Holocene II terrace	5.5	
Total thickness of Riverbank Formation	11.0 m	

The weak buried soil(?) in the type section has demonstrable counterparts on the lower fans west of Madera (cf. map units of Ulrich and Stromberg, 1962, for example, Grangeville, Hanford, Pachappa (on upper member) over hardpan (buried Fresno soil formed on lower member). The presence of these moderately to weakly developed soils between the lower and upper members of the Modesto and recognizable differences in relict soils formed on the lower member and those formed on the upper member suggest a period of weathering and nondeposition between two alluvial events. Judging from the intra-Modesto soil, this time interval must have been longer than Post-Modesto time but shorter than the Riverbank-Modesto hiatus.

Lower member

Alluvial fans associated with the lower member of the Modesto Formation cover an extensive part of the northeastern San Joaquin Valley, but appear to be mostly covered by younger fan deposits south of Fresno and by younger eolian sand on the Merced River fan toe. The lower member is also thicker than the upper member: the lower member is up to 25 m thick or more, whereas the younger alluvial fill rarely exceeds 8-10 m, even along channelways.

The lower member is in places associated with two terrace-fan surfaces (representing phases of the lower member), the older of which is usually covered by the younger or has been removed by erosion. At the time of writing we are unable to determine if there were two early Modesto alluvial fills, or if the late surface is a strath cut into the lower member. One of the best examples of both surfaces is in the Oakdale 7 1/2' quadrangle (secs. 9, 10, and 17, T. 2 S., R. 11 E), where remnants of the older surface stand about 4-5 cm below the upper surface of the middle unit of the Riverbank Formation and about 3 m above a channelway of the younger surface. Both surfaces are relatively smooth and show dissection only near bluff edges where some gullying has occurred.

Although the lower member of the Modesto is composed primarily of sand, a substantial proportion of the deposits is well stratified silt and fine sand, especially near the base of the unit and toward alluvial fan toes. Some of this fine sediment may be of local lacustrine origin, like that of the Laguna, Turlock Lake, and Riverbank Formations. Gravel also makes up a significant part of the lower member, particularly close to the foothills near or above the lower Modesto fan apexes. The lower member includes a large amount of locally derived detritus, largely andesitic, from drainages heading in the foothills.

The surfaces of the lower member bear a variety of soils, the most characteristic of which are the Borden and Greenfield series. These soils have minimal argillic horizons with 10YR to 7.5YR hues. The profiles are shallower, less acid, and not as red as those developed on Riverbank alluvium, and they lack silica-iron hardpans (table 2). Along the Chowchilla River N1/2 sec. 8, T. 9 S., R. 17 E., Le Grand 7 1/2' quadrangle) two lower member surfaces bear Borden soils with somewhat different degrees of profile development. Calcium carbonate-silica-cemented hardpans with overlying argillic horizons (Fresno soil series) have developed under impeded drainage in early Modesto overbank and floodbasin rim deposits. Stringers of less well developed basin soils (Traver, Dinuba (with Bt horizon)) passing through areas of the more strongly developed Fresno, Waukena, and Pond soils may represent channels within interdistributary deposits of the same age or a younger phase of lower member deposition (see above). A generalized description of the Greenfield soil series, as developed on uneroded well drained arkosic alluvial sand, is given below:

0-46 cm	A or Ap	Sandy loam; brown (10YR 5/3 m); medium to coarse subangular blocky, clods moderately strong
46-102 cm	Bt	Sandy clay loam; brown to pale red-brown (7.5YR or 10YR hue, 4 chroma); medium to coarse subangular to angular blocky peds, moderately strong to strong; clay fills pores and thinly coats some fragments but not ped surfaces
102-150 cm	Clox	Sandy loam or loamy sand; brown or yellowish brown (10YR 5/3 to 5/4 m); oxidized but otherwise only slightly weathered and only slightly aggregated
150 cm^{+}	Cn	Sand, single-grain; unweathered and unconsolidated; light gray to pale brown (10YR 5/2 or 6/2m)

The Ryer soil series is commonly mapped on alluvium of andesitic source associated with sidestream terraces that grade to the lower member surfaces on the mainstream (pl. 3, fig. 2).

Recognizable facies of early Modesto age include channel deposits, interdistributary and floodbasin deposits, colluvium, and eolian sand, the latter deposited widely over the Merced River fan toe and along the south side of early Modesto terraces. The Atwater soil series, which has a distinct textural B horizon, is mapped on the lower Modesto eolian sand. These eolian materials are better sorted than the alluvial deposits from which they were apparently derived but much less well sorted and rounded than typical eolian dune sands, suggesting a short transport distance. Their geographical location close to the apparent fan and terrace source areas also indicates limited transport.

The lower member is as yet undated except for a tentative open system uranium series age (29,407±2027 years) on bone in basin alluvium bearing a Dinuba soil north of Modesto (E. L. Begg, oral commun., 1975). This date is probably a minimum age for the lower unit. If the lower unit of the Modesto is in part glacial outwash, it may be correlative with isotope stage 4 of the marine climatic record, presently dated at about 70,000 years (Hays, Imbrie, and Shackleten, 1976; Broecker and Van Donk, 1970).

Upper member

The upper member of the Modesto Formation is exposed in a series of up to four terraces and fans associated with major Sierra Nevada rivers (including the Fresno and Chowchilla Rivers) tributary to the lower San Joaquin River (pl. 2)and also form two or more terraces along the lower San Joaquin River (pl. 4; fig. 3). We have been able to distinguish only one or two correlatable terraces along smaller streams heading in the foothills. On most of the major rivers, terraces associated with the lower member open up into fans 2-20 km east of the lower San Joaquin River. The upper member may be recognized by its topographic position between the lower Post-Modesto terrace and flood-plain surfaces, and the higher terraces and fan surfaces of the lower member and of the Riverbank Formation. Unlike the Post-Modesto surfaces, the longitudinal profiles of the upper member surfaces converge significantly downstream toward the modern river profiles (table 1).

The upper member includes deposits comprising several facies, many of them mappable. It is primarily composed of arkosic coarse sand and gravel that gives way to fine sand and silt near the lower San Joaquin River. Typical exposures of crossbedded coarse sand and gravel may be seen in the Munn and Perkins Quarry (SW1/4 sec. 15, T. 2 S., R. 9 E.), on the north side of the Stanislaus River and 5 km southeast of Escalon (Escalon 7 1/2' quadrangle). Some finer grained deposits of the lower member are also exposed beneath the upper member toward the east end of the quarry. Locally derived material, usually andesitic in composition, is associated with sidestream terraces graded to the main-stream terraces and is considered part of this member. The Wyman and Marguerite soil series, which have somewhat more strongly developed profiles than those formed on arkosic sediments of the same age, are commonly mapped on these sidestream terraces. Eolian sand bearing relatively weak thin A/Cox/Cn soil profiles (Delhi, Hilmar) conformably overlies alluvium of the upper member; the associated dunes are truncated by Post-Modesto terrace surfaces (pl. 4, fig. 3), indicating deposition during latest Modesto time. These eolian deposits are very extensive, especially on the toe of the Merced River fan. Young colluvial deposits in the foothills grade into late Modesto terraces and bear similar soils.

At least four terrace-fan surfaces are associated with the upper member. At present we are uncertain whether these surfaces represent separate alluvial fills, in which case they could be designated as sub-units of the upper member, or whether the younger surfaces are erosional features cut across one early fill. Gordon Huntington (oral cummun., 1976) reports evidence of four separate fills associated with the Kings River in Fresno County and along the Tuolumne and Stanislaus Rivers several of the terraces appear to open onto fans, suggesting separate fills. In this report we refer to the four surfaces as representing four phases. The geomorphic surface associated with phase 1 (the oldest) was probably the most extensive originally but seems in many areas to have been modified by phase 2 erosion or covered by phase 2 deposits. Phase 1 surfaces are best preserved on the upper parts of Modesto fans and as the highest upper member terraces, for example along the Stanislaus River at the town of Riverbank. Phase 2 surfaces are most readily recognizable as channels cut into phase 1 surfaces along the lower Merced River (pl. 4, fig. 3), on the south side of the San Joaquin River immediately west and southwest of Herndon (Herndon channel), and on the west side of the Kings River southwest of Sanger (Sanger 7 1/2' quadrangle). The alluvium in the channels lies 2-5 m below the surrounding phase 1 fan surface and contains coarser material than the adjacent fan, suggestive of a separate alluvial fill. Phase 3 is recognizable as a terrace between phase 2 and phase 4 terraces on the Tuolumne and Stanislaus Rivers and as a few small terrace remnants along the San Joaquin River. Phase 4 terraces (youngest) lie in narrow bands along the present rivers, closer in elevation to the Holocene terraces than to phase 2 or 3 surfaces. Near fan toes, cross cutting soil units with associated leveelike topography suggest successive deposition (pl. 4, fig. 3). All four terraces can be crossed in sequence along Henry Road north of the Stanislaus River (Escalon 7 1/2' quadrangle), about 5-6 km southeast of Escalon, but the phase 1 and 2 terraces here are veneered by upper Modesto eolian sand.

The best developed upper member soils (Pachappa, Oakdale, Hanford, strong variant, Honcut, strong variant), usually associated with the oldest surface (phase 1), have thick AC or weak cambic B horizons (table 2) overlying oxidized C horizons. Their B horizon hues of 10YR tend toward 7.5YR in places, especially toward the north in Stanislaus County, and their maximum chromas are 4. Pore fillings of clay are common, but the pores usually less than half filled and thin, very discontinuous clay coatings are only locally evident on the surface of clasts. Soil structure is fine to coarse subangular blocky, with weak to moderate ped strength. Less developed Hanford, Grangeville, Cajon, Wunjey, and Visalia soils with deep Ap/AC/Cl/Cn profiles (table 2) characterize phase 2 and 3 surfaces. Tujunga and some coarse Hanford soils with similar but thinner profiles occur on the more restricted stringers and narrow terraces associated with the youngest surface (phase 4). On the Chowchilla and Fresno River fans, the four phases may be interpreted from crosscutting patterns shown by the soil map units of Ulrich and Stromberg (1962): Pachappa and Chino on phase 1; Grangeville and Hanford on phase 2; Cajon, Visalia, Wunjey, and Hanford (Hfa) on phase 3, and Tujunga on phase 4. Although soil formation on the four terrace-fan surfaces changes slightly with age, the influence of even minor differences in parent material and climate tends to overshadow the effects of time. Well drained soils formed in comparable parent materials tend to be slightly better developed toward the north (Stanislaus River terraces) and toward the foothills, probably owing in part to the increased effective leaching potential (precipitation minus actual evapotranspiration) but perhaps also to the higher percentage of Mehrten andesitic detritus to the north and east. The time interval between the deposition or erosional planation that formed the terraces was apparently very brief, judging from the similar nature of the relict soils formed on the four surfaces.

The age of the upper member is probably bracketed by carbon-14 ages of approximately 27,000 and 9,000 years b.p. on wood below and above the subsurface A clay (Janda and Croft, 1967; Croft, 1968, 1972). A new carbon-14 age of 14,100±200 years[4/] on wood about 12 m beneath

[4/] U.S.G.S.-38. Radiocarbon analysis performed in the laboratories of the U.S. Geological Survey, Menlo Park, Calif. by Steven W. Robinson.

the Kern River alluvial fan at Bakersfield corresponds almost exactly with a subsurface carbon-14 age of 14,060±450 years b.p. (W-1650; Ives and others, 1967; Croft, 1968) on wood at the top of lacustrine sediment derived from the Sierra Nevada within the A clay about 40 km to the west. Fan deposition and basin lakes were therefore contemporaneous in late Modesto time, as they were when the Friant Pumice Member of the Turlock Lake Formation was laid down over the Corcoran Clay Member.

Post-Modesto deposits

Holocene deposits Post-dating the Modesto Formation in the northeastern San Joaquin Valley are generally located close to modern drainageways and to the present valley axis; most small foothill streams, except those near Merced, have not built Post-Modesto fans. In general Post-Modesto deposits are relatively thin and essentially unweathered. Holocene alluvium of four ages (pl. 4, fig. 3) is recognized along most of the major rivers by topographic expression and position and, secondarily, by minor differences in soil profile development (table 2). These Holocene deposits are informally designated Post-Modesto I, II, III and IV, respectively.

The deposits tentatively assigned to Post-Modesto I in the northeastern San Joaquin Valley underlie a low terrace about 6-8 m above base flow level along the Stanislaus, Tuolumne, Merced, and San Joaquin Rivers. An equivalent surface has not yet been found on the lower San Joaquin River or on streams heading in the foothills. This terrace is seen in few places and appears to have been largely removed by erosion before or during the development of the slightly lower Post-Modesto II surface. It appears to converge very slightly downstream toward the present river profile. The Post-Modesto I terrace occurs locally along the lower Merced River (pl. 4), where it stands slightly above the more extensive Post-Modesto II terrace. The older surface is also evident along the south side of the Tuolumne River in the SW1/4 SW1/4 sec. 33, T. 2 S., R. 11 E., Waterford 7 1/2' quadrangle, where it occupies an elevation between Post-Modesto II and late Modesto terraces. The Post-Modesto I deposits bear a soil with Cox horizons tending toward an AC horizon. The soil profile does not appear to be as deep as those of the Post-late Modesto soils, but good exposures in Post-Modesto I materials are rare. Low terrace/floodplain surfaces along the lower San Joaquin River bear Temple and Merced soils which are in places buried by Post-Modesto II alluvium bearing Columbia soils.

Post-Modesto I deposits in the northeastern San Joaquin Valley may be correlative with deposits elsewhere in the central valley of California. Extensive fan alluvium at Davis, west of Sacramento, bears a A/Cox/Cn soil (Yolo series) that contains organic carbon dated at about 4,000 years B.P. (Shlemon and Begg, 1972). The soil is buried by 1-2m of younger alluvium bearing a Sycamore soil, and overlies an older buried soil (Capay series) showing an A/AC/Cox/Cn profile whose A horizon contains organic carbon dated at 9150$\pm$650 years B.P. The deposits were therefore laid down in some time interval between 9,000 and 4,000 years ago. Early Man sites flanking the Buena Vista lakebed west of Bakersfield are situated on lacustrine sediment associated with a former higher stand of the lake. Mollusc shells from the shoreline have yielded carbon-14 ages ranging from 7800-8200 years B.P. (Ives, Levin, Oman, and Rubin, 1967, p. 287-288).

Post-Modesto II deposits lie beneath a lower terrace-flood plain surface[10/], overtopped by occasional high floods prior to dam con-

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[10/] The term "terrace-flood plain" is applied to this surface to emphasize the prehistoric materials that underlie it, its prehistoric origin, and the fact that this same surface has also been modified both erosionally and depositionally by historic floods.

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struction on the rivers draining the Sierra Nevada, about 3-5 m above river level. This terrace-flood plain surface can be traced along sidestreams and Sierra Nevada rivers into a comparable level along the lower San Joaquin River. Small alluvial fans have developed near the confluence of the Sierra Nevada rivers with the lower San Joaquin (pl. 4), but these fans are almost an order of magnitude smaller than the late Modesto fans (pl. 2). Unlike the Post-Modesto I and all older terraces, the Post-Modesto II terraces do not significantly converge downstream toward the modern stream profile (table 1).

The width of the Post-Modesto II surface is normally less than 200 m, but on the Merced River west of Snelling the surface widens to over 5 km. The extent of this surface, the thickness of coarse sand and gravel underlying it, as seen in many quarries along the Merced and other rivers, and the absence of any evidence of Holocene tectonism in the region suggest that the Post-Modesto II deposits may reflect late Holocene (Neoglacial) climatic events in the Sierra Nevada, which could have altered the load-to-discharge ratio of the rivers to the point at which they could transport and redeposit coarse material. Alternatively, these deposits could simply represent the reworking of pre-Holocene alluvium by major floods unrelated to a significant change in climate. Historic floods, however, do not appear to have caused major erosion, transport, or deposition of coarse material beyond their present channels.

Recognizable, and in some places mappable Post-Modesto II deposits include channel, point bar, levee, interdistributary, and floodbasin alluvium. Some local bodies of eolian sand, probably reworked from late Modesto eolian deposits, mantle Post-Modesto I and II terraces. These sand bodies are not extensive but show some dunal topography indicative of a young age. In a few areas, agricultural practices have reactivated dunes.

The most typical soil series on Post-Modesto II surfaces are the Tujunga, Grangeville, and Foster on arkosic alluvium along the major rivers; the Honcut and Yolo on locally derived alluvium associated with drainages tributary to the major rivers; and the Columbia on mixed arkosic and Coast Range-derived detritus along the lower San Joaquin River. These soils usually show only a shallow A/Cox/Cn profile (table 2). A slight increase in bulk density (1.5-1.6 compared with about 1.3 in the Cn) occurs at the top of the Cox horizon, but otherwise there is no indication of a transitional AC horizon. Fresh loose parent material is normally found within a meter of the surface. Reaction is slightly alkaline, usually close to pH 8. Weak buried soils between the upper member of the Modesto and Post-Modesto II deposits west of Madera along the lower San Joaquin River show that the Post-Modesto II is significantly younger than the Modesto (see map units of Ulrich and Stromberg, 1962: Foster, Grangeville, Columbia soils over Temple soils).

The Post-Modesto II deposits appear to be prehistoric but late Holocene in age, judging from the soils and a few radiocarbon dates. A log buried about 17 feet beneath the Post-Modesto II alluvial surface along the Tuolumne River (SE1/4SW1/4 sec. 33, T. 3 S., R. 11 E., Waterford 7 1/2' quadrangle) in coarse gravelly alluvium has yielded a carbon-14 age of 370±200 years[11]. Because of the very young age and the fact that quarry workers recovered the sample, this date should be regarded with caution.

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[11] Raciocarbon determination (W-3378) performed by Meyer Rubin in the laboratories of the U. S. Geological Survey, Reston, Va.

Radiometric determinations on material from Indian occupation sites associated with what appear to be Post-Modesto II surfaces and deposits have yielded somewhat older and probably more reliable ages[12/]. Charcoal 1.6 m below an elevated terrace bearing a Columbia

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[12/] All information in this paragraph supplied by Eugene L. Begg, Department of Land, Air and Water Resources, Soils and Plant Nutrition Section, University of California, Davis, written commun., 1977.

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silt loam surface soil along the Feather River south of Oroville in the Sacramento Valley has given a carbon-14 age of 3,020 ± 130 years (GX 2191). Charcoal from a low terrace along French Camp Slough southwest of Stockton has yielded a carbon 14-date of 2,020 ± 160 b.p. (GX 1926), but bone collagen from the same location gave a 2,985 ± 160-year age (GX 1925). The bone collagen age is probably more reliable than the charcoal because of possible mixing of younger charcoal from above. A University of California, Davis, uranium-thorium age determination on the same bone material yielded a 4,440 ± 230-year age. From this information, it appears that the Post-Modesto II deposits are about 3,000 years old.

Deposits of Post-Modesto III age include fluvial sand, silt, and clay associated with a distinctive and well preserved constructional topography of abandoned meander loops and arcuate levees 2-4 m above present river level along the lower reaches of the Sierra Nevada rivers and along the lower San Joaquin River. They are not usually recognizable on streams heading in the foothills, including the Chowchilla and Fresno Rivers. The Post-Modesto III geomorphic surface is a part of the modern flood plain but stands slightly above the modern channelways. The deposits range from gravels near the foothills to fine silt and clay along the San Joaquin River. Soils formed on this surface display very immature (A/Cn) profiles; they not only lack AC horizons but also show little or no Cox horizon development (table 2). Even the A horizons do not appear to be fully developed. The weakest variant of the Columbia soil series is mapped along the lower San Joaquin River on mixed parent materials, and the weakest variants of the Tujunga, Grangeville and Foster series are mapped on arkosic alluvium along the Sierran rivers. The age of the Post-Modesto III deposits is unknown but probably spans the last few hundred years.

Modern deposits (Post-Modesto IV) include unvegetated channel and point bar alluvium along all major streams, but overbank facies in most places are too thin to map. Lacustrine, swamp, and marsh deposits are presently accumulating in poorly drained areas on the alluvial fan toes, especially between and along the margins of late Modesto sand dunes and in oxbow lakes on river flood plains. A few small areas of modern reactivated sand dunes may be found on the Merced River fan, usually within areas of stabilized late Modesto dunes. Post-Modesto IV deposits are thin and not laterally extensive. All of these modern deposits underlie presently active depositional surfaces and show neither A nor Cox soil horizons.

Summary

The Tertiary formations of the northeastern San Joaquin Valley differ markedly in lithology and are similar only in that they all represent Sierran-derived, primarily fluvial materials. The Ione, Valley Springs, Mehrten, and Laguna Formations dip southwest at respectively lesser gradients, and their strike changes from N 50° W in Ione time to N 30° W in North Merced time (table 1); all contain at least some coarse materials. Their deformation appears to have been closely related to tectonic events in the Sierra Nevada; their deposition may have been in response to tectonism, volcanism, and perhaps climatic events as well.

The members of the Quaternary alluvial sequence (Turlock Lake, Riverbank, and Modesto Formations) are relatively undeformed, lithologically indistinguishable (with some minor exceptions), and do not appear to have been deposited in response to tectonic events. The North Merced Gravel, which separates the Tertiary and Quaternary sequences, differs from both older and younger deposits in that it is thin and represents lag deposits on a surface of erosion and transport rather than an alluvial fill.

The Laguna, Turlock Lake, Riverbank and Modesto deposits are similar in four respects: (1) the arkosic nature of their sand and silt fraction, (2) a tendency toward coarsening-upward sedimentation cycles (prograding alluvial fans?), (3) deposition as sequential overlapping alluvial terrace and fan systems, and (4) probable glacial origin of much of the sediment (Janda, 1965, 1966). The four formations differ in age, topographic expression, geomorphic position, postdepositional soil development, and geographical occurrence. Some minor lithological differences in present surface exposures are apparent, although not necessarily significant: well stratified silts and fine sands seem to be more commonly exposed in both units of the Turlock Lake and the Modesto than in all three units of the Riverbank; gravels tend to be common in both members of the Modesto and in the upper part of the lower Turlock Lake but are less abundant in the upper unit of the Turlock Lake and in the Riverbank. The gravel in the upper member of the Modesto is confined to relatively narrow channels and may reflect reworking of coarse fragments from older deposits.

The units of the Turlock Lake, Riverbank, and Modesto Formations take the form of a series of terraces opening westward into alluvial fans, each terrace-fan system appearing successively west of the previous one and filling an incision into it. Soil profile development and degree of erosional modification of the original depositional surface decrease basinward and streamward on the younger, lower geomorphic surfaces [13/]. The soil and topographic discontinuities are sufficiently well defined to permit the subdivision of the Turlock Lake Formation into two units, each with several subunits, the Riverbank into three units, and the Modesto Formation into two members, each having two to four phases. Similar criteria may be used to differentiate (Post-Modesto) deposits into four age subdivisions.

[13/] Soil properties also show contrasts due to drainage, position on slopes, parent material, and, over broad areas, to contrasting climate and vegetation.

Soil development in well drained relatively uneroded arkosic parent materials of similar grain size distribution shows several trends with increasing age (table 2): (1) increased thickness of horizons and depth to fresh parent material, (2) redder hues, (3) brighter chromas, (4) lower pH, (5) sharper definition of horizon boundaries and more horizons, and (6) sequential development of Cox, AC, cambic B, weak argillic horizons and finally, in post-Turlock Lake soils, a very strong argillic horizon. Pedogenic clay and iron oxide first coat, then fill root holes and pores, then cover clast surfaces, and finally extend over ped surfaces and to greater depth. In hardpan soils, the chronosequence involves a change from calcium carbonate silica hardpan with no overlying B horizon (El Peco series in Fresno County) to a fairly strong calcium carbonate-silica pan beneath a good argillic horizon (Fresno series), to a relatively weak silica-iron hardpan soil with calcium carbonate seams (Madera series), and finally to red, acid, strongly developed silica-iron hardpan soil with a very strong argillic horizon above the pan (San Joaquin, normal and strong variants). The older Redding hardpan soils on the North Merced Gravel and the China Hat Gravel Member of the Laguna Formation, differ from the San Joaquin in that they are usually redder, much more acid, show brighter chromas and thicker, more continuous clay coatings on ped surfaces, and frequently display translocated clay well below the hardpan, suggesting engulfment of an older argillic horizon by later silica-iron cementation.

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Figure 1. Relationship of proposed stratigraphic units to those previously used in the northeastern San Joaquin Valley.

Age		Gale & others (1939)	Davis & Hall (1959)	Arkley (1962)	Janda (1965)			This paper		
		Mokelumne area	Eastern Stanislaus and northern Merced Counties	Merced River area	San Joaquin River fan			Northeastern San Joaquin Valley		
Holocene	Modern	Recent alluvium	Recent alluvium, Sand dunes	Recent alluvium, Sand dunes	Recent alluvium			Post-Modesto	IV	
	Historic								III	
	Pre-historic								II	
	Early Holocene								I	
Pleistocene		Victor Formation	Modesto Formation	Modesto Formation	Modesto Formation	Younger portion		Modesto Formation	Upper member	
						Older portion			Lower member	
			Riverbank Formation	Riverbank Formation	Riverbank Formation			Riverbank Formation	Upper unit	
									Middle unit	
									Lower unit	
			Turlock Lake Formation	Turlock Lake Formation	Turlock Lake Formation	Younger portion	Pumice near Friant	Turlock Lake Formation	Upper Unit	Friant Pumice Member
							Cocoran Clay Member			Corcoran Clay Member
						Older portion			Lower Unit	
Pleistocene or Pliocene		Arroyo Seco Gravel		North Merced Gravel				North Merced Gravel		
Late Pliocene		Laguna Formation		China Hat Gravel				Laguna Formation	Upper Unit	China Hat Gravel Member
									Lower unit	

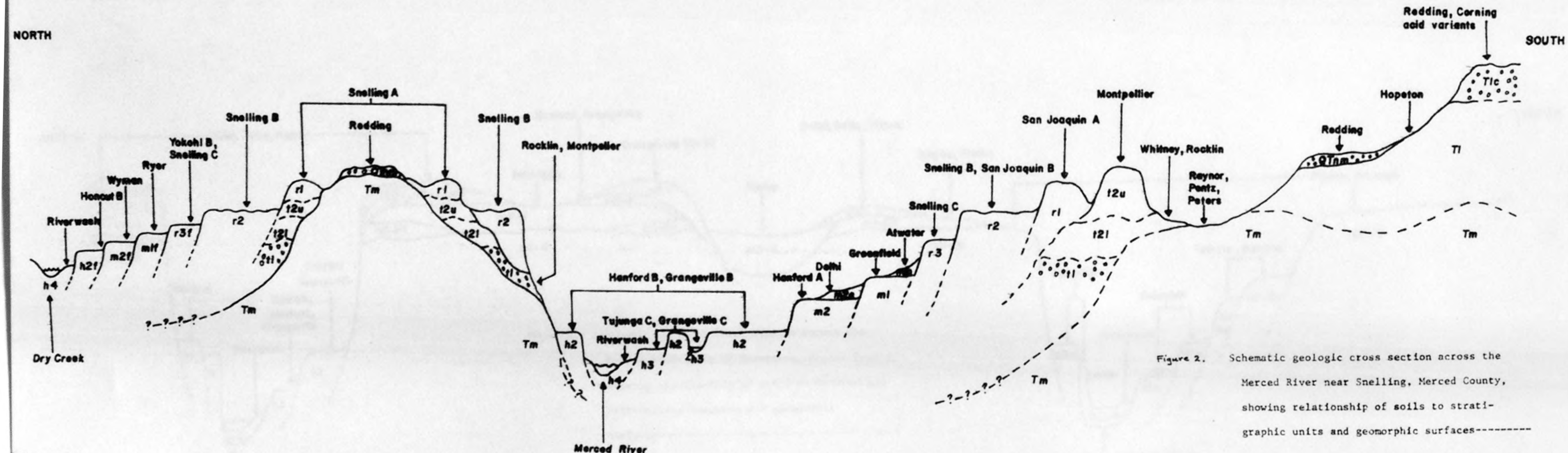

Figure 2. Schematic geologic cross section across the Merced River near Snelling, Merced County, showing relationship of soils to stratigraphic units and geomorphic surfaces---------

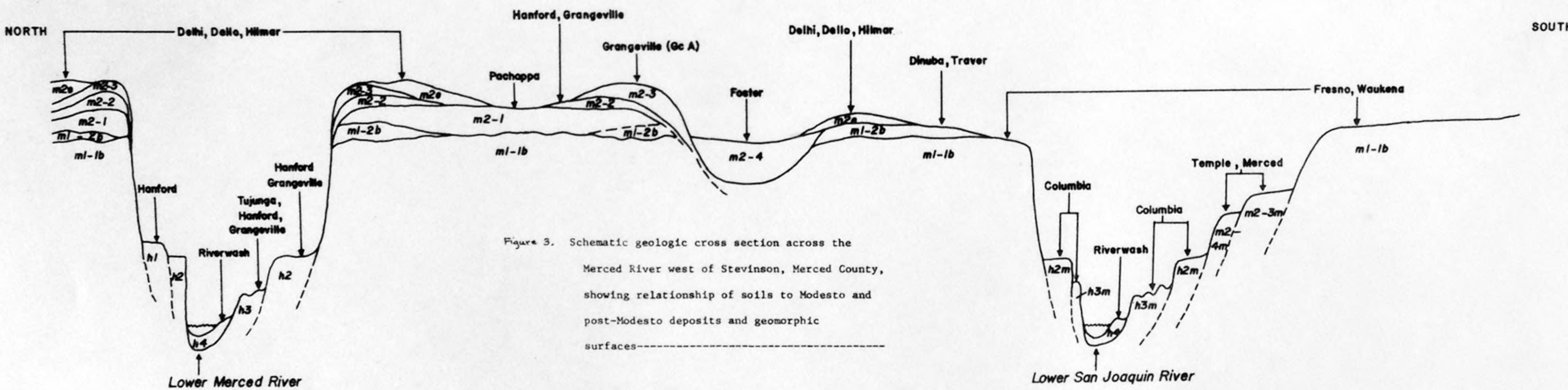

Figure 3. Schematic geologic cross section across the Merced River west of Stevinson, Merced County, showing relationship of soils to Modesto and post-Modesto deposits and geomorphic surfaces--