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# THE QUATERNARY DELTAIC AND CHANNEL SYSTEM IN THE CENTRAL GREAT VALLEY, CALIFORNIA[1]


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ABSTRACT. Three and possibly four Mokelumne River fan deposits and gravel-filled channels interfinger deltaic sediments in the central part of the Great Valley of California. The channels were probably cut during successive glaciations in the Sierra Nevada Mountains, and graded to eustatically lowered and possibly subsiding base levels. Rising seas caused thalassostatic sedimentation and headward expansion of the California Delta during interglacial time. Radiocarbon dating of basal deltaic peat indicates the Pleistocene-Holocene transition occurred about 10,700 years ago in this part of California.


KEY WORDS: *California, Channel deposits, Delta, Quaternary stratigraphy, Radiocarbon dating, Sea level change.*


BELOW the surface of the Great Valley of California are remnants of a once great river system that traversed parts of the Valley in deep channels, and carried sediments to a base well below present sea level.[2] The old channel system existed not once, but perhaps three or even four times during the Pleistocene Epoch, each time slowly evolving into a drainage network similar to the present.

The ancestral Sacramento and San Joaquin rivers, major drainages of the Great Valley, intermixed in the California Delta before passing through the Carquinez Strait and northern San Francisco Bay on the way to the sea. The Delta, although some fifty miles (80 km) from the Pacific Ocean, also responded to Pleistocene climatic change by expanding and contracting areally with each glacioeustatic oscillation. In the California Delta, channels of the lower Sacramento-San Joaquin river system and local tributaries apparently were repeatedly incised and backfilled with each major climatic fluctuation.

Although complicated by subsidence and isostatic adjustment, deltas have been regarded as excellent recorders of Quaternary eustatic fluctuation. A major problem, however, has been to correlate downstream deltaic sediments with upstream entrenched channel-fill and glacial deposits. Such correlation has always been difficult for mid-latitude streams with extensive drainage basins, including the well-studied Mississippi and Rhine rivers.[3]


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[1] A. Carlton and E. Begg, University of California, Davis, assisted in collection of data. Field work, in part, was supported by A. Teichert and Son (Sacramento, California), and by a University Faculty Research Grant.


[2] The Great Valley of California, also called the Central Valley, is frequently divided into the Sacramento Valley, the San Joaquin Valley, and the California Delta. There is no obvious surficial separation between the Sacramento and San Joaquin valleys, but the boundary is frequently placed at the Sacramento-San Joaquin County line. The study area encompasses this boundary.

[3] Some problems associated with correlation of glacial-interglacial deposits, and the relative influence of subsidence and eustacy for deltas in general and the Mississippi River in particular, are reviewed in H. N.

More meaningful correlation is possible where glacial and interglacial deposits physically interfinger, but this stratigraphic relationship occurs in relatively few places; for example, where alpine streams enter a broad coastal valley. However, direct contact of deltaic sediments and glacial outwash is now known to exist in the central part of the Great Valley of California. Here the Mokelumne River, a tributary of the lower San Joaquin, drains the glaciated Sierra Nevada Mountains, flows across the Great Valley, and debouches almost directly into the California Delta. Composed of an alternating sequence of glacial, gravel-filled, channels and overlying fan deposits, the Mokelumne River sediments merge directly into interglacial, deltaic deposits.

Despite these fortuitous stratigraphic relationships, geomorphic studies of the alluvial sequence in this part of California are conspicuously lacking.[4] This lack may have been attributable to a dearth of subsurface data, but analysis of hundreds of new water-well logs and levee borings shows that the Quaternary gravel-filled channels, alluvial fan sediments, and deltaic deposits are systematically related.[5] The light-colored "oxidized" sediments of the Mokelumne River cyclically transgressed upon dark-colored, "reduced" deposits of the California Delta. As a first step in reconstructing the regional paleogeography, it now appears possible to outline the general evolution of the Quaternary deltaic and channel system in the central part of the Great Valley of California, and to propose a correlation of glacial, deglacial, and interglacial sediments. Radiometric and faunal dating of the alluvial sequence

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Fisk and E. McFarlan, Jr., "Late Quaternary Deltaic Deposits of the Mississippi River," in A. Poldervaart, ed., *Crust of the Earth*, Geological Society of America, Special Paper 62 (1955), pp. 279–302; F. P. Shepard, F. B. Phleger, and T. H. van Andel, eds., *Recent Sediments, Northwest Gulf of Mexico* (Tulsa, Oklahoma: The American Association of Petroleum Geologists, 1960); F. P. Shepard, "Criteria in Modern Sediments Useful in Recognizing Ancient Sedimentary Environments," in L. M. J. U. van Straaten, ed., *Deltaic and Shallow Marine Deposits* (Amsterdam: Elsevier Publishing Company, 1964), p. 1025; and H. A. Bernard and R. J. LeBlanc, "Résumé of the Quaternary Geology of the Northwestern Gulf of Mexico Province" in H. E. Wright, Jr., and D. G. Frey, eds., *The Quaternary of the United States* (Princeton: Princeton University Press, 1965), pp. 137–85. Fluvial-deltaic correlation of the Rhine River sequence is summarized by S. Jelgersma, "Holocene Sea Level Changes in the Netherlands," *Mededelinger van de Geologische Stichting*, Serie C-VI, No. 7 (1961), pp. 9–76.

[4] The possible effect of Wisconsin sea level fluctuation in the California Delta is briefly treated in *San Joaquin County Ground Water Investigation*, Bulletin 146 (Sacramento: Department of Water Resources, 1967).

[5] Over a thousand water wells have been drilled into the Mokelumne Alluvial Fan and the California Delta. By law, drillers are required to log each well on prescribed forms and submit these to the California Department of Water Resources (Sacramento). The logs contain information concerning the location and depth of the well, type of casing used, and nature of sediments penetrated. Although drillers' descriptions are notoriously diverse, lithologic, color, and texture data are adequate to differentiate major alluvial fan and deltaic facies. The Department of Water Resources locates each well to at least the nearest forty acres (16 ha), but often to within twenty or thirty feet (6 or 9 m). The well logs are filed by township and range, and made available for inspection to federal, state, and local agency personnel studying ground-water resources. Because of their water-bearing capacity, sand and gravel units are almost always identified by drillers. Also recorded are striking changes in color, especially the red and yellow-brown of fan sediments, and the black and blue of deltaic deposits. The depth of lithologic, texture, and color contacts is often accurate to within one foot (0.3 m). Most wells on the Mokelumne Fan are less than 200 feet (61 m) deep, but this penetrates most of the Quaternary sequence. Well density ranges from forty or fifty per square mile (15 or 19/km$^2$) near Lodi to three or four per square mile (1 or 2/km$^2$) in the Delta. Approximately fifty deep wells, many over 500 feet (150 m), have been drilled within the study area for use in urban water and fire protection systems. The logs of these wells, often prepared by professional geologists, are likewise filed with the Department of Water Resources. Gravel-filled channels of the ancestral Mokelumne River can be readily identified in well logs, especially between Lockeford and Victor, for they extend directly downstream from terrace deposits. In contrast, small gravel lenses of distributaries within the Fan are quite thin, discontinuous, and trend away from the main channel fill. Upstream, between Clements and Lockeford, well-log data were supplemented by a portable seismic system ("Terra Scout"), which can be used to identify buried channels less than fifty feet (15 m) below the surface. Downstream, west of Lodi, lithologic, texture, and color data from levee borings and canal cuts were helpful for differentiating natural levee, fan, and peat deposits within about 125 feet (38 m) of the surface (essentially sea level). Most subsurface geologic data for the Mokelumne River-California Delta area are unpublished, but are available in manuscript form in the Sacramento offices of the California Department of Water Resources, the U.S. Geological Survey, and the U.S. Bureau of Reclamation.

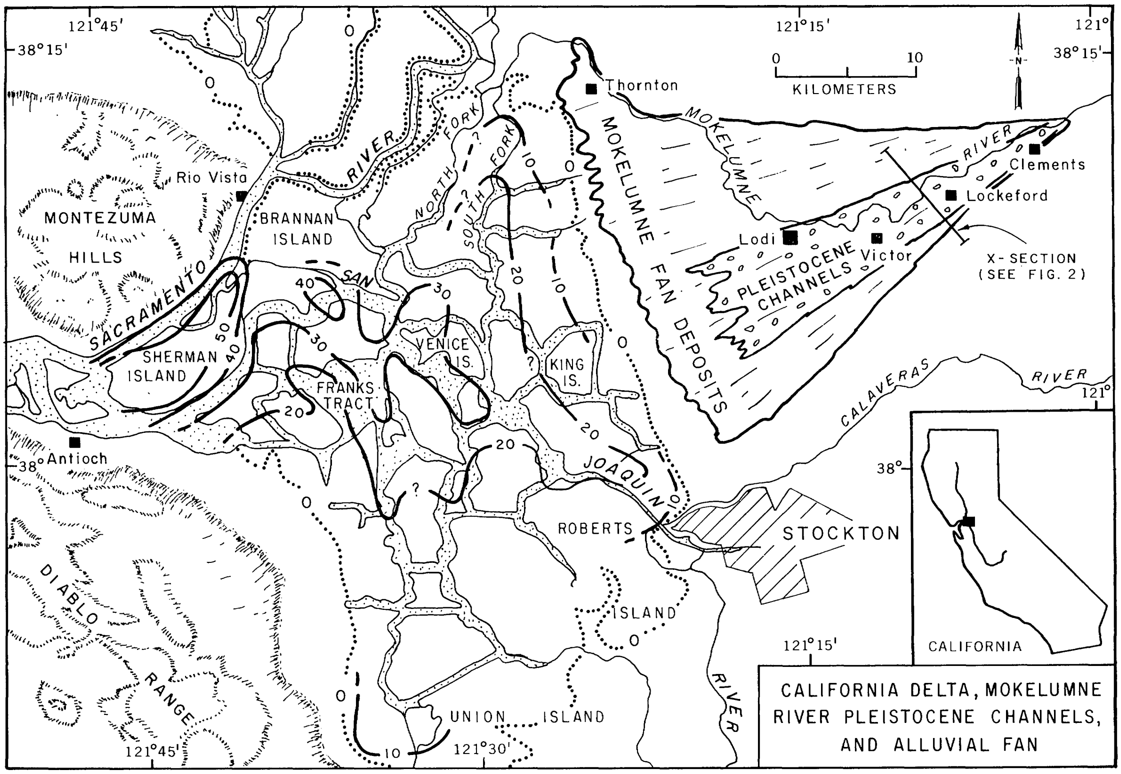


FIG. 1. The California Delta and the Mokelumne Alluvial Fan. Buried Pleistocene Mokelumne River channels extend from terraces near Clements southwestward toward the Delta. The base of Delta peat (below mean sea level) is shown by contours (in feet); present sea level is indicated by the dotted line.

also suggest correlation with glacial and glacioeustatically controlled deposits elsewhere.

### REGIONAL LANDFORMS

The boundary between the California Delta and surrounding alluvial fan deposits is marked by a stark contrast in soils and contemporary land use. This contrast is seen especially in the adjacent yellow and brown fan deposits laid down by the Mokelumne River, and the dark-colored, organic-rich sediments of the California Delta. The Mokelumne Fan has been built up by many now-abandoned distributaries that radiated outward from the mountain front carrying small gravel and coarse-grained sediments onto older Pleistocene surfaces or into the Delta (Fig. 1). Deposited in the inter-distributary swales were silt and clay; these too now merge almost imperceptibly into deltaic sediments. To the west, although greatly modified by one hundred years of reclamation and intensive agriculture, some of the islands and surrounding natural levees of the California Delta still receive fine-grained sediments derived from the Sierra Nevada and the Coast Ranges.

Although common in local usage, the term "delta" is perhaps a misnomer, for the California version does not have easily recognizable prodelta, distal bar, or similar facies characteristic of many coastal deltaic deposits. Yet it is an area of sea level-controlled sedimentation, though in the interior of California. It also differs from other great deltas of the world in that it is not growing seaward. Restricted by the Montezuma Hills and a part of the Diablo Range on the west, the California Delta responded to Pleistocene sea level oscillations by expanding and contracting to the east, or "input," side (Fig. 1). The Delta is stratigraphically unique, for here, because of the interior location, deltaic and glacial outwash deposits merge. Moreover, peat beds in the Delta can be radiometrically dated, thus providing data about the Pleistocene-Holocene boundary in this part of California, and the rate of post-glacial sea level rise.

The juxtaposition of the Mokelumne Alluvial Fan and the California Delta presents an interesting contrast in landform genesis. Whereas deltaic sediments were laid down primarily during interglacial time, the fan deposits are probably of glacial origin. The response of these two landforms to changing Pleistocene environments apparently was controlled mostly by change of local stream regime and regional base level.

### *The Mokelumne Alluvial Fan*

The Mokelumne Alluvial Fan is one of several great coalescing fan systems on the east side of the Great Valley laid down by major tributaries of the Sacramento and San Joaquin rivers. Draining about 700 square miles (1,800 $km^2$) in the high Sierra Nevada, the modern Mokelumne River is incised about sixty feet (18 m) at the fan apex near the town of Clements. Turning abruptly near Lodi, the river flows along the northern margin of its fan before entering the Delta near Thornton. Breaking up into distributaries, the Mokelumne joins the San Joaquin River in the heart of the Delta (Fig. 1).

Relatively undissected distributary ridges and fan surface, and youthful soils, attest that the Mokelumne River has been building its fan throughout at least late Pleistocene, and probably Holocene time.[6] Buried and relict soils show that the modern fan, in part, has been deposited on older Pleistocene fluvial sediments. Young fan deposits now cover about 6,000 acres (2,400 ha) from the apex near Clements westward to the place where they merge into organic sediments of the Delta.

Near its apex, the Mokelumne Fan has been cut and filled by at least three terrace deposits. The terraces, converging downstream, are underlain primarily by gravels which, in turn, are buried successively by younger alluvium. Traced in well logs, the gravels diverge vertically in the subsurface, and continue westward as the buried Mokelumne River channels.

### *The California Delta*

A triangular-shaped plexus of channels and islands, the California Delta has been a marshalling point for the Sacramento, San Joaquin, and Mokelumne rivers since at least middle Pleistocene time. From the Delta, an ancestral Sacramento River flowed through Suisun Bay, the Carquinez Strait, and into San Pablo and San Francisco bays before entering the Pacific Ocean at the Golden Gate.[7]

Though now in part below sea level and protected by levees, the Delta has been an area of seasonal overflow, an aquatic environment dominated by tules or bulrushes (*Scirpus lacustris* L.) and fibrous reeds (chiefly *Phragmites communis* Trin.).[8] Water wells and levee borings show that decaying organic matter has accumulated to form peat beds, some of which are now sixty feet (18 m) below present sea level in the western part.[9] The peat thins

[6] The Quaternary sediments in the lower Mokelumne area were originally subdivided into "younger" and "older" alluvium, the separation based primarily on relative dissection of the fan surface; H. T. Stearns, T. W. Robinson, and G. H. Taylor, *Geology and Water Resources of the Mokelumne Area, California*, Water Supply Paper 619 (Washington: U.S. Geological Survey, 1930). Later A. M. Piper, H. S. Gale, H. E. Thomas, and T. W. Robinson, *Geology and Ground-Water Hydrology of the Mokelumne Area, California*, Water Supply Paper 780 (Washington: U.S. Geological Survey, 1939), delimited four Quartenary formations: gravels of uncertain age, the Arroyo Seco Gravel and Victor formations of Pleistocene age, and Recent sediments. Soils of the lower Mokelumne area are described in S. W. Cosby and E. J. Carpenter, *Soil Survey of the Lodi Area, California*, Bureau of Chemistry and Soils, Series 1932, No. 14 (Washington: U.S. Department of Agriculture, 1937); and S. W. Cosby, *The Sacramento-San Joaquin Delta Area, California*, Bureau of Plant Industry, Series 1935, No. 21 (Washington: U.S. Department of Agriculture, 1941).

[7] N. L. Taliaferro, "Geology of the San Francisco Bay Counties," in O. P. Jenkins, ed., *Geologic Guidebook of the San Francisco Bay Counties*, California Division of Mines Bulletin 154 (1951), pp. 75–94; and G. D. Louderback, "Geologic History of San Francisco Bay," ibid., pp. 117–50.

[8] Several of the Delta islands are now twenty feet (6 m) below mean sea level and protected from inundation only by the continuing artificial buildup of the surrounding levees. Commonly called "subsidence," lowering of the Delta surface is due to several factors, including surficial compaction of the peat, oxidation, shrinking, burning, and wind erosion; W. W. Weir, "Subsidence of Peat Lands of the Sacramento-San Joaquin Delta, California," *Hilgardia*, Vol. 20, No. 3 (1950), pp. 37–56.

[9] The deepest known peat in the Delta underlies Sherman Island. Although generally thinning east-

as a wedge to the east and generally interfingers dark, fine-grained sediments carried in by streams.

The origin of the peat is not clear. According to one hypothesis, it was probably "sedimentary," settling out of floating reed mats into deep water; another hypothesis suggests that the peat accumulated near sea level in an area undergoing slow and continuous geologic subsidence.[10] Analysis of well logs and deep cores shows that most of the peat beds are less than four or five feet thick, and separated by "mineral," fine-grained sediments. The peat probably formed in interdistributary basins (now islands) in a freshwater environment close to sea level. These basins under natural conditions received fine detritus during river floods, and the deltaic sedimentary section generally has intercalated silt, clay, and plant remains.

### PLEISTOCENE CHANNELS

The Pleistocene Mokelumne River channels bear little relation to the present stream. Whereas the modern stream meanders in its floodplain and carries fine-grained sediments, the Pleistocene rivers cut deep, canyon-like channels into underlying, older fan deposits. The ancient rivers had greater hydraulic competence and carried glacially-derived boulders and cobbles much farther downstream than the present stream.

By analyzing well logs, tracing buried soils, and projecting terrace gradients, four distinct subsurface ancestral channels of the Mokelumne River have been identified. The channels trend down the center of the Mokelumne Alluvial Fan, generally south of the present river (Fig. 1). No buried soils or erosional unconformities separate the glacial channel gravels from the overlying deglacial fan sand and silt deposits, thus suggesting that the change in depositional facies was transitional. One of the older and deeper channels is identified in only a few well logs. Its stratigraphic relation is not completely clear and hence it is called simply "channel of unknown age." The other three Pleistocene Mokelumne rivers, from older to younger, have been designated channels of "Laguna," "Riverbank," and "Modesto" age, respectively, after the geologic formations in which they occur.

Correlation of alluvial formations in the Great Valley is based primarily on lateral continuity of sediments, relative dissection of slopes, and degree of soil profile development (Table 1).[11] In general, the Pleistocene formations near the mountain front form a sequence of nested alluvial fans and terraces, with the younger sediments successively deposited westward, filling parts of river valleys cut in the older fans. The surface of the Modesto Formation, the youngest Pleistocene unit, is almost undissected and gives rise to relatively undeveloped soils having, at best, only a slight increase in B horizon clay compared with the underlying parent material. The surfaces of the older formations are progressively more dissected, and have soils ranging from medial to maximally developed Noncalcic Browns.[12] Often the well-developed soils can

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ward, reentrants of mixed peat and mineral sediments, forty to fifty feet (12 to 15 m) below mean sea level, extend "upstream," generally underlying the modern Sacramento, San Joaquin, and Mokelumne rivers (Fig. 1).

[10] A. P. Dachowski-Stokes, *Peat Land in the Pacific Coast States in Relation to Land and Water Resources*, Miscellaneous Publication 248 (Washington: U.S. Department of Agriculture, 1936); and Cosby, op. cit., footnote 6, p. 17.

[11] Piper, et al., op. cit., footnote 6, named the Mehrten, Laguna, Arroyo Seco, and Victor formations from type localities in the lower Mokelumne area (Table 1). Later S. N. Davis and F. R. Hall, "Water Quality of Eastern Stanislaus and Northern Merced Counties, California," *Stanford University Publications in the Geological Sciences*, Vol. 6, No. 1 (1954), subdivided the Pleistocene alluvium and established the Turlock Lake, Riverbank, and Modesto formations as new units. The younger formations, Riverbank and Modesto, were later extended into the American River area, about thirty miles (50 km) north of the Mokelumne by R. J. Shlemon, *Quaternary Geology of Northern Sacramento County, California*, Annual Field Trip Guidebook (Sacramento: Geological Society of Sacramento, 1967).

[12] The relationship of great soil groups and landforms on the east side of the San Joaquin Valley is described in R. Ulrich and L. K. Stromberg, *Soil Survey of Madera Area, California*, Soil Conservation Service, Series 1951, No. 11 (Washington: U.S. Department of Agriculture, 1962); R. J. Arkley, *Soil Survey of the Eastern Stanislaus Area, California*, Soil Conservation Service Series 1957, No. 20 (Washington: U.S. Department of Agriculture, 1954); and R. J. Janda, "Quaternary Alluvium Near Friant, California," in *Northern Great Basin and California*, International Association of Quaternary Research, VII Congress Guidebook I (Lincoln, Nebraska: Nebraska Academy of Sciences, 1965), pp. 128–33. In the "7th

TABLE 1.—CORRELATION OF QUATERNARY FORMATIONS IN A PART OF THE EAST SIDE OF THE GREAT VALLEY, CALIFORNIA

| EPOCHS | Lower Mokelumne River Area (1) | | Lower Mokelumne River Area (2) | Lower Tuolumne River Area (3) | Lower American River Area (4) | | |
|---|---|---|---|---|---|---|---|
| HOLOCENE | Alluvium and Basin Deposits | | Alluvium | Alluvium and Eolian Sand | Alluvium and Basin Deposits | | |
| PLEISTOCENE | Modesto Formation | Alluvial Fan and Distributary Deposits | Victor Formation | Modesto Formation | Modesto Formation | | Upper Member |
| PLEISTOCENE | Modesto Formation | Mokelumne River Channel Gravel and Sand Deposits | Victor Formation | Modesto Formation | Modesto Formation | | Lower Member |
| PLEISTOCENE | Riverbank Formation | Alluvium | Victor Formation | Riverbank Formation | Riverbank Formation | | |
| PLEISTOCENE | Riverbank Formation | Mokelumne River Channel Gravel | Victor Formation | Riverbank Formation | Riverbank Formation | | |
| PLEISTOCENE | Laguna (Fair Oaks) Formation | Deposits Above Mokelumne River Channel Gravel | ? | ? Turlock Lake Formation ? | Fair Oaks Formation | Upper Mem. | Deposits Above Lower Buried Soil and American River Channel Gravel |
| PLEISTOCENE | Laguna (Fair Oaks) Formation | Mokelumne River Channel Gravel and Gravel of Unknown Age | ? Arroyo Seco Gravel and ? Gravel of Uncertain Age ? | | Fair Oaks Formation | Lower Member | Gravels underlying Arroyo Seco Surfaces and Deposits Below Lower Buried Soil |
| PLIOCENE (?) AND PLEISTOCENE (?) | Laguna (Fair Oaks) Formation | Gravel Underlying Arroyo Seco Surface and Deposits Below Mokelumne River Channel Gravel ? ? | Laguna Formation | | Fair Oaks Formation | Lower Member | Gravels underlying Arroyo Seco Surfaces and Deposits Below Lower Buried Soil |
| PLIOCENE (?) AND PLEISTOCENE (?) | Laguna - Mehrten Transitional Zone | | Mehrten Formation | Mehrten Formation | Laguna - Mehrten Transitional Zone | | |
| PLIOCENE (?) AND PLEISTOCENE (?) | Mehrten Formation | | Mehrten Formation | Mehrten Formation | Mehrten Formation | | |

_ _ _ _ Unconformity
. . . . . Inferred position in Stratigraphic Sequence
_ ? _ ? Inferred Correlation

Sources: column (1), field mapping by the author; column (2), Piper, et al., op. cit., footnote 6; column (3), Davis and Hall, op. cit., footnote 11; and column (4), Shlemon, op. cit., footnote 11.

be traced westward in the subsurface, where they separate the respective Pleistocene formations.

### *Channel of Unknown Age*

South of the Mokelumne River, near Lockeford, a gravel-filled ancestral channel is traced about five miles (8 km) in the subsurface. This "channel of unknown age" is about one-half mile (0.9 km) wide and generally less than ten feet (3 m) thick. Identified only in well logs, the gravels of this channel are sixty-five feet (20 m) below the present surface. Its absolute age is unknown, but because it occurs at a subsurface elevation similar to the channel of Laguna age, it is inferred to be an early (?) Pleistocene Mokelumne River or distributary.

### *Channel of Laguna Age*

Underlying the present floodplain near Lockeford, a Pleistocene channel of the Mokelumne River is traced continuously in the subsurface downstream to about three miles (5 km) southwest of Victor, and then intermittently into the California Delta. The channel was possibly one mile (1.6 km) wide at the apex of a Laguna age alluvial fan, spreading out to over three miles (5 km) near Lodi. The absolute age of this ancient stream is unknown, but because it occurs within the upper part of the Laguna Formation, it is called "channel of Laguna age." In the Mokelumne area, the Laguna Formation occurs at the same stratigraphic level as sediments in the San Joaquin Valley about 100 miles (160 km) to the south, which are radiometrically dated as approximately 600,000 years old.[13] Inferentially the Laguna channel may be at least this old and thus possibly correlative with the Hobart glaciation in the northern Sierra Nevada.[14]

The Laguna channel is approximately 80 feet (25 m) below present sea level at Lockeford, or about 180 feet (55 m) below the surface. Because of this depth, few water wells have penetrated the gravel-filled channel. Nevertheless sufficient data are available to outline generally its width, thickness, and elevation. From drillers' logs, the gravels of the Laguna age channel are primarily metamorphic, consisting of "rocks" and "boulders" two to three inches (5.0 to 7.5 cm) in diameter, enclosed in a granitic sand matrix.[15] The channel deposit is about 15 feet (4.5 m) thick just

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Approximation Soil Classification System," soils on the Mokelumne fan deposits range from Aquic Xerofluvents and Typic Xerothents (no textural B horizon) to Typic Haploxeralfs (medial development), and Abruptic Durixeralfs (maximal development); State Soil Scientist, *Soil Series Mapped in California*, Soils Advisory Cal-5 (Berkeley: U.S. Department of Agriculture, Soil Conservation Service, 1970).

[13] Janda, op. cit., footnote 12, p. 131.

[14] The glacial stratigraphy of the northern Sierra Nevada was established by P. W. Birkeland, "Pleistocene Stratigraphy of the Northern Sierra Nevada, North of Lake Tahoe, California," *Journal of Geology*, Vol. 72 (1964), pp. 810–25. The Hobart and Donner Lake advances are pre-Wisconsin, the later possibly somewhat less than 300,000 years old. An inferred correlation of alluvial formations in the southeastern Sacramento Valley with Sierran glaciations is in Shlemon, op. cit., footnote 11, p. 11; a detailed correlation of alluvium in the San Joaquin Valley with Sierra Nevada advances was proposed by R. J. Janda and M. G. Croft, "The Stratigraphic Significance of a Sequence of Noncalcic Brown Soils Formed on the Quaternary Alluvium of the Northeastern San Joaquin Valley, California," in R. B. Morrison and H. E. Wright, eds., *Quaternary Soils*, International Association for Quaternary Research, VII Congress, Proceedings, Vol. 9 (Reno: Desert Research Institute, University of Nevada, 1967), pp. 157–90. For correlation of the Sierran glaciations and the Midcontinental sequence, see R. P. Sharp, and J. H. Birman, "Additions to the Classical Sequence of Pleistocene Glaciations, Sierra Nevada, California," *Geological Society of America Bulletin*, Vol. 74 (1963), pp. 1079–86; and R. B. Morrison and J. C. Frye, *Correlation of the Middle and Late Quaternary Successions of the Lake Lahontan, Lake Bonneville, Rocky Mountain (Wasatch Range), Southern Great Plains, and Eastern Midwest Areas*, Nevada Bureau of Mines Report No. 9 (1965).

[15] The lithologic data are based on logs of water wells drilled at the junction of State Highways 12 and 88 (sec. 1, T. 3 N., R. 7 E., Mount Diablo principal meridian). Although not exposed at the surface, the Laguna age metamorphic gravels are probably lithologically similar to those in the younger Riverbank and Modesto age channels, generally derived from the Sierra Nevada foothills. Dredge tailings upstream near Clements contain about twenty, twenty-five, and thirty percent, respectively, of vein quartz, greenstone and quartzite metasediments. Generally less than ten percent of the gravels are granitic; W. B. Clarke, "Mines and Mineral Resources of San Joaquin County, California," *Californa Journal of Mines and Geology*, Vol. 51, No. 1 (1955), p. 61. Much of the coarse-grained granitic sand matrix apparently was decomposed to grus before being transported to the Great Valley. The same general gravel-sand lithology occurs in Pleistocene channels of the lower American River; Shlemon, op. cit., footnote 11.

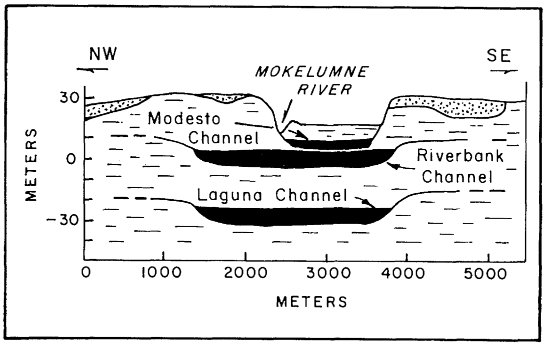


FIG. 2. Section across the Mokelumne River near Lockeford showing three buried Pleistocene channels (see Fig. 1 for location).

southeast of Victor, where it is identified 125 feet (38 m) below present sea level. The gradient of the Laguna age Mokelumne River is about fourteen feet per mile (3.9 m/km). Projecting this gradient places the channel approximately 180 feet (55 m) below sea level at Lodi and -325 feet (-99 m) in the eastern part of the Delta. Whether the Laguna age Mokelumne River maintained this gradient into the Delta is conjectural, but several deep wells penetrate gravel lenses at these depths.[16]

### *Channel of Riverbank Age*

At the base of the Riverbank Formation, a Mokelumne River channel extended downstream from near Clements to a point just east of Lodi. This channel of Riverbank age, underlying the present floodplain, cut a trench about three miles (5 km) wide in the Victor-Lodi area (Fig. 2). Traced to twenty feet (6 m) below sea level north of Victor, the channel deposit is about forty feet (12 m) thick, containing discontinuous lenses of metamorphic gravel in a coarse-grained, granitic sand matrix.

The Riverbank age channel, like the other Pleistocene Mokelumne rivers, probably was entrenched and filled during the initial stages of Sierran glaciation. There is no direct tie between the alluvium of the Mokelumne area and glacial deposits in the high Sierra, owing to extensive postglacial erosion in the intervening canyons. However, stratigraphic position and relative soil profile development suggest that the Riverbank age channel was probably cut during the Donner Lake advance in the Sierra Nevada.[17]

Two buried channels of Riverbank age occur on the American River about thirty miles (50 km) north of the Mokelumne area. Radiometric dating of faunal remains in sediments immediately above the younger glacial channel yielded ages approximately 80,000 to 105,000 years B. P. (Before Present). Bones from alluvium now believed correlative with the older channel may be 280,000 years old.[18] If contemporaneous with the American River channels, as seems likely, the Mokelumne Riverbank age channel thus is bracketed between approximately 75,000 and 300,000 years B. P. Gravel lenses and fan deposits, about fifty feet (15 m) below the well-defined Riverbank channel, can be traced westward into the Delta (Fig. 3). These deposits may be equivalent to the older Riverbank age channel of the American River.

### *Channel of Modesto Age*

The Modesto age channel is the youngest glacially-controlled course of the Mokelumne River. It underlies the floodplain from just a few feet (about 1 m) at Clements to about thirty-five feet (11 m) north of Victor (Fig. 3). The channel gravels are about thirty-five feet (11 m) thick, thinning somewhat downstream. The base of the channel is at sea level just east of Lodi. This channel was probably entrenched and filled during the last major Sierran glacial advance (Tahoe), and later covered with fine-grained outwash during deglaciation. Two fill-terraces inset in the Mokelumne suggest that the Modesto age alluvium was laid down in distinct periods, probably

[16] Louderback, op. cit., footnote 7, p. 83, observed that a main stream in San Francisco Bay cutting bedrock during late Pleistocene time must have had a gradient of eight or nine feet per mile (2.2 to 2.5 m/km). This is somewhat less than that calculated for the Laguna age Mokelumne river channel. At present it is not possible to correlate Bay bedrock and Mokelumne River channels across the California Delta by gradient projection alone in view of well-documented Pleistocene Bay area deformation and possible deltaic subsidence.

[17] Birkeland, op. cit., footnote 14; and Janda and Croft, op. cit., footnote 14, p. 176.

[18] R. J. Shlemon and R. O. Hansen, "Radiometric and Faunal Dating of Quaternary Alluvium in the Sacramento Area, California," (Abstract), *Geological Society of America*, Cordilleran Section, Part 3, 65th Annual Meeting (Eugene, Oregon), 1969, pp. 61–62.

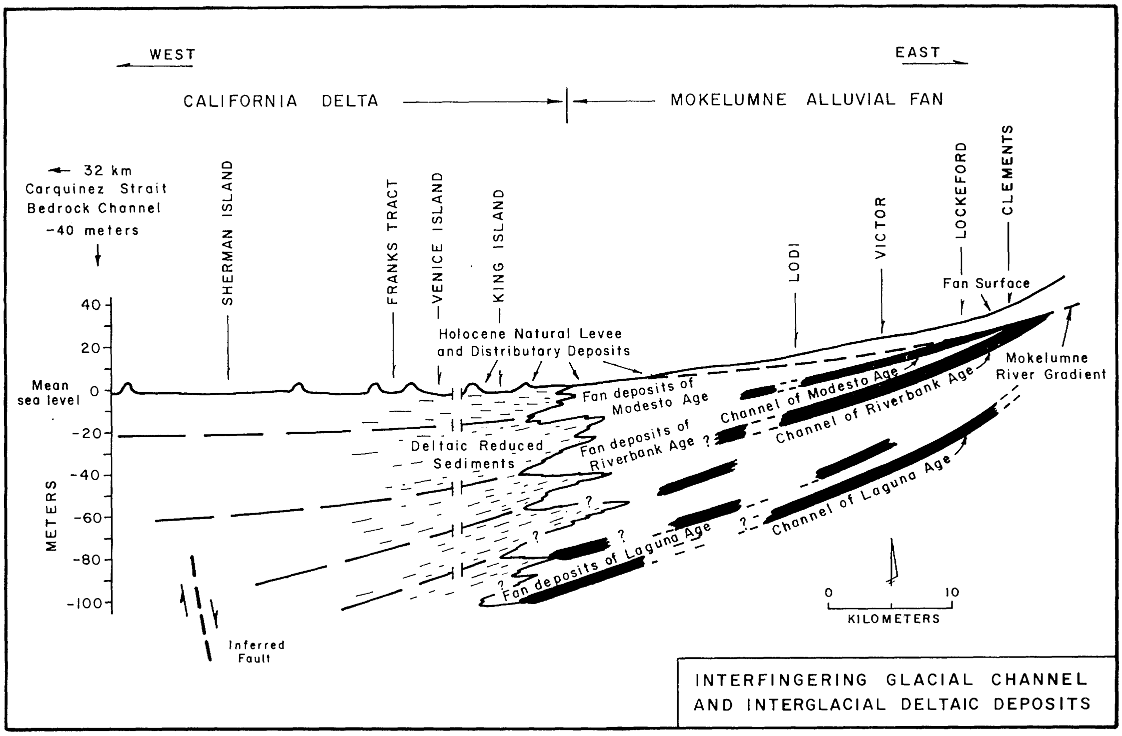


FIG. 3. Generalized geologic section showing interfingering of California Delta and Mokelumne Fan sediments. Gravel-filled channels are identified in well logs. An inferred early Quaternary fault possibly offsetting deltaic sediments is shown under Sherman Island.

correlative with alluvial episodes in the San Joaquin Valley assigned to Wisconsin stage advances.[19] The precise age of the formation is unknown; however, it buries the post-Riverbank Formation soil, which itself is probably younger than 80,000 years.[20] Preliminary uranium-thorium dating of elephant teeth recovered from the Modesto Formation about forty miles (65 km) south of the Mokelumne area yielded ages ranging from about 16,000 to 27,000 years B. P.[21] Because the glacial channel occurs at the base of the formation, it is probably somewhat older than 27,000 years, and perhaps is correlative with radiometrically dated lacustrine sediments of similar age recently found in the San Joaquin Valley.[22]

## RELATIONSHIP OF THE RIVER CHANNELS AND THE DELTA

From their direction, gradient, and depth, most of the older Mokelumne River channels are identified at or below present sea level where they interfinger peat beds and organic-rich sediments of the California Delta. Compared with the Mokelumne Fan, water wells

[19] Janda and Croft, op. cit., footnote 14, p. 177.

[20] The "time 0" for formation of the post-Riverbank soil (San Joaquin series) is based on my interpretation of data in R. O. Hansen and E. L. Begg, "Age of Quaternary Sediments and Soils in the Sacramento Area, California by Uranium and Actinium Series Dating of Vertebrate Fossils," *Earth and Planetary Science Letters*, Vol. 8 (1970), pp. 411–19. The San Joaquin series is maximally developed with iron-silica hardpan (Abruptic Durixeralf). Frequently identified in the subsurface, it is taken to mark the boundary between the Riverbank and the overlying Modesto formation.

[21] The elephant teeth were recovered just below the surface near Salida in Stanislaus County and dated by Dennis Garber, University of California, Davis (oral communication, 1970). The clay in the B horizon of the enclosing Dinuba soil is approximately ten percent more than in the underlying material. This degree of profile development is consistent with other soils formed on older Modesto age alluvium in the Great Valley; Arkley, op. cit., footnote 12.

[22] Janda and Croft, op. cit., footnote 14, p. 167.

in the California Delta are more widely distributed; thus precise subsurface contacts between channel, fan, and deltaic facies cannot be as accurately delimited. Nevertheless gross stratigraphic relationships suggest that just as the hydraulic regime of the lower Mokelumne River changed during glaciation of its headwaters in the Sierra Nevada, so also did the fluvial environment and extent of the California Delta. Studies elsewhere in the Great Valley have shown that periods of alluvial fan formation probably correlate with glacial advances in the Sierra Nevada, and relative landscape stability and soil formation occurred during interglacial time.[23] Thus in the Mokelumne area, as indicated by well log data, subsurface oxidized sediments are interpreted as channel and fan deposits laid down by the Mokelumne River and its distributaries during glacial time; and reduced sediments are peat and dark, fine-grained, thalassostatic deposits formed during postglacial time when rising seas caused the California Delta to expand headward. Before intensive agricultural development the surficial boundary between deposits of the Mokelumne Fan and the California Delta closely paralleled the ten foot (3 m) contour line. This elevation suggests that peat formation may have occurred in interdistributary basins above present sea level, or that the Holocene postglacial high sea (hypsithermal ?) may have been several feet (2–3 m) above the present. The concept of a postglacial sea level higher than the present is controversial, although evidence for such has been reported from New Zealand, Australia, Japan, and elsewhere around the Pacific. Similar observations have been made in San Francisco Bay, where undeformed mud thought to have been deposited in the last several thousand years occurs at an elevation close to that of the highest peat in the Delta.[24]

Undoubtedly there were many fluctuations along the Mokelumne Fan—California Delta boundary, probably caused by minor changes in Pleistocene stream regime or eustatic-isostatic changes of base level. But the interior location of the California Delta apparently has afforded "protection" from much of the well-known Quaternary coastal tectonism, so that the five to six miles (8–10 km) of interfingering sediments are interpreted as a response, in delta and fan, to major changes of climate.

*Depth of the Mokelumne Channels*

The origin of many gravel-filled terraces and buried channels is still not clearly understood. Depending on the broad interaction of climate, relief, and tectonic controls, erosion and channel cutting may be dominant processes in one region, whereas aggradation and channel filling may occur elsewhere at the same time. Thus to explain the origin and depth of the now-buried Mokelumne gravel-filled channels, it is necessary to evaluate the relative influence of regional and local tectonism, and Pleistocene climatic change.

The Great Valley of California is generally regarded as a depositional basin that has been subsiding and accumulating sediments since mid-Cretaceous time. The amount of downwarping in the Great Valley during the Quaternary is unknown; however, in the southern part (San Joaquin Valley) periodic uplift of the Sierra Nevada Mountains or tectonic "pulsations" of the Valley trough have been re-

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[23] Shlemon, op. cit., footnote 11; and Janda and Croft, op. cit., footnote 14.

[24] D. Hopley, "World Sea Levels During the Past 11,000 Years Evidence from Australia and New Zealand," *Résumés des Communications*, VIII Congress (Paris: International Association for Quaternary Research, 1969), p. 260; S. Fujii, "Sea Level Changes in Japan During the Past 11,000 Years," ibid., p. 198; R. W. Jessup, "The Late Quaternary Eustatic and Geologic History of Northern Yorke Peninsula, South Australia," in R. B. Morrison and H. E. Wright, eds., *Means of Correlation of Quaternary Successions*, International Association for Quaternary Research, VII Congress Proceedings, Vol. 8 (Salt Lake City, Utah: University of Utah Press, 1968), pp. 395–406. For the general argument in support of a Holocene high stand of sea level (hypsithermal) see R. W. Fairbridge, "Eustatic Changes in Sea Level," in L. H. Ahrens, F. Press, K. Rankama, and S. K. Runcorn, eds., *Physics and Chemistry of the Earth* (London: Pergamon Press, 1961), Vol. 4, pp. 99–185. For evidence from the Pacific against the postglacial high stand of sea level, see J. R. Curry, F. B. Shepard, and H. H. Veeh, "Late Quaternary Sea-Level Studies in Micronesia: CARMARSEL Expedition," *Geological Society of America Bulletin*, Vol. 81 (1970), pp. 1865–80; and N. D. Newell, and A. L. Bloom, "The Reef Flat and 'Two-Meter Eustatic Terrace' of Some Pacific Atolls," ibid., pp. 1881–93. For the San Francisco Bay area see R. C. Treasher, *Geology of Sedimentary Deposits in San Francisco Bay, California*, California Division of Mines and Geology, Special Report 82 (1963), pp. 11–24.

jected as the major causes of cutting and filling.[25] In the central part, too, as suggested by the parallelism of Pleistocene terrace and modern stream gradients, late Quaternary uplift of the Sierra Nevada seems not to have significantly controlled downstream channel incision. In contrast, Tertiary formations and adjacent pediments all dip steeply into the subsurface. Nevertheless the slight downstream vertical divergence of the Mokelumne buried channels and the depth of the older ones below present sea level suggest that eustatic base level control and Quaternary geologic subsidence in the California Delta cannot be ruled out. The California Coast Ranges underwent intense deformation during the Pleistocene, and this tectonism is probably continuing.[26] The Montezuma Hills north of Sherman Island, for example, are in fault contact with deltaic sediments; the faulting is late Pleistocene and possibly Holocene in age (Fig. 3).[27] Many of the world's major deltas are continuously subsiding, and the California Delta, interfingering the Mokelumne channels, may be no exception.

The evidence for early Quaternary subsidence of the California Delta is indirect, based primarily on the absolute depth of the Mokelumne River channels relative to inferred Pleistocene sea levels, and the depth of bedrock channels in the Carquinez Strait and San Francisco Bay. The three well-defined buried channels of the Mokelumne River diverge vertically downstream, the oldest being the deepest. If the depth of each channel were singularly the product of glacioeustatic lowering, then each should have been graded to a base approximating the low stand of of worldwide glacial sea levels. If one accepts Fairbridge's concept of Quaternary eustatic oscillation, the low stand of sea level has progressively decreased in elevation with each younger glaciation. Relative to the present level, the Kansas glacial sea was lowered about 40 meters; the Illinoian about 65 meters; and the classic Wisconsin perhaps 100 meters.[28] Because of their inland location, the Mokelumne channels undoubtedly graded to higher levels than if they had been on the coast. If stratigraphic position and limited radiometric data are used tentatively to correlate the Mokelumne channels with the continental glacial sequence, the youngest channel (Modesto age) should have graded to the lowest base, and the oldest well-defined channel (Laguna age) should have cut to a higher level. However, the reverse is true. The Laguna age channel, at least 250 feet (61 m) below present sea level, is well under the younger Pleistocene channels (Fig. 3). This depth, therefore, may be due in large part to Quaternary slow subsidence or faulting in the western part of the California Delta. Although the evidence for subsidence is still equivocal, it appears that some downwarping occurred in early Quaternary time. However, lateral continuity of the younger channels and peat beds suggests that little, if any, significant movement affected the area during the Holocene.

Glacioeustatic control of the lower course of the Mokelumne River seems clear. The interfingering of oxidized channel gravel and alluvial fan deposits with reduced deltaic sediments suggests a broad pattern of cyclic sedimentation during the Pleistocene. Eustatic control of this sedimentation is supported by engineering studies of sediments in San Francisco and adjacent bays that show at least three late-Pleistocene episodes of cutting and filling, possibly correlative with an Illinoian and two Wisconsin oscillations of sea level.[29] Radiocarbon dates indicate that the "younger bay mud," the last eustatically controlled fill in San Francisco Bay, ranges in age from at least 7,400 to 2,400 years B. P.; it is therefore correlative with radiometrically dated peat of similar age in the Delta, the latter probably having been formed during the most recent major postglacial rise in sea level.[30]

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[25] Janda and Croft, op. cit., footnote 14.

[26] C. Wahrhaftig and J. H. Birman, "The Quaternary of the Pacific Mountain System in California," in Wright and Frey, op. cit., footnote 3, pp. 299–340.

[27] F. H. Olmstead and G. H. Davis, *Geologic Features and Ground-Water Storage Capacity of the Sacramento Valley, California*, Water Supply Paper 1497 (Washington: U.S. Geological Survey, 1961), p. 131.

[28] The depths are interpreted from Quaternary eustatic curves in Figure 9 of Fairbridge, op. cit., footnote 24, p. 131.

[29] Treasher, op. cit., footnote 24.

[30] J. A. Storey, V. E. Wessels, and J. A. Wolfe, "Radiocarbon Dating of Recent Sediments in San Francisco Bay," *California Division of Mines and Geology, Mineral Information Service*, Vol. 19, No. 3 (1966), pp. 47–50; and H. B. Goldman, "Geology of San Francisco Bay," in H. B. Goldman, ed., *Geo-*

Projecting an extremely conservative gradient of five feet per mile (0.5 m/km) places the Mokelumne River Laguna age channel approximately 310 feet (95 m) below sea level under Sherman Island on the western side of the Delta. This depth is less than the –380 foot (–116 m) bedrock "notch" of the Pleistocene Sacramento River at the Golden Gate, about fifty miles (80 km) "downstream" from the Delta.[31] However the maximum depth to bedrock in the intervening Carquinez Strait, only twenty miles (32 km) west of the Delta, is 130 feet (40 m) below present sea level, well above the Laguna age channel in the Mokelumne area.[32] Apparently, therefore, the most deeply buried Mokelumne River channels subsided to their present depth or, alternatively, Pleistocene uplift in the San Francisco Bay area has raised bedrock channels far above their original levels.[33] It thus appears that the lower courses of the Pleistocene Mokelumne River were graded to a base controlled by glacioeustatic oscillations of sea level, possibly superimposed on deltaic subsidence.

### *The Pleistocene-Holocene Boundary*

No obvious hiatus in the alluvial stratigraphic record separates Pleistocene and Holocene sediments in much of the central part of the Great Valley of California. Especially in the center of the Valley trough, sedimentation was probably continuous; elsewhere minor topographic or geomorphic features indicative of local hydrologic fluctuation seem to have been obliterated by man. In the Delta, however, the Pleistocene-Holocene boundary is apparently delimited by a change in the hydrologic regime of the Delta itself, and of the streams traversing it.

Depth contours, based on well log and levee boring data, show that the base of the peat is about sixty feet (18 m) below present mean sea level in the western part of the Delta, sloping upward to the surface about twenty-five miles (40 km) to the east toward the Mokelumne Alluvial Fan (Fig. 1).[34] Along this contact there is a transition from dark-colored, fluvial sand and silt to the overlying peat and black clay. This change in sedimentation, consistent throughout the Delta, suggests that gradients of streams flowing through the Delta were reduced, and fresh-water or slightly brackish marshes developed. In these marshes grew tules and reeds that eventually became widespread deposits of peat. The depth of the peat below sea level is evidence of a relative positive change in level resulting primarily from subsidence (downwarping) or glacioeustatic rise. Subsidence includes compaction, the reduction of sediment volume following deposition. Subsidence in the Delta may have been significant in early Quaternary time, but little appears to have taken place during the Holocene. Compaction, however, apparently is a modern occurrence, for many Delta islands are now below sea level.

Lowering of the Delta land surface has often been confused with geologic "downwarping" or negative tectonism. Indian mounds, now below sea level, have been cited as evidence of continuing rapid downwarping in the axial trough of the Great Valley.[35] But lowering of the Delta surface probably results from near-surface compaction of peat and detrital sediments above the regional water table, which began with reclamation of the islands about 100 years ago. The total amount of compaction in the Delta is thus probably very slight. Reeds cored forty feet (10.2 m) below the surface show little effect of crushing. Appar-

*logic and Engineering Aspects of San Francisco Bay Fill*, California Division of Mines and Geology, Special Report 97 (1969), pp. 9–29.

[31] P. D. Trask and J. W. Rolston, "Engineering Geology of San Francisco Bay, California," *Geological Society of America Bulletin*, Vol. 62 (1951), pp. 1079–1110; and P. R. Carlson, R. R. Alpha, and D. S. McCullock, "The Floor of Central San Francisco Bay," *California Division of Mines and Geology, Mineral Information Service*, Vol. 23 (1970), pp. 97–107.

[32] Bridge boring data provided by the California Division of Highways show that bedrock elevation in the Carquinez Strait decreases from 120 feet (37 m) below sea level on the east at Sherman Island (Antioch Bridge) to –130 feet (–40 m) on the west near Vallejo (Carquinez Bridge).

[33] For a synthesis of Quaternary deformation in the San Francisco Bay area see Louderback, Taliaferro, and A. D. Howard in Jenkins, op. cit., footnote 7, pp. 95–106; M. N. Christensen, "Quaternary of the California Coast Ranges," in E. D. Bailey, ed., *Geology of Northern California*, California Division of Mines and Geology, Bulletin 190 (1966), pp. 305–14; and Wahrhaftig and Birman, op. cit., footnote 26.

[34] Levee boring logs provided by A. B. DeRutte, State of California, Department of Water Resources.

[35] Stearns, et al., op. cit., footnote 6, p. 32.

ently permanent saturation of peat and clay below the water table has maintained pore pressure and prevented significant compaction. The idea of recent geologic subsidence was further supported by the thickness and depth of the peat.[36] However, the depth and the general three-dimensional configuration of the deltaic peat can be better explained by the Holocene rise in sea level.

Only a few of the Delta peats as yet have been dated by radiocarbon. Samples from sixty and thirty-three feet (18 and 10 m) below Sherman Island in the western part of the Delta yielded ages of 10,690 ± 300 and 6,600 ± 250 years, respectively.[37] The 10,690-year-old peat directly overlies coarse-grained, fluvial sand and is the deepest presently known in the Delta. If compaction of near-surface, deltaic deposits is negligible, then the age of the peat, and its depth and environment, suggest that it marks the approximate Pleistocene-Holocene boundary in this part of California. The age of almost 10,700 years correlates fairly well with a worldwide rapid rise in sea level generally regarded as the end of the Pleistocene Epoch.[38] The depth of the dated peat also suggests that sea level may have been at least sixty feet (18 m) below the present level about 11,000 years ago in the central part of the Great Valley. Since that time the California Delta has gradually expanded "headward" to its approximate present area.

Assuming a constant rate of deltaic sedimentation caused by rising sea level, then, based on the limited radiocarbon data, the postglacial sea rose about 0.7 feet (0.21 m) per 100 years between 10,700 and 6,600 years ago, decreasing to about 0.5 feet (0.15 m) a century from 6,600 years ago to the present. These values of inferred Holocene sea level rise are first approximations only. Undoubtedly there were many Holocene sea level fluctuations, and the rate of sea level rise must have varied accordingly. Some workers, for example, suggest that an initial rapid rise in the postglacial sea culminated in a higher than present stand about 5,000 years ago, followed by a slow decrease to the present level.[39] Others assume a relatively constant rise throughout Holocene time; still others indicate a rise to the present position 3,000 to 5,000 years ago, and only minor oscillations since.[40] Further complicating glacioeustatic levels are the effects of coastal isostatic adjustments, neotectonism in the San Francisco Bay area, and possible deltaic subsidence.[41] Nevertheless, within the limits of the data presently available, the California Delta seemingly records the gross Pleistocene-Holocene boundary; and additional carbon dating and pollen studies of the many overlying peat beds may show that the Delta is an unusually sensitive indicator of Holocene climatic and sea level changes.

## SUMMARY AND CONCLUSIONS

The stratigraphic relationships of fan and deltaic deposits in the central part of the Great Valley show that the lower course of the Pleistocene Mokelumne River graded into a eustatically fluctuating base level. At least three Mokelumne River gravel-filled channels extend in the subsurface from fluvial terraces westward to the California Delta. Each

[36] Cosby and Carpenter, op. cit., footnote 6, p. 3.

[37] United States Geological Survey, "Sherman Island Series, California," *Radiocarbon*, Vol. 1 (1959), p. 156.

[38] W. S. Broecker, M. Ewing, and B. C. Heezen, "Evidence for an Abrupt Change in Climate Close to 11,000 Years Ago," *American Journal of Science*, Vol. 258 (1960), pp. 429–48. The Pleistocene-Holocene boundary problem is reviewed in R. W. Fairbridge, "Holocene, Postglacial or Recent Epoch," in R. W. Fairbridge, ed., *The Encyclopedia of Geomorphology* (New York: Reinhold Book Corporation, 1968), pp. 525–36. The apparent 10,700-year-old postglacial rise in the California Delta corresponds remarkably well with sudden desiccation of several large lakes in the California desert. See, for example, G. I. Smith, "Late Quaternary Geologic and Climatic History of Searles Lake, Southeastern California," in Morrison and Wright, op. cit., footnote 24, pp. 293–310.

[39] Curry, et al., op. cit., footnote 24, p. 1878.

[40] See, for example, F. P. Shepard, "Rise of Sea Level Along Northwest Gulf of Mexico," in Shepard, et al., op. cit., footnote 3, pp. 338–44; idem, "Sea Level Changes in the Past 6,000 Years: Possible Archaeological Significance," *Science*, Vol. 143 (1964), pp. 574–76; R. Koster, "Postglacial Sea-Level Changes in the Western Baltic Region in Relation to Worldwide Eustatic Movements," in Morrison and Wright, op. cit., footnote 24, pp. 407–20; and Newell and Bloom, op. cit., footnote 24.

[41] The pitfalls of sea level correlation in tectonically unstable areas are reviewed by C. G. Higgins, "Causes of Relative Sea-Level Changes," *American Scientist*, Vol. 53 (1965), pp. 464–76; and by R. B. Morrison, "Means of Time-Stratigraphic Division and Long-Distance Correlation of Quaternary Successions," in Morrison and Wright, op. cit., footnote 24, pp. 1–114.

channel was probably incised during onset of glaciation in the Sierra Nevada Mountains. With deglaciation and rising sea level, fine-grained glaciofluvial outwash was carried into the Valley, burying each channel and spreading out along distributaries to form large coalescing alluvial fans. Relative landscape stability and soil formation ensued in interglacial time. Succeeding episodes of climatically-controlled cutting and filling incised new channels and often covered portions of the older fans, burying many preexisting soils.

Tules, reeds, and other fibrous aquatic plants growing at water level were preserved as peat beds when postglacial sea levels slowly rose and inundated the present California Delta. Areal expansion and contraction of the Delta were periodic, controlled primarily by worldwide eustasy. The Delta reached its greatest extent in interglacial times, and perhaps expanded to about the ten foot (3 m) elevation in the central part of the Great Valley during the last postglacial rise in sea level.

The oldest well-defined buried Mokelumne River channel (Laguna age) grades into deltaic sediments approximately 325 feet (99 m) below present sea level. This depth, however, in large part may be due to post-channel subsidence of the Delta. The younger channels may also have graded to base levels higher than those indicated by their depths.

About 11,000 years ago, the post-Wisconsin sea began to rise. Defining the middle-latitude, Pleistocene-Holocene boundary, the rising sea entered the California Delta through San Francisco and Suisun Bays and the Carquinez Strait. Deposition of sand first gave way to mud and organic-rich thalassostatic sediments at Sherman Island in the western or seaward side as the Delta slowly transgressed headward to the east. Minor postglacial eustatic oscillations undoubtedy affected the rate of Holocene deltaic growth, but since the end of the Pleistocene approximately sixty feet (18 m) of intercalated peat and clay have been deposited. The modern Mokelumne River occupies a distributary on the northern edge of its fan. Recent fan and natural levee deposits are now transgressing over deltaic sediments along the continually fluctuating eastern boundary of the California Delta.