DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

TO ACCOMPANY MAP MF-1790

GEOLOGIC MAP OF THE LATE CENOZOIC DEPOSITS OF THE SACRAMENTO VALLEY AND NORTHERN SIERRAN FOOTHILLS, CALIFORNIA

By

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INTRODUCTION

Sheet 1

The southernmost (sheet 1) of five map sheets depicts the late Cenozoic geology of the Sacramento Valley. This map area extends from the northern part of the Sacramento-San Joaquin delta north to about the latitude of Cache Creek, 16 km north of Sacramento. The foothills of the Sierra Nevada form the east margin; the low foothills of the Coast Ranges form the west margin. The western part of the map area is underlain by the Pliocene Tehama Formation, which also underlies the Dunnigan Hills in the northwestern part of the mapped area. Along much of the west margin of the valley, the Tehama lies unconformably on Cretaceous sedimentary rocks and is uncomformably overlain by the Pleistocene Red Bluff Formation and younger alluvium. Farther east, however, lower Tertiary rocks occur between the Cretaceous and Pliocene rocks. West of the Sacramento River, all the post-Red Bluff alluvium is deposited at a level below or in channels cut into the Tehama and Red Bluff Formations. These younger deposits, which include primarily the Modesto Formation and Holocene alluvium, form broad alluvial fans, the most prominent of which emanate from Cache and Putah Creeks.

The valley in the central part of the map area is formed mainly by Holocene basin deposits (Qb) that were laid down by the Sacramento River and its two major local tributaries, Putah and Cache Creeks. In the southern part of the map area these deposits grade basinward into peat-rich muds of the Sacramento River delta.

East of the Sacramento River, most of the map area is covered by large alluvial fans of the Riverbank Formation that appear to bury older alluvial fans of the Turlock Lake, Laguna, and Mehrten Formations. The flood plain and central part of the Sacramento Valley are formed mainly by Holocene alluvial (Qsc, Qa) and basin deposits (Qb).

Sheet 2

The south-central part of the valley (sheet 2) extends from the confluence of the Sacramento and Feather Rivers northward to include about three-fourths of the Sutter Buttes. It extends in an east-west direction from the Coast Ranges foothills to the Sierran foothills east of Marysville and Yuba City.

The most salient geologic feature of this area is the Sutter Buttes, which rise abruptly about 700 m above the valley floor. Their sharp, jagged peaks stand in marked contrast to the relatively flat alluvial fill of the valley.

The western foothills are underlain by the Tehama Formation, which is sporadically capped by the Red Bluff Formation. Younger sediments are incised into the Tehama and Red Bluff; these sediments also form broad fans spilling into the Colusa Basin. A few scattered remnants of alluvial fans of Riverbank age are found along the foothill front in the northwest corner of the map area. Riverbank-age alluvial fans are also found on the western side of the Sutter Buttes. Holocene alluvial and flood-basin deposits of the Sacramento River are actively burying the fans there.

The eastern side of the valley is covered by deposits of the Feather River and smaller streams of the western Sierra Nevada. The broad alluvial fan of Riverbank age, located east of Sacramento, underlies most of the eastern part of this map area in an outcrop belt that narrows northward toward Marysville. Eroded remnants of the Turlock Lake, Laguna, and Mehrten Formations are buried with the Riverbank alluvium and all are presently being dissected by Holocene stream channels.

Sheet 3

The central part of the valley (sheet 3), extends north from the northern one-fourth of the Sutter Buttes to the latitude of Chico and extends in an east-west direction from the Coast Ranges foothills to the Sierran foothills and Chico monocline.

The Tehama Formation is not exposed in the southwestern two-thirds of this map area, but it does underlie the foothills south of the Orland Buttes at the extreme northwest corner of the map area. Where the Tehama is absent, Cretaceous marine rocks are dissected by Holocene streams that carry debris to the flood basins. The Red Bluff caps the Tehama in the northwestern part of the map area, and it also caps the Cretaceous marine rocks to the south and west. The fan of Stony Creek dominates the north-central part of the map area. Its large distributary channels form an anastomosing network of linear deposits that range from early Riverbank age to Holocene. The large sediment load supplied to the Sacramento River by Stony Creek is probably responsible for the large levee deposits along the Sacramento River below Stony Creek.

The northeastern part of the map area is underlain by the Pliocene Tuscan Formation which unconformably overlies rocks of Miocene, Eocene, and Cretaceous age.

The conspicuous geomorphic landmark at Oroville, the north and south Oroville Table Mountains, is composed of dense, black Lovejoy Basalt. The Lovejoy Basalt also caps the Orland Buttes.

South of Oroville the Laguna Formation is dissected and backfilled with deposits of Turlock Lake age. Several thin cappings of the Red Bluff unconformably overlie these deposits. Alluvial deposits of Riverbank age form cut-and-fill channel deposits in all older units. Younger deposits of Modesto and Holocene age flank the Feather River and occupy most of the area east of the Sutter Buttes and west of the Sierran basement.

Sheet 4

The north-central part of the valley (sheet 4), extends from the Orland Buttes to the south to just north of Red Bluff and the Iron Canyon section of the Sacramento River. It is bounded on the west by the Coast Ranges foothills and on the east by the Chico monocline.

The Coast Ranges foothills are underlain by the Tehama Formation, which unconformably overlies more steeply dipping Cretaceous marine strata. The Tehama also unconformably overlies the Miocene Lovejoy Basalt on the east flank of the Orland Buttes. Excellent exposures of the Nomlaki Tuff Member are found within the Tehama Formation near its base in stream cuts all along the western side of the valley. In the southern half of the western foothills the Nomlaki dips 15-17° E. whereas in the northern half of the western foothills it is nearly flat lying. The dip changes across the projection of the Cold Fork and Elder Creek faults. The Nomlaki also occurs at the base of the Tuscan Formation along the Chico monocline where the tuff is exposed in the bottom of deeply incised stream channels along the monoclinal flexure.

Of all the published maps that cover the Sacramento Valley, this one displays the best developed and most widely preserved areas of the Red Bluff pediment. The Red Bluff truncates and caps the Tehama on the west and truncates and forms fans on the older gravels derived from the Tuscan on the east. The Red Bluff is deformed in a series of folds along the central and western parts of the map area. Bryan (1923) first noted the domes at Corning, but others exist at Hooker (west of Red Bluff and north of Blossom) and also southwest of Red Bluff between Red Bank and Oat Creeks. An exposure of the Tehama in the channel of Stony Creek due south of the Corning Dome suggests that more doming may exist south of Corning.

All the younger deposits, which include the Riverbank Formation, Modesto Formation and Holocene alluvium, are cut and back filled in a series of nested terraces and fans topographically below the Tehama, Tuscan, and Red Bluff Formations. Younger deposits are basinward and topographically lower then Tehama, Tuscan, and Red Bluff Formations.

Sheet 5

The northernmost (sheet 5) of the five maps in this study depict the northern geology of the Sacramento Valley. Its south boundary is near Bend on the incised meander loops of the Sacramento River and extends northward almost to Shasta Dam. Its west boundary is the foothills of the Klamath Mountains and Coast Ranges, and the east border is marked by the various volcanic rocks derived from the Lassen Peak area. The western part of the valley floor is underlain by the Tehama Formation while its temporal equivalent, the Tuscan Formation, underlies the eastern part. In the area of this map, the Tehama unconformably overlies primarily plutonic and metamorphic rocks of the Klamath Mountains, and the Tuscan either overlies the alluvial deposits of the Eocene Montgomery Creek Formation or the Cretaceous Chico Formation. The Tehama and Tuscan Formation interfinger near the present center of the Sacramento Valley, and we have arbitrarily chosen to use the channel of the Sacramento River as the Tehama-Tuscan contact. The Nomlaki Tuff Member (3.4 m.y.) occurs locally near the bases of the Tehama and Tuscan Formations.

These Pliocene rocks are beveled and capped by the thin Red Bluff pediment. Some of the best examples of the Red Bluff pediment can be seen in the river bluffs near the city of Redding. On the western side of the Sacramento River, the Red Bluff Formation forms the highest part of the landscape, but east of the river younger volcanic flows extend westward over part of the Red Bluff. These younger volcanic rocks, as well as the underlying Pliocene rocks, have been deeply eroded by west-flowing streams that locally expose the Cretaceous and Eocene rocks along their canyon walls. The Chico Formation is highly susceptible to landsliding.

The Battle Creek fault zone is one of the most prominent structural features in northern California. It crosses the southeastern part of the map area and strikes about N. 75° E. East of the Sacramento River, the Battle Creek fault zone forms a prominent escarpment rising to the northeast that is buried by late Quaternary flows from the Lassen Peak area. The sense of motion on the dominantly normal Battle Creek fault zone is north-side up. The basaltic cinder cone of Black Butte sits atop the escarpment and displays little erosion. Westward, the Battle Creek fault zone probably controls the orientation of Cottonwood Creek valley. Linear geomorphic features that may be related to faulting extend westward along the South Fork of Cottonwood Creek, Mitchel Gulch, Colyear's Spring, Sour Grass Gulch, and finally into the Coast Ranges (Helley and others, 1981). Along the tributaries of Cottonwood Creek, Quaternary terraces of Riverbank age display features such as vegetation lines and linear depressions. Good examples of linear features may be seen near the confluences of Red Bank Gulch, Sour Grass Gulch, and Wild Hide Gulch with the South Fork of Cottonwood Creek. This area is just west of the Inks Creek fold system and may be affected by these structures. A few kilometers north of, and parallel to, the Battle Creek fault zone the Bear Creek fault also shows north-side up displacement, although on a much smaller scale than that of the Battle Creek fault zone.

A large area underlain by the Red Bluff south and east of Redding is dissected by very straight northwest-trending stream channels. These channels may be structurally controlled.

PREVIOUS WORK

Since the turn of the century, most geologic studies of the area have concentrated on the oil and gas potential of the older, pre-Pliocene rocks. Diller (1894) described the rocks surrounding and underlying the Sacramento Valley. He also described and named the Red Bluff Formation and noted that these Pleistocene gravels were involved in the deformation of the Coast Ranges. Bryan (1923) described the ground-water resource and the valley physiography when natural artesian flow conditions existed. He subdivided the valley into five natural provinces (1923, p. 9): the redlands, the low plains, the river lands, the flood basins, and the island country. Bryan also recognized, that the Red Bluff Formation was more widespread than Diller had previously recognized, but more importantly he noted that it was deformed at Corning, along the Chico monocline, and at Dunnigan Hills. Olmsted and Davis (1961) described the regional ground-water hydrology, and they were the first to use stratigraphic nomenclature in order to rank geologic units in terms of their water yield. They also recognized the widespread distribution of the Red Bluff Formation and that these gravels truncated and beveled a surface of low relief across the Tehama and Tuscan Formations. They also noted that the hardpans that developed on the Red Bluff soils act as aquicludes to prevent percolation of surface water (Olmsted and Davis, 1961, p. 35). Safanov (1968) and Redwine (1972) summarized the geologic framework of the oil and gas potential for this area.

On August 1, 1975, residents of the Sacramento Valley and adjacent Sierra Nevada foothills were startled by a moderate-size earthquake ($\underline{M}_S$ = 5.6) centered near Oroville. Previously, this region was considered to be tectonically stable, but this earth tremor sparked new interest in the seismogenic potential of the valley. The tectonic activity in the Sacramento Valley and foothills and the possibility of active faulting have been assessed for selected areas by studies of structural history (Woodward Clyde Consultants, 1977; Harwood and others, 1981; Helley and others, 1981; and Harwood and Helley, 1982).

The maps presented here provide a greater subdivision of the late Cenozoic deposits (65 map units). Limits are placed in a time-stratigraphic context based on absolute ages of ash beds and volcanic rocks that are interbedded with the alluvial deposits. The deposits and map units are also related to their geomorphic forms, lithologies, and post-depositional soil profiles.

GEOLOGIC MAPPING TECHNIQUES

One way to assess the recency of tectonic activity in any area is to differentiate and map the youngest deposits and then evaluate their origin. In the Sacramento Valley such deposits include fluvial, paludal, lacustrine, estuarine, and volcanic materials that comprise a broad, largely featureless physiographic plain within the Coast Ranges to the west, the Sierra Nevada to the east, and the Klamath Mountains to the north (fig. 1). In our mapping we attempted to relate the deposits to the processes responsible for their deposition. By such association, any deviation from an expected geomorphic form of a given depositional process might be caused by tectonism and thus warrant closer scrutiny.

The alluvial and volcanic units of this series of maps were differentiated by various geologic criteria including age, lithology, induration, compaction, texture, depositional environment, geomorphic expression, and soil-profile development. The alluvial deposits were mapped on the basis of their topographic expressions, which were determined, in part, by interpretation of aerial photographs and partly from geologic interpretation of published and unpublished soils-series maps. The quality, vintage, and type of aerial photography available varies considerably over the area. Some areas are covered by standard black and white photos, whereas other areas are covered by special photos, such as false-color infrared photography.

Some of the mapping was incorporated directly from published sources and some was modified from published and unpublished work (fig. 2). The geologic map for the Whitmore quadrangle, in the northeast corner of sheet 5, is reproduced without modification or field checking from Macdonald and Lydon (1972). We modified slightly the work of Busacca (1982) in the Oroville quadrangle and that of M. P. Doukas (unpub. data, 1981) in the Chico area. We also used the mapping of Williams and Curtis (1977) for the Sutter Buttes area, although we combined some of their units. We used the basal contact of the Tehama Formation drawn by Murphy and others (1969) in the Ono quadrangle and modified that contact in the Colyear Springs quadrangle (Bailey and Jones, 1973) after field checking. Mapping in the Sacramento-San Joaquin delta was taken from Atwater (1982) and Atwater and Marchand (1980). The remaining areas of these five oversized sheets were compiled from our own published and unpublished mapping at scales of 1:24,000 and 1:62,500; base maps used in compilation for each sheet are shown in figures 3 through 7.

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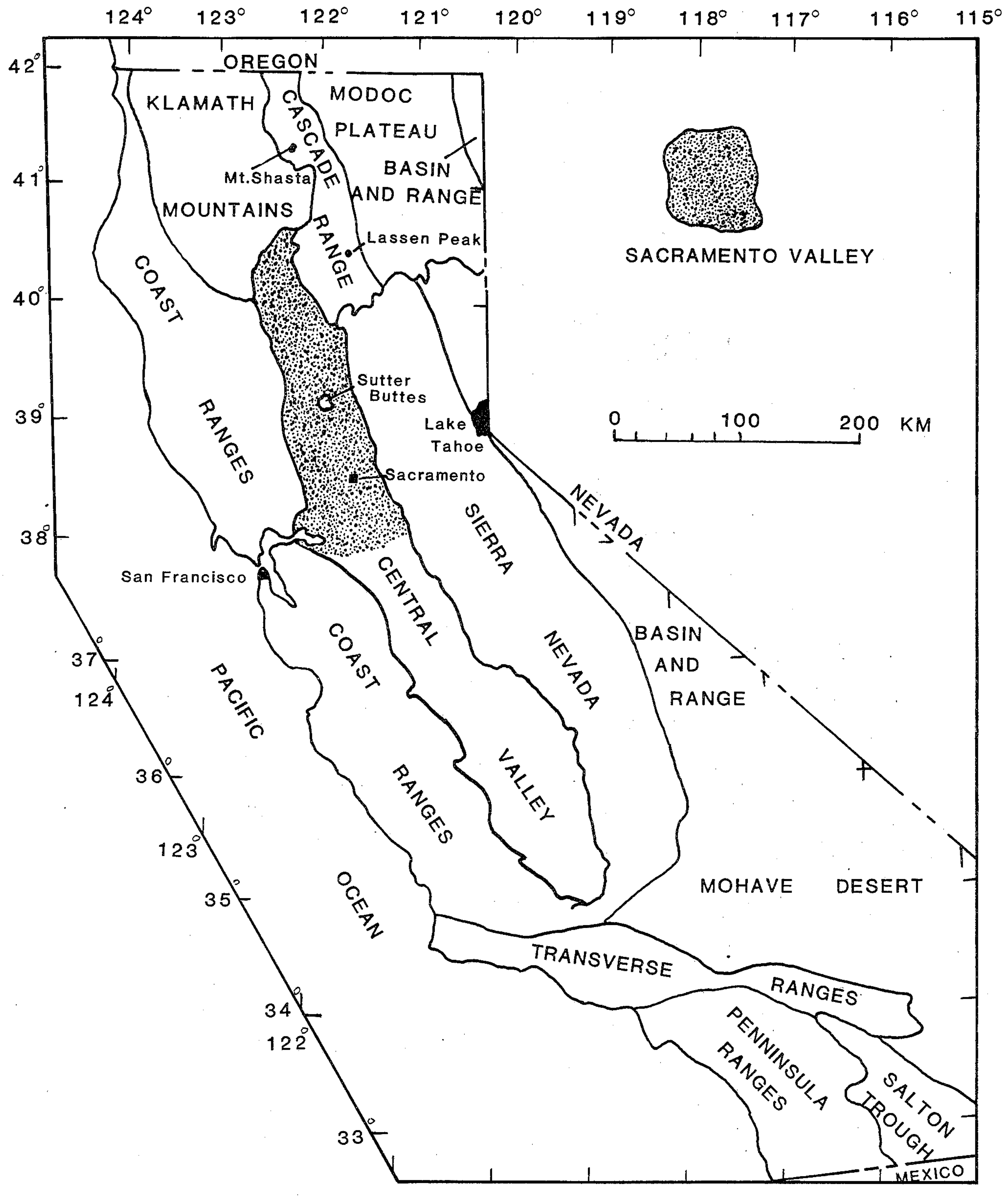


Figure 1.--Location map of the Sacramento Valley, California.

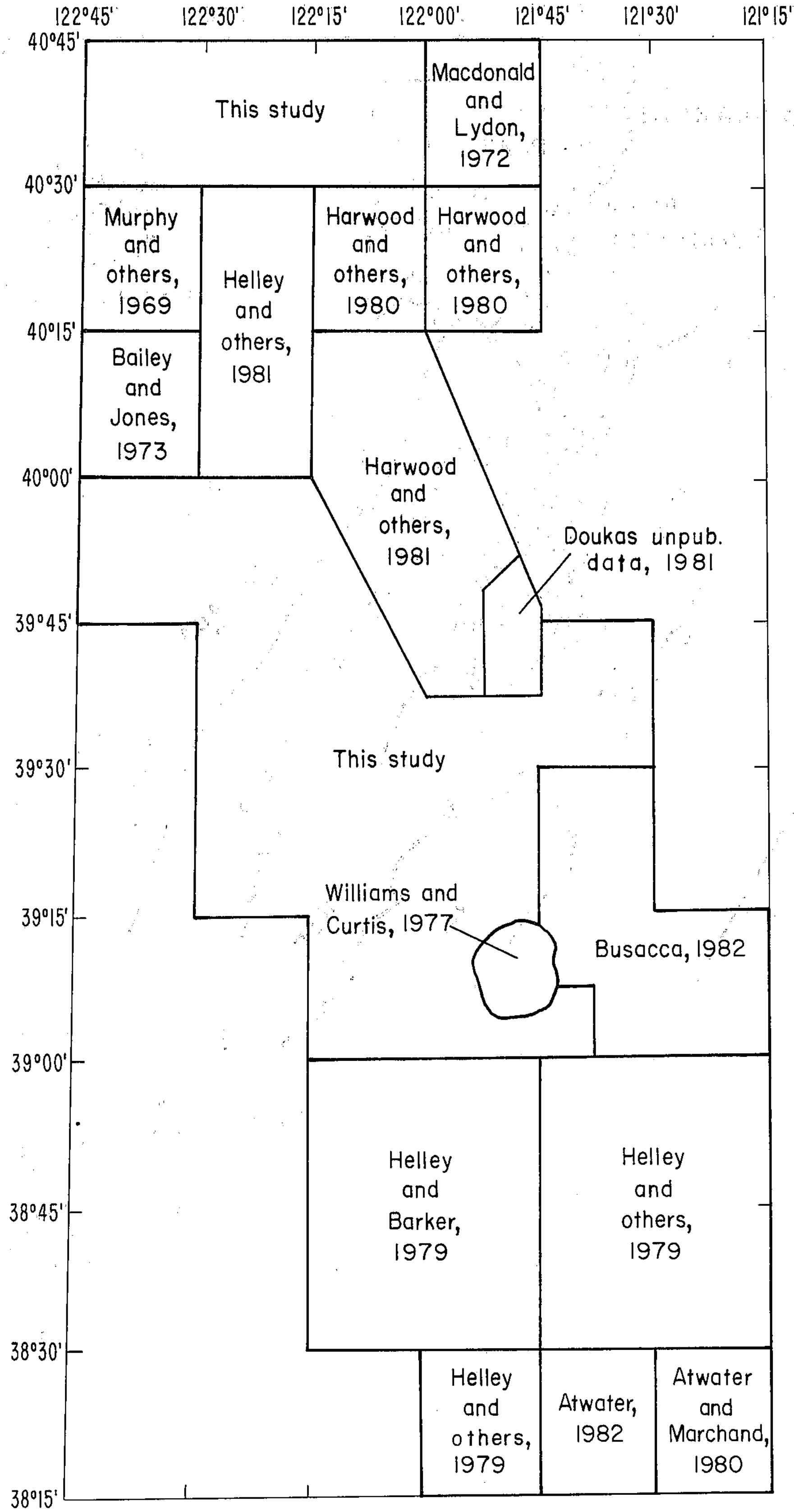


Figure 2.--Sources of data.

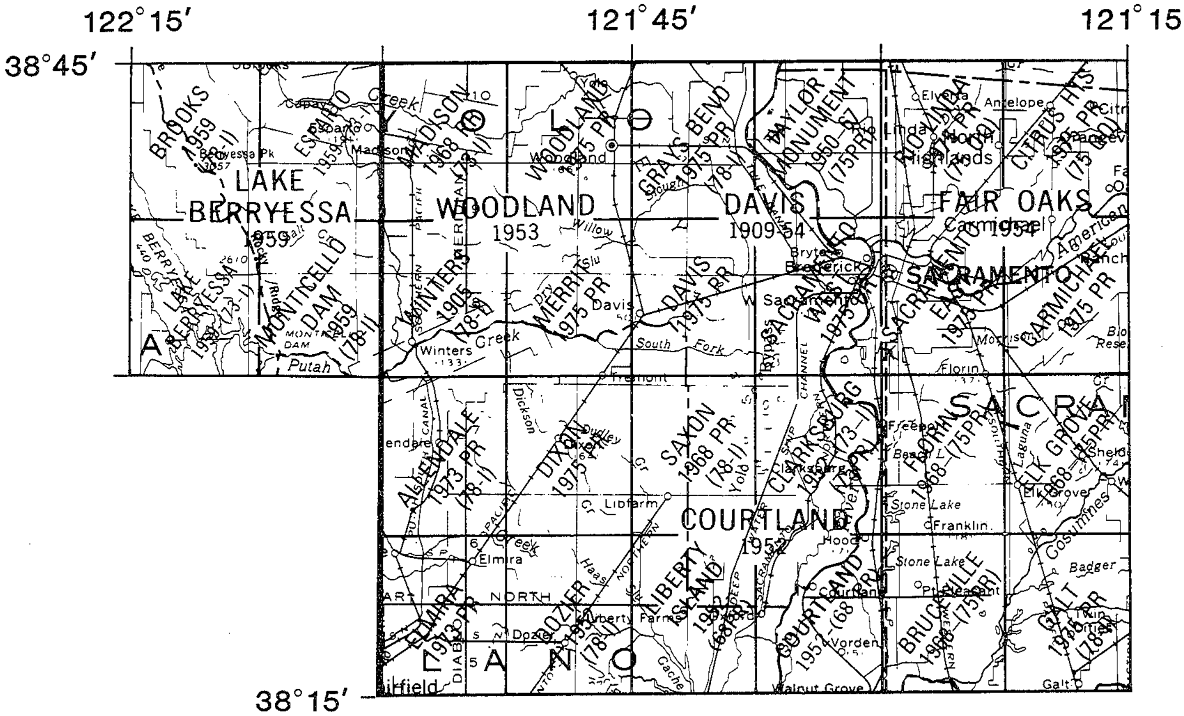


Figure 3.--Index map for the southern Sacramento Valley.

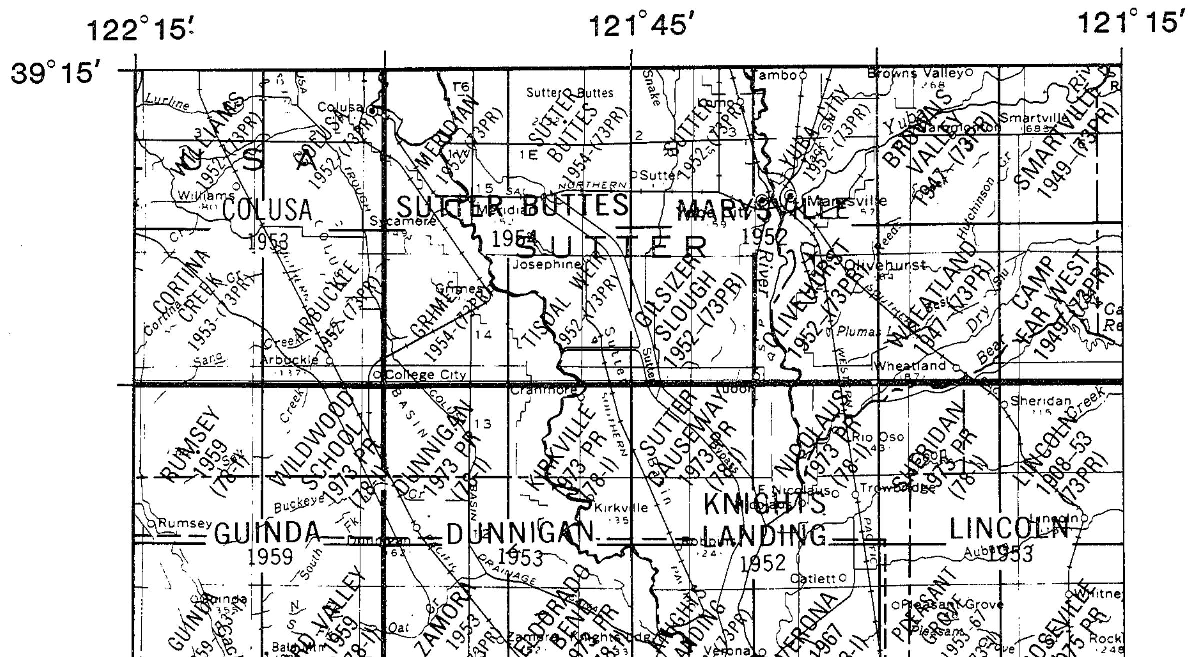


Figure 4.--Index map for the south-central Sacramento Valley.

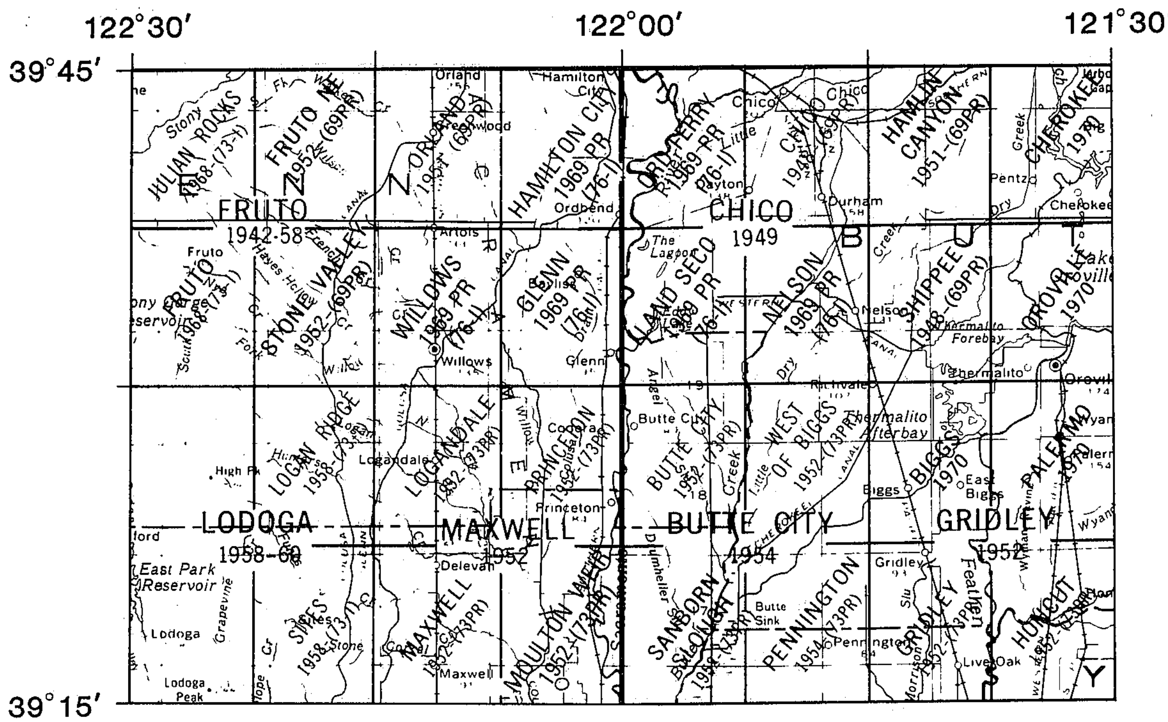


Figure 5.--Index map for the central Sacramento Valley.

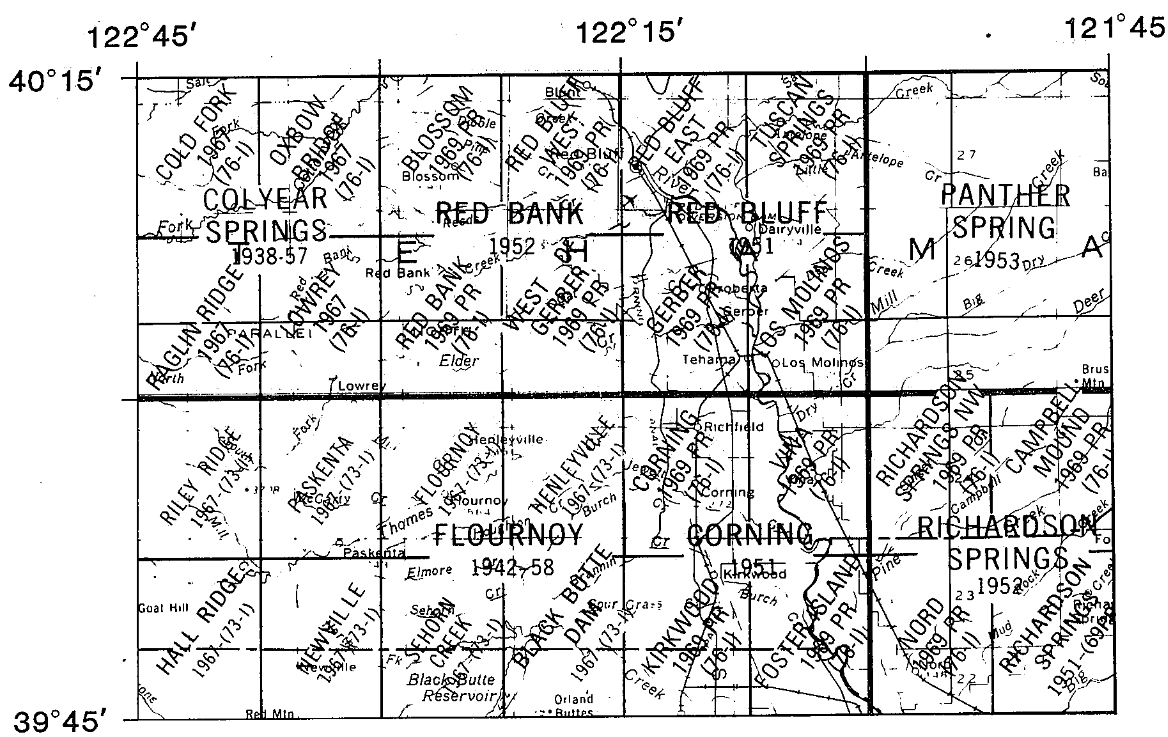


Figure 6.--Index map for the north-central Sacramento Valley.

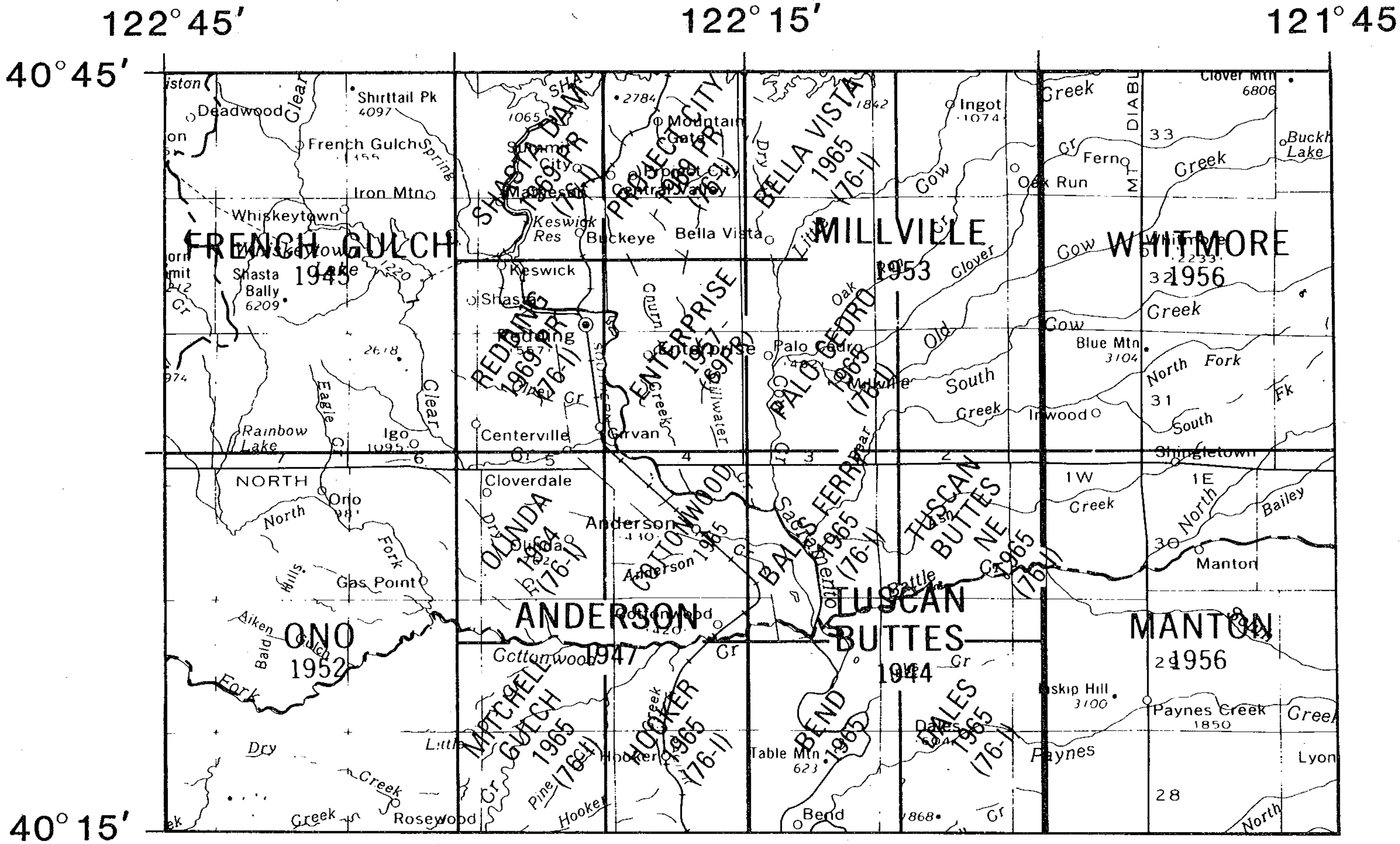


Figure 7.--Index map for the northern Sacramento Valley.

DESCRIPTION OF MAP UNITS
SURFICIAL DEPOSITS

Alluvial deposits

Qsc STREAM CHANNEL DEPOSITS (HOLOCENE)--Deposits of open, active stream channels without permanent vegetation. These deposits are being transported under modern hydrologic conditions; consequently they are light tan and gray, unweathered, and usually in contact with modern surface waters. Our mapping merely limits the right and left bank boundaries of the active stream channel. Morphology within the deposits is constantly changing. Thickness may reach 25 m on the Sacramento River or be less than a few centimeters in bedrock canyons

Qa ALLUVIUM (Holocene)--Unweathered gravel, sand, and silt deposited by present-day stream and river systems that drain the Coast Ranges, Klamath Mountains, and Sierra Nevada. Differentiated from older stream-channel deposits (Qao and Qal) by position in modern channels. These units lie outboard of unit Qsc but inside the first low terraces flanking modern stream channels. The deposits form levees along the main course of the Sacramento River, and broad alluvial fans of low surface relief along the western and southwestern side of the valley. Because of high organic content the levee deposits are darker gray than the alluvium flanking the channels on smaller streams. Thickness varies from a few centimeters to 10 m

Qo OVERBANK DEPOSITS (HOLOCENE)--Sand, silt, and minor lenses of gravel deposited by floods and during high water stages; form low terraces adjacent to present-day alluvial stream channels; coincident with tan and gray organic-rich sediments (Qm), which generally mark high-water trimlines of historic floodwaters. Probably do not exceed 3 meters in maximum thickness

Qao ALLUVIAL AND OVERBANK DEPOSITS, UNDIVIDED (HOLOCENE)--Consists of units Qma and Qo

Qal ALLUVIAL DEPOSITS, UNDIVIDED (HOLOCENE AND PLEISTOCENE)--Undivided gravel, sand, and silt; this unit generally taken from previous mapping

OLDER ALLUVIUM (PLEISTOCENE)--A general description of the older alluvium applies to the Pleistocene Modesto, Riverbank, Turlock Lake, and Red Bluff Formations. Mainly forms fans and terraces whose distal ends grade to low plains and basins and whose proximal ends grade to colluvium along the foothills surrounding the valley. Consists of tan, brown, gray, black, and red gravels, sands, silts, and clays that lithologically reflect local source areas. The youngest of these deposits are unconsolidated and show minimal weathering, while the oldest display maximal weathering and are semiconsolidated. Soil profiles were used to help differentiate members. The Upper Pleistocene older alluvium is incised into older Quaternary and upper Tertiary deposits. Thickness ranges from zero to as much as 120 m in the central part of the valley. The stream systems that deposited the older alluvium are essentially those that flow today as all deposits border modern streams. The youngest deposits lie only a few meters above present stream channels and may even be overtopped by infrequent flooding. The oldest Pleistocene alluvial surface lies tens of meters above modern flood plains. Consists of:

MODESTO FORMATION--The youngest unit comprising the Pleistocene alluvium consists of distinct alluvial terraces and some alluvial fans and abandoned channel ridges. The unit forms the lowest deposits lying topographically above the Holocene deposits along streams and in valleys. It consists of tan and light-gray gravely sand, silt, and clay except where derived from volcanic rocks of the Tuscan Formation; it then is distinctly red and black with minor brown clasts. The Modesto was deposited by streams still existing today because the deposits, for the most part, border existing streams. An exception is the abandoned channel filled with deposits belonging to the upper member of the Modesto on the south side of the alluvial fan of Stony Creek. Divided into:

Qmu Upper member--Unconsolidated, unweathered gravel, sand, silt, and clay. The upper member forms terraces that are topographically the lowest of the two Modesto terraces. It also forms alluvial fans along the east side of the Sacramento Valley from Red Bluff to Oroville. Soils at the top of the upper member have A/C horizon profiles, but unlike the lower member they lack argillic B horizons. Deposits belonging to the upper member of the Modesto are only a few meters thick and generally form a thin veneer deposited on older alluvial deposits. Original surficial fluvial morphology is usually preserved and gives relief of 1 or 2 m. C^{14} age determinations on plant remains from the upper member at Tulare Lake suggest that the unit is between 12,000 and 26,000 yr old (Brian Atwater, oral commun., 1982). Thus the deposition of the upper member of the Modesto Formation appears to correspond with the Tioga glaciation in the Sierra Nevada (Birkeland and others, 1976)

Qml Lower member--Unconsolidated, slightly weathered gravel, sand, silt, and clay. The lower member forms terraces that are topographically a few meters higher than those of the upper member. It forms alluvial fans along the main channel of the Sacramento River and Feather River and large levees bordering the Sacramento River from Stony Creek to Sutter Buttes. Upstream from Stony Creek the lower member of the Modesto is preserved as scattered terrace remnants. Alluvium of the lower member of the Modesto surrounds the Dunnigan Hills and borders Cache Creek near Esparto. Soils developed on the lower member contain an argillic B horizon, which is marked by a noticeable increase in clay content and a distinct red color. Its surface fluvial morphology is remarkably smooth and displays little relief. The unit is much more extensive than the upper member and probably represents a longer period of deposition. The lower member of the Modesto unit is the youngest deposit from which we have evidence for possible fault displacement. Conspicuous linear-edged terraces composed of the lower member are found just south of Orland Buttes and may be a reflection of the Willow fault zone. The lower member deposited along the northeast fan of the Dunnigan Hills may also reflect fault displacement.

Marchand and Allwardt (1981) gave an age for the lower member as probably Altonean (early and middle Wisconsinan) based on an open-system uranium series minimum age of 29,407±2,027 yr on bone from basin deposits of the lower member of the Modesto. A radiocarbon age on wood from a depth of 15-16 m in basin deposits of the lower member was 42,400±1,000 yr B.P. (Marchand and Allwardt, 1981, p. 57). They speculated that this may be the older age limit of the lower member. Since the dates were from flood-basin deposits where deposition may have continued long after terrace deposition ceased, the ages may be too young

RIVERBANK FORMATION--Weathered reddish gravel, sand, and silt forming clearly recognizable alluvial terraces and fans. Riverbank alluvium is distinctly older than the Modesto and can be differentiated by (1) its geomorphic position in terraces topographically above the terraces of Modesto age and (2) the degree of post-depositional soil-profile development. The Riverbank displays thicker argillic B horizons with a consistent shift in hue from 10 YR to 7.5 YR and even some 5 YR hues (Munsell color notations). We have divided the Riverbank into two informal members in contrast to the northeastern San Joaquin Valley where Marchand and Allwardt (1981, p. 36) recognized three members. Based on soil-profile development, we tentatively correlate the two members of the Riverbank in the Sacramento Valley with the upper two members in the San Joaquin Valley as described by Marchand and Allwardt (1981). The main distinction between the two areas is lithology: the Riverbank of the San Joaquin Valley is predominantly arkosic alluvium while that of the Sacramento Valley contains more mafic igneous rock fragments. Consequently, Riverbank deposits in the Sacramento Valley tend toward stronger soil-profile development for deposits of the same age. Both members of the Riverbank in the Sacramento Valley are lithologically very similar, but the upper member is more widespread and less dissected.

The upper member is prominent in the northwestern part of the Sacramento Valley from Red Bluff to about Willows; it is absent from Willows south toward Winters along the west side of the valley. The upper member is not widespread on the east side of the Sacramento Valley from Red Bluff to Chico, but it does occur around the western half of Sutter Buttes. However, both members form a dominant part of the landscape from Oroville south to the delta along the east side of the valley. Their asymmetrical distribution, widespread extent in the northwest and southeast, and absence in the southwest may reflect broad, slow, and relatively aseismic tectonic movement of the valley. Deposits of both Riverbank members are well preserved on the Stony Creek fan and along Cottonwood Creek and the Sacramento River near Anderson.

The Riverbank alluvium is older than the Modesto alluvium but younger than the Red Bluff Formation. Since the Red Bluff is overlain by the Rockland ash bed (0.45 m.y.), the Riverbank, which is cut and filled below the Red Bluff, can be no older than the ash bed and is probably much younger. Considering the degree of erosional dissection of the Riverbank and strong soil-profile development, it must be at least twice as old as the older Modesto age of about 50,000 yr. Marchand and Allwardt (1981 p. 41) placed the Riverbank of the San Joaquin Valley between 130,000 to 450,000 yr B.P. They used several lines of evidence including uranium-trend dating on soils (Rosholt, 1978), which gave the younger limit, while the older limit was based on stratigraphic evidence. The Riverbank in the San Joaquin Valley occupies the stratigraphic interval between the Modesto above and Turlock Lake Formation below. The upper part of the Turlock Lake contains the Friant Pumice Member (600,000 yr old). The Riverbank in the San Joaquin Valley must be considerably younger since a period of erosion and soil formation occurred between its deposition and that of the Turlock Lake. Divided into:

Qru Upper member--Unconsolidated but compact, dark-brown to red alluvium composed of gravel, sand, silt and with minor clay. Topographically forms the lower of the two Riverbank terraces; forms dissected alluvial fans on the northwest and southeast sides of the Sacramento Valley with distinct and now abandoned distributary channels cut into the lower member and older deposits. The Riverbank members generally are separated vertically by about 3 m, but the lower member of the Modesto may be more than 5 m lower in elevation. The upper member, while smoother than the more dissected lower member, displays more relief than the lower member of the Modesto

Qrl Lower member--Red semiconsolidated gravel, sand, and silt. Comprises the higher of the two Riverbank terraces and remnants of dissected alluvial fans. This terrace is cut and backfilled into the Red Bluff and older alluvial deposits. Its surface is much more dissected than the upper member with several meters of local relief. Where eroded it also displays much stronger, almost maximal soil profiles with hues approaching a maximum 2.5 YR. Like the upper member, the lower member is best preserved in the northwestern and southeastern parts of the valley; the most extensive exposures are in and around the city of Sacramento. Most of the alluvium of the lower member near Sacramento is very arkosic, and it was probably derived from the western slopes of the Sierra Nevada and deposited by the American River. The modern Sacramento River impinges on the alluvial fan comprising the lower member of the Riverbank and appears to be cannibalizing it.

Northwest of the confluence of the Sacramento and American Rivers, numerous small discontinuous outcrops of the lower member are buried partially by Holocene alluvial and basin deposits. The deposits of the lower member in that area probably mark the ancient distal edge of the Riverbank fan. It also appears that the lower member was cut by a south-flowing ancient channel of the Feather River or Bear River, or both. Today, the Feather River departs from its due-south course below its confluence with the Bear and abruptly strikes southwesterly around the numerous outcrops of the lower member of the Riverbank

Qrb RED BLUFF FORMATION--A thin veneer of distinctive, highly weathered bright-red gravels beveling and overlying the Tehama, Tuscan, and Laguna Formations. In this study we interpret the Red Bluff Formation as a sedimentary cover on a pediment surface and therefore suggest that it formed in response to a fixed base level caused by impeded or closed drainages of the Sacramento Valley. The Red Bluff pediment is overlain by the Rockland ash bed (0.45 m.y. old) (Meyer and others, 1980) and in turn overlies the basalt of Deer Creek (1.08±0.16 m.y.). Therefore, the pediment must have formed sometime within that 630,000-yr interval.

The Red Bluff is best preserved in the northern part of the valley from Redding to south of Orland Buttes on the west and south to Chico on the east; it also occurs along the southwest side of the valley where its pediment character is less clear. The scattered cappings of the Arroyo Seco Gravel of Piper and others (1939) and Shlemon (1967) in the Sacramento area and also the half dozen or so scattered gravel remnants south of Woodland between Cache and Putah Creeks may actually be Red Bluff. The Red Bluff is deformed by the Dunnigan Hills anticline, a doubly plunging fold west of Arbuckle, and it unconformably overlies the Tehama on a structural high south of Woodland that may be a continuation of that fold. The Red Bluff also unconformably overlies the Tehama in intermittent patches along the western valley between Winters and the mouth of Cache Creek

Qtl TURLOCK LAKE FORMATION (PLEISTOCENE)-Deeply weathered and dissected arkosic gravels with minor resistant metamorphic rock fragments and quartz pebbles; sand and silt present along the south and east sides of the Sacramento Valley. The Turlock Lake is more widespread in the San Joaquin Valley where Arkley (1954) first recognized this unit, but it was named by Davis and Hall (1959) for arkosic alluvium overlying the Mehrten Formation and underlying the Riverbank Formation in eastern Stanislaus and northern Merced Counties. The Turlock Lake is easily recognized in both valleys by its characteristic arkosic lithology, geomorphic form, and relation to underlying and overlying units. The Turlock Lake stands topographically above the younger fans and terraces commonly displays as much as 30 m of erosional relief. The unit represents eroded alluvial fans derived primarily from the plutonic rocks of the Sierra Nevada to the east.

In the San Joaquin Valley, Arkley (1954) recognized that the Turlock Lake consists of two distinct units separated by a very strongly developed soil on the lower part, while the upper part contained two distinct members, the Corcoran Clay Member and the Friant Pumice Member. Janda (1965) reported a K-Ar age of 0.62±0.02) m.y. for the pumice member. The paleomagnetic data of Verosub (in Marchand and Allwardt, 1981) support this age by showing that the upper part of the Turlock Lake has normal polarity and the lower part has reversed polarity, and thus is greater than 0.7 m.y. old. The upper part of the Turlock Lake is probably correlative with the Red Bluff pediment because there is overlap in the age range of the units. The upper part of the Turlock Lake and the Red Bluff pediment also may be physically related through the Corcoran Clay Member of the Turlock Lake, which represents lacustrine conditions that may have impeded through-flowing drainage from the Sacramento Valley thus favoring the Red Bluff pediment-forming process. The Turlock Lake mapped in the Sacramento Valley probably correlates with the lower part of the Turlock Lake of the San Joaquin Valley since it overlies the Laguna Formation and is truncated by the Red Bluff Formation pediment. The Red Bluff pediment may have developed in the time interval between the deposition of the Corcoran Clay Member about 600,000 yr ago and the deposition of the Rockland ash bed approximately 450,000 yr ago

QTog OLDER GRAVEL DEPOSITS (PLEISTOCENE AND (OR) PLIOCENE)--Moderately well indurated, coarse to very coarse gravel with minor coarse sand resting unconformably on a truncated soil profile developed on the Tuscan Formation that is well-exposed along Hogback Road and in Salt Creek east of Red Bluff. These coarse gravels, derived from the Tuscan Formation, are bright reddish tan (2.5 YR) to yellowish tan, well rounded, and locally deeply weathered. The deposits are expressed geomorphically as very steep-sloping, symmetrical alluvial fans that probably developed during or soon after formation of the Chico monocline

Basin deposits

Qb BASIN DEPOSITS, UNDIVIDED (HOLOCENE)--Fine-grained silt and clay derived from the same sources as modern alluvium. The dark-gray to black deposits are the distal facies of unit Qa. The undivided basin deposits provide rich and valuable farmland especially for rice production in the Sacramento Valley. This unit covers much of the valley in the southern half of map area. Thickness varies from 1 or 2 m along the valley perimeter to as much as 60 m in the center of the valley

Qm MARSH DEPOSITS (HOLOCENE)--Fine-grained, very organic rich marsh deposits; differentiated from the undivided basin deposits (Qb) by generally being under water

Qp PEAT DEPOSITS (HOLOCENE)--Composed of decaying fresh-water plant remains with minor amounts of clay and silt generally deposited below historic high-tide lines. Original presettlement maximum thickness about 25 m

Landslide deposits

Qls LANDSLIDES (HOLOCENE AND PLEISTOCENE)--Slumped, rotated chaotic mixtures of underlying bedrock units and colluvium; particularly abundant and extensive in the Montgomery Creek and Chico Formations. Arrows show direction of movement

VOLCANIC ROCKS INCLUDING MINOR
SEDIMENTARY DEPOSITS

BASALTIC ROCKS OF INSKIP HILL VOLCANIC CENTER (PLEISTOCENE)--Divided into:

Qif_3-Qif_1 FLANK FISSURE FLOWS--Several small, blocky basalt flows originating from vents along two parallel, northeast-trending fissures on the north slope of Little Inskip Hill located 29 km northeast of Red Bluff. These flows extend 1 to 2.5 km northward toward Battle Creek. Although the flows appear to be contemporaneous, three separate pulses of lava, which are inferred from their superposition, are labeled from oldest to youngest, Qif_1, Qif_2, and Qif_3. Flows erupted first from the northern fissure and their proximal parts were overlapped by subunit Qif_3 from the northeast end of the upper fissure. Individual thickness of the flows is unknown due to their blocky nature and brushy cover; they probably are less than 5 m in individual thickness

Qic CINDER CONE DEPOSITS--Red and black basaltic cinders forming the prominent cones of Inskip Hill and Little Inskip Hill; four small cinder cones with essentially uneroded morphology are superposed on the larger older cone of Inskip Hill. These smaller cones are crudely alined in a north-south direction across the main mass of Inskip Hill and, thus reflect the north-trending fracture system prominent in the underlying Tuscan Formation. Two satellitic eruptive centers marked by small basaltic lava flows and cinder cones lie southeast of Inskip Hill near the settlement of Paynes Creek and in the upper reaches of Oak Creek near McKenzie Place (southwest corner of the Manton 15' quadrangle)

Qip BASALT FLOWS OF PAYNES CREEK--Thin, black to dark-gray basalt flows that were erupted at Inskip Hill and flowed primarily westward into the drainage of Paynes Creek and reached the Sacramento River at Chinese Rapids near Bend (southwest corner Tuscan Buttes 15' quadrangle). On the flanks of Inskip Hill, the flows are characterized by small lava tubes, pahoehoe texture, and thin scoria layers. Farther from the eruptive center the Paynes Creek flows display scattered yellowish-brown phenocrysts of olivine and glassy-green phenocrysts of clinopyroxene, set in a matrix of fine-grained plagioclase, clinopyroxene, and glass. Northeast of Dales in the Tuscan Buttes 15' quadrangle, the Paynes Creek lava is about 8 m thick; where it crosses the Manton Road northeast of Dales Lake, it is about 2 m thick. The age of the Paynes Creek flows is unknown, but it must be less than 26,000 yr and possibly less than 12,000 yr because the flows overlie the upper member of the Modesto Formation in a tributary of Inks Creek

Qiu UNDIFFERENTIATED BASALT FLOWS OF INSKIP HILL

BASALTIC ROCKS OF BLACK BUTTE VOLCANIC CENTER (PLEISTOCENE)--Divided into:

Qbbb CINDER BLANKET DEPOSITS--Black, well-bedded basaltic cinder deposits forming a dissected ejecta blanket that ranges in thickness from about 10 m just north of Black Butte to about 1.5 m on the south rim of Ash Creek. Beds ranging from 1 to 20 cm thick show normal grading. No major unconformities or buried soil horizons were found in the cinder deposits suggesting rapid accumulation. Total remaining volume of cinder blanket and cone deposits is estimated to be about 6×10^6 m^3

Qbbf BASALT FLOW OF BLACK BUTTE--Dark-gray to black basalt similar in texture and mineralogy to the Paynes Creek flows from Inskip Hill. Olivine and clinopyroxene phenocrysts are scattered in a diktytaxitic matrix of clinopyroxene and plagioclase. Volcanic activity at Black Butte began with the eruption of a small flow of olivine basalt and progressed to the formation of a cinder cone. The flow formed two branches, one part moved about 1 km west of the vent into the upper reaches of Rancherio Creek; the other part cascaded over the Battle Creek fault scarp and formed a bulbous puddle of blocky lava just north of the Darrah Spring Fish Hatchery. The basalt flow of Black Butte, like that of Paynes Creek, is high in aluminum (17.41 percent) and remarkably low in potassium (0.19 percent). The basalt flow of Black Butte is probably no older than the basalt flows of Paynes Creek

Qbbc CINDER CONE DEPOSITS--Thinly layered and loosely aggregated, brick-red and black basaltic cinder deposits containing scattered red and black scoriaceous to glassy bombs of basalt as much as 2 m in length. The vent is marked by a conical depression 15 to 20 m deep and offset slightly to the south of center. The north rim of the cone is a spatter rampart that rises about 25 m above the south rim of the cone

BASALTIC ROCKS OF DIGGER BUTTES VOLCANIC CENTER (PLEISTOCENE)--Divided into:

Qdbc CINDER CONE DEPOSITS--Black and red basaltic cinders forming two small cones atop the east end of the basalt flows of Digger Buttes

Qdb BASALT FLOWS OF DIGGER BUTTES--A series of thin, dark-gray to black, high alumina olivine basalt flows that originated from a vent or vents at Digger Buttes and flowed westward about 4.5 km. Unconformably overlies the Rockland ash bed (0.45 m.y.) and volcanic units as old as the Tuscan Formation. The rock is a fine-grained olivine basalt with trachytic texture that contains scattered olivine phenocrysts in a matrix of clinopyroxene and plagioclase. Total thickness of the flows is unknown but is probably only a few tens of meters

Qtbb BASALT OF TUSCAN BUTTES (PLEISTOCENE)--Gray to reddish-gray and black, fine-grained, porphyritic to glomeroporphyritic basalt and basaltic andesite composed of olivine and clinopyroxene phenocrysts in a matrix of plagioclase microlites and variable amounts of glass. Thin basaltic flows vary in texture from coarsely vesicular in Sevenmile Creek to massive and platy elsewhere. The flows overlie and interfinger with red scoria and breccia on the west slope of the Tuscan Buttes where they form three small isolated, but probably contemporaneous, fissure-vent deposits extending along a nearly north-trending fracture system. Extrusion of the flows postdated folding, uplift, and erosion in the area. They unconformably overlie broadly warped beds of the Tuscan Formation and locally rest on steeply inclined beds of the Upper Cretaceous Chico Formation in Sevenmile Creek

Qvu VOLCANIC ROCKS OF THE WHITMORE, MILLVILLE, AND MANTON QUADRANGLES (PLEISTOCENE)--Dark-gray, moderately diktytaxitic, high-alumina basalt (Al_2O_3 18.4 to 19.1 percent) composed of openwork plagioclase laths, fine-grained clinopyroxene, and magnetite with small scattered phenocrysts of brownish-green olivine. Distribution of these basalt flows in the Whitmore quadrangle is mapped by Macdonald and Lydon (1972)

Qbs_3-Qbs_1 BASALT OF SHINGLETOWN RIDGE (PLEISTOCENE)--Composed of three subunits of dark-gray, fine-grained, diktytaxtic, and locally porphyritic basalt with rounded phenocrysts of brownish-green olivine scattered in an openwork mesh matrix of plagioclase and clinopyroxene. They are high-alumina basalts containing about 47.6 percent SiO_2, 18.09 percent Al_2O_3, and 0.19 percent K_2O. Chemically, mineralogically, and texturally the rocks are very similar to the underlying basalt of Coleman Forebay, and both units may have originated from the same source area at separate, but perhaps not widely spaced, times. The flows of olivine basalt cap Shingletown Ridge north of Manton and extend westward north of Ash Creek to Bear Creek. The flows extend westward from the southern part of the Whitmore quadrangle (Macdonald and Lydon, 1972) and Macdonald (1963) traced them eastward in to the Red Mountain Lake area in the Manzanita Lake quadrangle where they may have originated from a series of vents distributed along a fissure system trending north-northwest from the vicinity of Lassen Peak. The basalt flows overlie the Tuscan Formation and have a total thickness of about 30 m north of Manton, but they are only about 5 m thick near Bear Creek

Qab ANDESITE OF BROKEOFF MOUNTAIN (PLEISTOCENE)--At least two distinct flows of porphyritic hypersthene andesite that contain abundant white plagioclase phenocrysts, minor amounts of hypersthene, and sparse augite phenocyrsts set in a fine-grained matrix of plagioclase microlites and brown glass. The lower part of the andesite sequence contains light-gray cumulate knots of plagioclase and clinopyroxene. These flows spill over the Battle Creek escarpment north of Digger Buttes and follow the Battle Creek fault zone to the southwest for about 35 km. The flows apparently are continuous with the andesite of Brokeoff Mountain mapped by Macdonald and Lyndon (1972) in the adjacent Whitmore quadrangle. On the Battle Creek escarpment, the hypersthene andesite flows rest unconformably on rocks as old as Eocene (Mongtomery Creek Formation), and on the footwall of the fault zone they rest on the Rockland ash bed, which is dated at 0.45 m.y. old (Meyer and others, 1980). North of Manton the total thickness of the andesite flows is about 20 m

Qar ROCKLAND ASH BED (PLEISTOENCE)--Unit is equivalent to the ash of Mount Maidu of Harwood and others (1981) and Helley and others (1981). We here use the name Rockland ash bed for this unit for reasons given by Sarna-Wojcicki and others (written commun., 1982). White loosely aggregated pumice lapilli ash with scattered coarse pumice fragments as large as 20 cm in diameter form a major dacitic to rhyolitic ash-flow tuff deposit between Digger Buttes and the Battle Creek escarpment. One arm of the deposit filled the lowland southeast of Digger Buttes and extends to the north rim of the canyon of the South Fork of Battle Creek. Scattered erosional remnants of the ash bed represent channel deposits north and northwest of Long Ranch. Round Mountain west of Table Mountain in the Bend section of the Sacramento River is made up of this ash deposit. Farther south the ash bed underlies a dozen or so low hills, locally known as the Sand Hills, that rise above alluvial fan deposits derived from the Tuscan Formation. The ash deposit has been dated by fission-track method at 0.45 m.y. (Meyer and others, 1980). The ash bed is also recognized in core samples from a test well near Zamora (T.12 N., R.1 E. SW 1/4 SE 1/4 sec 34) at a depth of 137 m (Page and Bertoldi, 1983), where it was deposited by the ancestral Sacramento River or a major tributary presumably at or near sea level. The position of the ash bed in the well at Zamora gives a local rate of subsidence of 0.3 m/10^3 yr. The ash is predominantly fine grained glass, locally distinctly bedded in the distal exposures and generally massive with scattered large pumiceous fragments in the proximal areas. The pumicious fragments are composed primarily of silky white, wispy, vesicular glass that contains scattered crystals of clear to white plagioclase and sanidine, green hornblende, hypersthene, and minor magnetite. Wilson (1961) determined the refractive index of the glass to be 1.500±.001, indicative of a silica content of about 67 percent, and an overall dacitic composition. The ash flow is at least 60 m thick north of Digger Buttes, but it is generally less than 5 m thick in the scattered patches to the west

Qeb BASALT OF EAGLE CANYON (PLEISTOCENE)--Dark-gray, vesicular, diktytaxitic olivine basalt underlying the broad plain carved by the North Fork of Battle Creek from the vicinity of Ponderosa Way on the east along the toe of Battle Creek escarpment nearly to the Coleman Powerhouse (northeast quarter of the Tuscan Buttes 15' quadrangle). This basalt, along with the underlying conglomerate here mapped as the Red Bluff Formation, and the basalt below the conglomerate were compositely grouped by Wilson (1961, p. 11) in his Long Ranch (basalt) unit. The upper unit of basalt is here designated the (olivine) basalt of Eagle Canyon; the lower basalt, which underlies the Red Bluff Formation, is herein termed the basalt of Coleman Forebay

Qcb BASALT OF COLEMAN FOREBAY (PLEISTOCENE)--Light-rusty-gray-weathering, dark-gray olivine basalt with pronounced diktytaxitic texture and scattered large vesicles and voids that form large rounded pits on the weathered surfaces. This basalt underlies the Red Bluff Formation in several isolated areas extending from Coleman Forebay on the Battle Creek fault escarpment southward to the vicinity of Hog Lake, 17 km northeast of Red Bluff on California Highway 36. The unit is undated but is older than the Red Bluff Formation and has a maximum thickness of about 10 m

Qbd OLIVINE BASALT OF DEVILS HALF ACRE (PLEISTOCENE)--Gray glomeroporphyritic vesicular basalt showing well-developed columnar jointing on the north rim of Antelope Creek. Aggregates of strongly zoned plagioclase as much as 10 mm in diameter and euhedral to anhedral olivine as much as 5 mm in diameter are set in an ophitic matrix of nearly equal amounts of plagioclase microlites and clinopyroxene. Magnetite is scattered throughout the matrix and rutile(?) is included within the plagioclase. Clear to white opal lines some vesicles and also occurs as fracture fillings in some plagioclase phenocrysts. Maximum thickness is 15 m

Qbdc OLIVINE BASALT OF DEER CREEK (PLEISTOCENE)--Dark-gray to greenish-black, sparsely vesicular olivine basalt flows locally exposed on the north and south rims of the canyon of Deer Creek (northeast quarter of the Corning 15' quadrangle). Euhedral to subhedral olivine phenocrysts as much as 3 mm in diameter set in a fine-grained matrix of plagioclase and clinopyroxene. The clinopyroxene is intergranular to plagioclase microlites and which are strongly alined giving a trachitic texture. Olivine and clinopyroxene are slightly altered to iddingsite. Magnetite and ilmenite are present in the intergranular spaces. Plagioclase microlites contain small amounts of black dust-like opaque inclusions of magnetite(?) and light-colored fluid inclusions. The contact between the olivine basalt of Deer Creek and the underlying older gravel deposits is exposed in the older, western part of the quarry at the head of Juniper Gulch. The base of the basalt exposed in the quarry is a scoriaceous layer 0.3 m thick showing westward overturned flow folds outlined by deformed vesicles. A K-Ar age of 1.08±0.16 m.y. (J. Von Essen, written commun., 1978) was obtained on basalt from the quarry; the maximum thickness is 20 m

Qbr BLUE RIDGE RHYOLITE OF COE (1977) (PLEISTOCENE)--Mottled and flow-banded, light- and dark-gray, pink, and lavender glassy rhyolite, variably devitrified; minor perlite, pumice, and pitchstone near base. Contains andesine, oxyhornblende, hypersthene, and rare biotite phenocrysts; potassium-rich glassy matrix devitrified to feldspar and silica-rich spherulites. Wilson (1961, p. 68) gives one complete and four partial chemical analyses for the rhyolite; Gilbert (1968, p. 27) gives K-Ar ages of 1.15±0.07 m.y. on glass and 1.24±0.11 m.y. on plagioclase from the rhyolite

VOLCANIC ROCKS AND LACUSTRINE DEPOSITS OF SUTTER BUTTES (PLEISTOCENE AND PLIOCENE)--The descriptions of the rocks and deposits around Sutter Buttes are shortened versions of those of Williams and Curtis (1977) to whom the reader is referred for greater detail. The K-Ar dates presented on the entire eruptive sequence by Williams and Curtis range in age from 1.9 to 2.4 m.y. (1977, p. 42). Divided into:

QTvl VOLCANIC LAKE BEDS--Well-bedded volcanogenic sediments of mainly lacustrine but partly fluviatile, origin occupying an area measuring 1.6 by 2.7 km in the center of the buttes; (Williams and Curtis, 1977, p. 35)

QTa ANDESITES--Gray and brown, porphyritic, biotite-hornblende andesite that contains variable amounts of biotite, hornblende, and plagioclase phenocrysts set in a dense nonvesicular pilotaxitic matrix; generally located in the central part of Sutter Buttes where the andesite forms a coalescing group of intrusive and extrusive domes (Williams and Curtis, 1977, p. 21-22, 44-45)

QTr RHYOLITE DOMES--Conspicuous white topographic domes composed of light-gray to white porphyritic rhyolite and dacite that contrast sharply with exposures of the darker andesites. Both rhyolite and dacite contain variable amounts of biotite, quartz, plagioclase, and subordinate sanidine phenocrysts in a dense, micro- to crypto-felsitic matrix (Williams and Curtis, 1977, p. 23-27, 46-47)

QTm TUFF BRECCIA--Tuff breccia primarily comprising the peripheral topographic ring surrounding Sutter Buttes; equivalent to the middle unit of the Rampart Beds of William and Curtis (1977, p. 26)

QTmb TUFF BRECCIA OF MINERAL AREA (PLEISTOCENE AND PLIOCENE)--These rocks were mapped and described originally by Wilson (1961, p. 14-16) and an abbreviated description based on his report and our reconnaissance is used here. The tuff breccia consists of layers of angular blocks of basaltic andesite and andesite interbedded locally with andesitic tuff, scoria, and minor andesite flows. The unit is about 240 m thick at the head of Mill Creek Canyon

Ta ANDESITE (PLIOCENE)--Undivided flows of predominantly two pyroxene andesite; commonly platy, medium to light gray, rarely dark gray, locally pink, greenish gray, or mottled; locally overlies hornblende-bearing pyroxene andesite containing abundant plagioclase phenocrysts and less abundant, smaller hornblende phenocrysts. This thick sequence of andesite lava flows with minor interbedded tuff and tuff breccia was mapped in the Whitmore quadrangle by Macdonald and Lydon (1972) and is mapped here without field checking

Tpa PLATY ANDESITE (PLIOCENE)--Light- to dark-gray, bluish-gray, and brick-red, fine-grained, sparsely porphyritic, slabby-weathering to massive, locally streaked and flow-banded platy andesite exposed on the Battle Creek escarpment near Bailey Creek and at the top of Tuscan Buttes. Andesite at these widely separated areas was never part of the same flow and it represents chemically and mineralogically different flows that originated at different, unknown sources. The rocks share only a common platy structure and a similar stratigraphic position unconformably above the Tuscan Formation. The andesite is about 70 m thick at Tuscan Buttes and about 55 m thick at Bailey Creek.

At Tuscan Buttes the unit consists of several flows that are gray through most of their thickness and brick red at their tops. The rock is fine grained, sparsely porphyritic and composed of a matrix of oriented plagioclase microlites rimmed by devitrified glass. Glass contains scattered phenocrysts of reddish-brown basaltic hornblende as much as 3 mm long altered to varying degrees to dust like opaque magnetite particles. Sparse hornblende phenocrysts define a subtle, subhorizontal lineation oriented roughly east-west throughout the flows; the phenocrysts lie parallel to distinct flow banding in the rocks exposed in cliffs on the southwest face of the east butte. Layers in the flow-banded andesite range in thickness from 3 to 10 mm and locally contain angular fragments of porphyritic andesite. The andesite at Tuscan Buttes probably represents the remnants of a channelized flow or flows (Anderson, 1933) that may have originated from a vent or vents now marked by andesite plugs located in and near Antelope Creek to the east.

At Bailey Creek the platy andesite is gray to bluish gray, locally flow banded, and composed predominantly of devitrified glass; phenocrysts of plagioclase, hypersthene, and green hornblende combine to make up generally less than 15 percent of the rock

Tbp OLIVINE BASALT OF PARADISE (PLIOCENE)--Gray, slightly vesicular, glomeroporphyritic olivine basalt with aggregates of plagioclase as much as 15 mm in length that form abundant white knots. Aggregates of olivine as large as 10 mm in diameter form glassy yellowish-green phenocrysts in a gray matrix of plagioclase microlites and intergranular clinopyroxene. Plagioclase phenocrysts have well-developed oscillatory zoning and pronounced sieve texture with abundant inclusions of clinopyroxene in the middle zones. The edges of the plagioclase crystals are resorbed and crowded with black dustlike opaque inclusions and clear fluid inclusions. Magnetite occurs with intergranular clinopyroxene. Maximum thickness in the map area is about 25 m. The most extensive exposures are in and around the village of Paradise just east of Chico with two less extensive exposures on Mill Ridge due north of Paradise. The basalt weathers to a bright-brick-red (5-2.5 YR) soil

Tbc OLIVINE BASALT OF COHASSET RIDGE (PLIOCENE)--Gray vesicular porphyritic basalt flows with olivine phenocrysts as much as 6 mm in diameter set in a diktytaxitic matrix of plagioclase and clinopyroxene. Clinopyroxene as much as 2 mm in length is intergranular to plagioclase microlites. Magnetite and ilmenite occur with clinopyroxene. High-relief, knee-shaped twinned crystals, possibly rutile, occur in the plagioclase. Drusy clear quartz and clear to white opal line many vesicles. A sample taken from the roadcut on the east side of Cohasset Highway at the intersection of Keeler Road gives a K-Ar age of 2.41 ± 0.12 m.y. (J. von Essen, written commun., 1978). Maximum thickness is about 25 m

Tba BASALTIC ANDESITE OF ANTELOPE CREEK (PLIOCENE)--Dark-gray to greenish-gray, massive to highly fractured, fine-grained, sparsely vesicular basaltic andesite exposed in Antelope Creek and to a lesser extent in Salt Creek; locally altered to brick red and reddish gray. Red and reddish-gray scoria layers about 1 m thick alternate with layers of more massive gray basaltic andesite of about equal thickness in the western exposures in Antelope and Salt Creeks, which suggests that these exposures are near the distal end of the flow. Plagioclase laths as much as 2 mm long are strongly aligned and locally swirled around equidimensional to elongate masses of iddingsite(?) and fine-grained magnetite, probably pseudomorphous after olivine. No fresh olivine was seen in this rock type, which was originally described as a basalt (olivine basalt of Antelope Creek) (Harwood and others, 1981), but which is now known to contain 54.7 percent SiO_2 and thus is located on the generally accepted basalt-andesite boundary of 54 percent SiO_2. A K-Ar age of 3.99 ± 0.12 m.y. was obtained on the basaltic andesite of Antelope Creek (J. Von Essen, oral commun., 1979)

SEDIMENTARY ROCKS INCLUDING SOME VOLCANIC ROCKS

Tte TEHAMA FORMATION (PLIOCENE)--Pale-green, gray, and tan sandstone and siltstone with lenses of crossbedded pebble and cobble conglomerate derived from the Coast Ranges and Klamath Mountains; named by Diller (1894) for typical exposures in Tehama County in northwestern Sacramento Valley.

The Tehama rests with marked unconformity on Cretaceous rocks of the Great Valley sequence along the west side of the valley and on plutonic and metamorphic rocks of the Klamath Mountains west of Redding where the Mesozoic sedimentary rocks are missing. The Tehama is unconformably overlain by gravels of the Red Bluff pediment; excellent exposures of this stratigraphic relation are visible a few kilometers south of Red Bluff along Interstate Highway 5 and along the river bluffs at Redding

1976, p. 18; oral commun., 1982).

The maximum thickness of the Tehama is about 600 m (Olmsted and Davis, 1961). The Tehama is significant because the base of the unit is also the base of fresh ground water in the entire Sacramento Valley. Divided into:

Ttn Nomlaki Tuff Member--See description under the Tuscan Formation

Ttep Putah Tuff Member--Buff to light-gray, poorly to well-sorted, moderately consolidated, hypersthene-hornblende, vitric pumiceous tuff (Sarna-Wojcicki, 1976). The map unit consists of several fluvial tuffs separated by nonvolcanic fluvial sediments and probably represents several closely spaced eruptive events. The tuff beds are massive but generally uncemented. At most exposures the tuffs are conformable with sediments above and below; it occurs at or very near the base of the Tehama Formation. Maximum thickness is about 15 m. Some of the very best exposures are at the type locality, a road cut along California Highway 128 (sec. 36, T. 8 N., R. 2 W.) in Yolo County. The Putah occurs as a nearly continuous outcrop for a distance of about 60 km along the southwest side of the Sacramento Valley from the Capay Hills south to the south end of the English Hills near Vacaville in Solano County. The closest surface exposures of the Putah and Nomlaki Tuff Members are approximately 80 km apart on the west side of Sacramento Valley. The Putah does not extend beyond the northeastern side of Capay Hills and the Nomlaki not beyond about 10 km south of Orland Buttes.

Miller (1966) obtained a K-Ar age of 3.3±0.1 m.y. on glass separated from the tuff. He also stated that although the age is analytically identical to that of the Nomlaki, the two tuffs are petrologically different. Sarna-Wojcicki (1976) agreed with Miller's (1966) conclusions based on differences in refractive indices of glass and differences in mineralogy. The Putah contains apatite and basaltic hornblende that are absent from the Nomlaki, whereas the Nomlaki contains zircon that the Putah does not. The Nomlaki came from a source in the Lassen area while the Putah came from a source near Mount St. Helena in the Sonoma volcanic field. Both tuffs were reported in stratigraphic superposition in a gas well (Johnson, no. 1, Orland Oil Syndicated, Sarna-Wojcicki, oral commun., 1982) where the Nomlaki occurs at 442 m and the Putah 10 m lower

Tt TUSCAN FORMATION (PLIOCENE)--Interbedded lahars, volcanic conglomerate, volcanic sandstone, siltstone, and pumiceous tuff. Divided into:

Ttd Unit D--Predominantly fragmental deposits characterized by large monolithologic masses of gray hornblende andesite, augite-olivine basaltic andesite, black pumice, and smaller fragments of black obsidian and white and gray hornblende-bearing pumice in a grayish-tan pumiceous mudstone matrix; locally in Battle Creek and elsewhere unit contains an unlayered basal deposit of dark-gray andesite tuff with abundant black scoria and less abundant black glass fragments. Size of monolithologic fragments increases to the east toward Mineral, Calif.; highly fractured monolithologic masses 8 to 10 m in diameter are exposed in new road cuts on California Highway 36 on the south slope of Inskip Hill. Unit D probably originated from a major explosive event at its source volcano and consists of directed blast or avalanche deposits, or both, juvenile pyroclastic deposits of andesitic tuff, and lahars derived from the blast deposits. Samples from two monolithologic masses of andesite in the avalanche(?) deposit at Inskip Hill gave K-Ar ages of 2.49±0.08 and 2.43±0.07 m.y. (J. von Essen, written commun., 1982); slightly older than the basalt of Cohasset Ridge. Locally separated from unit C by the tuff of Hogback Road; where tuff is absent, lahars of unit D are distinguished from those of unit C by the presence of monolithologic rock masses, black obsidian fragments, and white and dove-gray dacitic pumice fragments. Unit D lies gradationally above the tuff of Hogback Road and unconformably above unit C where the tuff is missing. The unit ranges in thickness from about 10 to 50 m

Tth Tuff of Hogback Road--Discontinuous thin lapilli tuff, pumiceous sandstone, and conglomerate composed of rounded white hornblende-bearing dacitic pumice fragments as much as 3 cm in diameter and smaller gray and black pumice fragments admixed with varying amounts of andesitic detritus. Unit is commonly thin bedded, locally cross-bedded water-worked dacitic ash deposit that rests unconformably on unit C. Excellent exposures are found on the southwestern slope of Tuscan Buttes and in the broad topographic depression between Tuscan Buttes and Tuscan Springs where the unit is about 15 m thick. The tuff is about 2.5 m thick at the hogback on Hogback Road

Ttc Unit C--Lahars with some interbedded volcanic conglomerate and sandstone locally, north of Antelope Creek, separated from overlying units by partially stripped soil horizon. Along the Chico monocline southeast of Richardson Springs, unit C consists of several lahars 3 to 12 m thick separated from each other by thin layers of volcanic sediments; lahars contain abundant casts of wood fragments and prominent cooling fractures. Along Dye Creek Canyon, unit C consists of interfingering and overlapping discontinuous lahars without significant interbeds of volcanic sediments. At Tuscan Springs and around Tuscan Buttes, unit C consists of indistinctly layered to chaotic lahars with minor scattered volcanic conglomerate and crossbedded sandstone occupying distinct and restricted channels in the volcanic deposits. Unit C is about 50 m thick in Mud Creek Canyon west of Richardson Spring and about 80 m thick near Tuscan Springs

Tti Ishi Tuff Member--White to light-gray, fine-grained, pumiceous air-fall tuff commonly reworked and contaminated with variable amounts of volcanic sandstone and silt. Distinguished by abundant black to bronze biotite flakes about 1 mm in diameter. The Ishi was originally identified along the Chico monocline where it occurs as a 0.03-m-thick ash layer deposited on volcanic conglomerate and silt at the top of unit B. Subsequent mapping identified a white, biotite-bearing tuff near Millville that correlates chemically with the Ishi (A. M. Sarna-Wojcicki, oral commun., 1982). East of Millville the Ishi contains pumice clasts as much as 8 cm in diameter and rests directly on a welded ash-flow tuff identical to that at Bear Creek Falls dated by Evernden and others (1964) at 3.4 m.y. and correlated by Anderson and Russell (1939) with the type Nomlaki Tuff Member (of the Tehama Formation). Biotite, plagioclase, and hornblende, which are separated from the large pumice clasts in the Ishi near Millville, give discordant K-Ar ages; a fission-track age of 2.7 m.y. obtained from zircons separated from the pumice clasts is the best current estimate of the age of the Ishi Tuff Member

Ttb Unit B--Defined along the Chico monocline as interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone similar to unit C, but underlying the Ishi Tuff Member. Lahars and volcaniclastic rocks interbedded in approximately equal proportions give a more regularly layered sequence than in the lahar-rich unit C. Maximum thickness of conglomerate layers about 15 m. Coarse cobble to boulder conglomerate predominant in the eastern and northern parts of mapped unit; crossbedded and channeled volcanic sandstone increases in abundance to the west and south. Unit B is about 130 m thick

Tta Unit A--Interbedded lahars, volcanic conglomerate, volcanic sandstone, and siltstone all containing scattered fragments of metamorphic rocks. Metamorphic rock fragments, as much as 20 cm in diameter, include white vein quartz, green, gray, and black chert, greenstone, greenish-gray slate, and serpentinite. Metamorphic clasts usually make up less than 1 percent of the rock, the remainder is basaltic and basaltic andesite volcanic fragments. The top of the member is defined by the highest lahar or volcanic conglomerate layer that contains metamorphic fragments. Unit A is about 65 m thick along the Chico monocline where it is defined

Ttn Nomlaki Tuff Member--White, light-gray, locally reddish-tan to salmon dacitic pumice tuff and pumice lapilli tuff exposed in widely separated areas at or very near the bases of the Tuscan and Tehama Formations. Pumice fragments as much as 20 cm in diameter are generally white in the lower part of the member and a mixture of white, light gray, and dark gray in the upper part. Member varies from massive nonlayered ash flow at Tuscan Springs, Gas Point, and Antelope Creek to distinctly bedded and crossbedded, reworked pumiceous sediment west of Richardson Springs. Maximum thickness is 25 m at Tuscan Springs, about 20 m at Antelope Creek, 1 m at Richardson Springs and 30 m at Gas Point on the west side of the valley in the Cottonwood Creek drainage. Lahars containing metamorphic rock fragments typical of unit A of the Tuscan occur below the Nomlaki Tuff Member in Rock Creek and at the west end of the exposures of the Lovejoy Basalt in Bidwell Park east of Chico. Evernden and others (1964) obtained a K-Ar age of 3.4 m.y. for a welded ash-flow tuff at Bear Creek Falls, which Anderson and Russell (1939) correlated with the type Nomlaki.

The Nomlaki Tuff Member has been identified from trace-element content of the glass by Sarna-Wojcicki, (written commun., 1982) at eight localities near the base of gravel and sand deposits, mapped as the Laguna Formation (Olmsted and Davis, 1961; Busacca, 1982), around Oroville and points south to the Yuba River and Beale Air Force Base. The presence of the Nomlaki Tuff near the base of the Laguna Formation suggests that the Laguna is coeval with the Tuscan and Tehama

Tla LAGUNA FORMATION (PLIOCENE)--Interbedded alluvial gravel, sand, and silt. Pebbles and cobbles of quartz and metamorphic rock fragments generally dominate the gravels, but the matrix of the gravelly units and finer sediments are invariably arkosic. In the vicinity of Oroville, volcanic rocks may comprise as much as 20 percent of the gravels, but again the finer sediments are dominantly arkosic. The Laguna is lithologically indistinguishable from the Turlock Lake Formation, but the Turlock Lake is more compact at the surface due to a preserved B_2t soil horizon. The Laguna, on the other hand, has had its former soil profiles stripped by erosion. The Turlock Lake and the Laguna can be distinguished by their stratigraphic positions relative to pediment gravels, by the presence or absence of some soil profiles, and by their topographic settings. In the Oroville area the Laguna is easier to distinguish because it contains the Nomlaki Tuff Member near its base (Busacca, 1982, p. 103). We have not found the Nomlaki in the Laguna in the Sacramento area nor anywhere south of Beale Air Force Base.

The Laguna Formation was named by Piper and others (1939) for arkosic alluvial deposits in the vicinity of Laguna Creek, San Joaquin County. These Sierran-derived deposits overlie the Mehrten Formation and are unconformably overlain by gravel of the North Merced pediment. Although the Laguna gravels are not exposed continuously from the type area northward into the Sacramento Valley, similar arkosic sediments overlying the Mehrten and truncated by the Red Bluff pediment occur in the Sacramento Valley and have been correlated with the Laguna (Olmsted and Davis, 1961 and Busacca, 1982). We agree with this correlation. The Laguna displays highly dissected rolling topography with tens of meters of relief. The only exposures are between Oroville and Sacramento on the southeast side of the valley. The Laguna was deposited by the ancestral west-flowing Feather, Yuba, Bear, and American Rivers.

The thickness of the Laguna is difficult to estimate because its base is rarely exposed and its surface has been highly eroded except where preserved beneath the Red Bluff Formation. The Laguna is probably about 60 m thick in the Oroville and thins to about 20 m or so south of Sacramento. Locally divided into:

Nomlaki Tuff Member--See description under the Tuscan Formation

Ts SUTTER FORMATION OF WILLIAMS AND CURTIS (1977) (PLIOCENE, MIOCENE, AND OLIGOCENE)--Williams and Curtis (1977) described these beds in the Sutter Buttes as consisting "almost exclusively of volcanic sediments transported by rivers from the Sierra Nevada to be deposited in deltaic fans and on broad flood plains that occupied most of the Sacramento Valley during Oligocene, Miocene, and Pliocene times" (Williams and Curtis, 1977, p. 13). Unit thickness ranges from 180 m to as much as 300 m

Tc CHANNEL DEPOSITS (PLIOCENE AND (OR) MIOCENE)--Tan, yellowish-tan to reddish-brown interbedded fluvial conglomerate and lesser amounts of sandstone exposed in some of the deeper canyons below the Tuscan Formation; includes the New Era Formation of Creely (1965). Unit is exposed near the New Era Mine in the northeast central part of the map, in Butte Creek, in Mud Creek below the Nomlaki Tuff Member of the Tuscan Formation and west of the Lovejoy Basalt, in the West Fork of Rock Creek below the Nomlaki, and at Tuscan Springs below the Nomlaki. Cobble to pebble conglomerate has rounded, commonly disk-shaped clasts showing variable degrees of imbrication. Clasts include greenstone, gray quartzite, red, green, and black chert, white vein quartz, and lesser amounts of green and gray phyllite. Variable amounts of basalt identical to that in the Tuscan Formation are intermixed with polycycle metamorphic fragments. Maximum thickness is about 20 m

Tm MEHRTEN FORMATION (PLIOCENE AND MIOCENE)--Sandstone, laminated siltstone, conglomerate, and tuff breccia composed almost entirely of andesitic material with only small amounts of igneous and metamorphic rock fragments. The fragments of andesite are almost always dark-gray porphyritic andesite with phenocrysts of hornblende and plagioclase in a microcrystalline to glassy groundmass. The only outcrops of the Mehrten in the map area occur in a few square kilometers of the southeast side of the valley northeast of Roseville along Interstate Highway 80 where the unit rests unconformably on granitic basement. In the San Joaquin Valley the strata that underlie the Laguna Formation and overlie the Valley Springs Formation have been mapped as the Mehrten Formation by Piper and others (1939)

Tl LOVEJOY BASALT (MIOCENE)--Black, dense, hard, microcrystalline to extremely fine grained, equigranular to sparsely porphyritic basalt. Where porphyritic, it contains scattered phenocrysts of plagioclase and lesser amounts of clinopyroxene in an hypocrystalline groundmass of felted plagioclase microlites, intergranular clinopyroxene, olivine and magnetite, and intersertal grayish-green to black, opaque basaltic glass. It is everywhere highly fractured with distinctive conchoidal fracture surfaces.

The Lovejoy comprises the prominent Orland Buttes on the west side of the valley as well as the conspicuous Table Mountain at Oroville on the east side of the valley. The Lovejoy Basalt is also exposed in deep canyons cut through the Tuscan Formation that narrow markedly where the Lovejoy is exposed. In Big and Little Chico Creeks, the Lovejoy is incised in very narrow channels only a few meters wide but as much as 60 m deep. The basalt at Putnam Peak at the south end of the English Hills near Vacaville is also composed of the Lovejoy Basalt (S. Gromme, oral comm., 1981). It is also exposed in the foothills northwest of Winters. The Lovejoy is penetrated by numerous wells in the valley (van den Berge, 1968) where a narrow linear subsurface distribution pattern strongly suggests that the Lovejoy flowed in a channel or channels across the present site of the Sacramento Valley. The outcrop and subcrop pattern (van den Berge, 1968) definitely suggests the Lovejoy flowed down more than one channel.

The maximum thickness in the mapped area is about 20 m (Harwood and others, 1981).

Dalrymple (1964) obtained a K-Ar age of 23.8 m.y. on a thin dacite ash just beneath the Lovejoy at Oroville Table Mountain. The date seems reasonable since the Lovejoy and the dacite ash overlie both the Eocene Ione and the auriferous gravels at Oroville. The Delleker Formation (not mapped in this report), which overlies the Lovejoy elsewhere, has been dated by Evernden and others (1964) at 22.2 m.y. near the type locality of the Lovejoy. Therefore the Lovejoy Basalt is bracketed within the early Miocene

Ts SEDIMENTARY ROCKS IN SUTTER BUTTES AREA (EOCENE)--Consist of what Allen (1925) and Williams and Curtis (1977) variously refer to as their "Capay Shales", "Ione Sands", and "Butte Gravels". At Sutter Buttes the Capay consists of "buff sands locally rich in ferruginous concretions and glauconitic shales rich in foraminifera. Carbonaceous mudstones are occasionally present as are thin seams of low-grade coal especially on the north and east sides of the Buttes" (Williams and Curtis, 1977, p. 12). Maximum thickness is about 1,200 m on the western side of the buttes. The Ione consists of white well-sorted quartz sand with irregular pink, purple, or brown streaks of oxidation with minor amounts of bleached anauxite. Thickness ranges from 30 to 50 m. The Butte Gravels consist of poorly consolidated interbedded gravel and sand with thin lenses of limestone and sandstone. The clasts in the gravel are primarily colorless and milky vein quartz with other minor clasts of quartz porphyry, varigated chert, schist, and hornfels. The Butte Gravels is as much as 400 m thick

Tmc MONTGOMERY CREEK FORMATION (EOCENE)--Gray, yellowish-orange-weathering, arkosic sandstone with conglomerate and shale; crops out on the Battle Creek escarpment along the road between Manton and Shingletown in the upper part of Lack Creek and Ash Creek, and occurs much more extensively in major southwest-trending drainages of the Millville and Whitmore quadrangles. The rock is commonly massive to thick-bedded nonmarine sandstone with scattered lenses of pebble conglomerate and shale. Detrital muscovite and feldspar are common in the sandstone; red, green, and gray chert are the most common clasts in the conglomerate lenses. The unit is about 80 m thick at its south limit and apparently thickens to the north where Anderson and Russell (1939) reported 200 m of the formation exposed in Montgomery Creek.

Anderson and Russell (1939) collected fossil leaves from the Montgomery Creek, which Chaney identified as definitely Eocene in age

Ti IONE FORMATION (EOCENE)--Light-colored, commonly white conglomerate, sandstone, and claystone. Argillaceous sandstone and claystone comprise about 75 percent of the Ione along the southeast side of Sacramento Valley; northward the rest of the unit consists of interbedded siltstone, conglomerate and shale. It should be noted that the map area is far north of the type locality at Ione in Amador County. The Ione is generally soft, deeply eroded, and marked by numerous landslides. Ione sandstones are characterized by fine grains of angular quartz and thin stringers of weathered anauxite. Allen (1929) interpreted the Ione sediments to be similar to modern deltaic deposits. He also correlated the Ione sediments with Sierran auriferous gravels based on a comparison of mineralogy and stratigraphic position. The Ione underlies the Lovejoy Basalt at Oroville Table Mountain and it is present in the Lincoln area. The maximum thickness of the Ione near Table Mountain is 200 m (Creely, 1965)

Kc CHICO FORMATION (CRETACEOUS)--Tan, yellowish-brown to light-gray, fossiliferous marine sandstone with lenticular beds of pebble to fine cobble conglomerate and minor siltstone. Clasts in the conglomerate include rounded to well-rounded, red, green, and black chert, white vein quartz, quartzite, granite, and greenstone. Calcite-cemented concretions and layers of fossil fragments are common. The sandstone is composed of fine to medium, angular to subrounded grains of quartz, plagioclase, alkali feldspar, lithic fragments, and detrital chert. At the type section on Big Chico Creek the unit is about 650 m thick (Taff and others, 1940, p. 1317)

BEDROCK

pKmi METAMORPHIC AND IGNEOUS ROCKS (PRE-CRETACEOUS)--Undivided slate, quartzite, metaconglomerate, marble, metavolcanic rocks, serpentinite, metagabbro, diorite, and monzonite (see Creely, 1965; Hietanen, 1973, 1976)

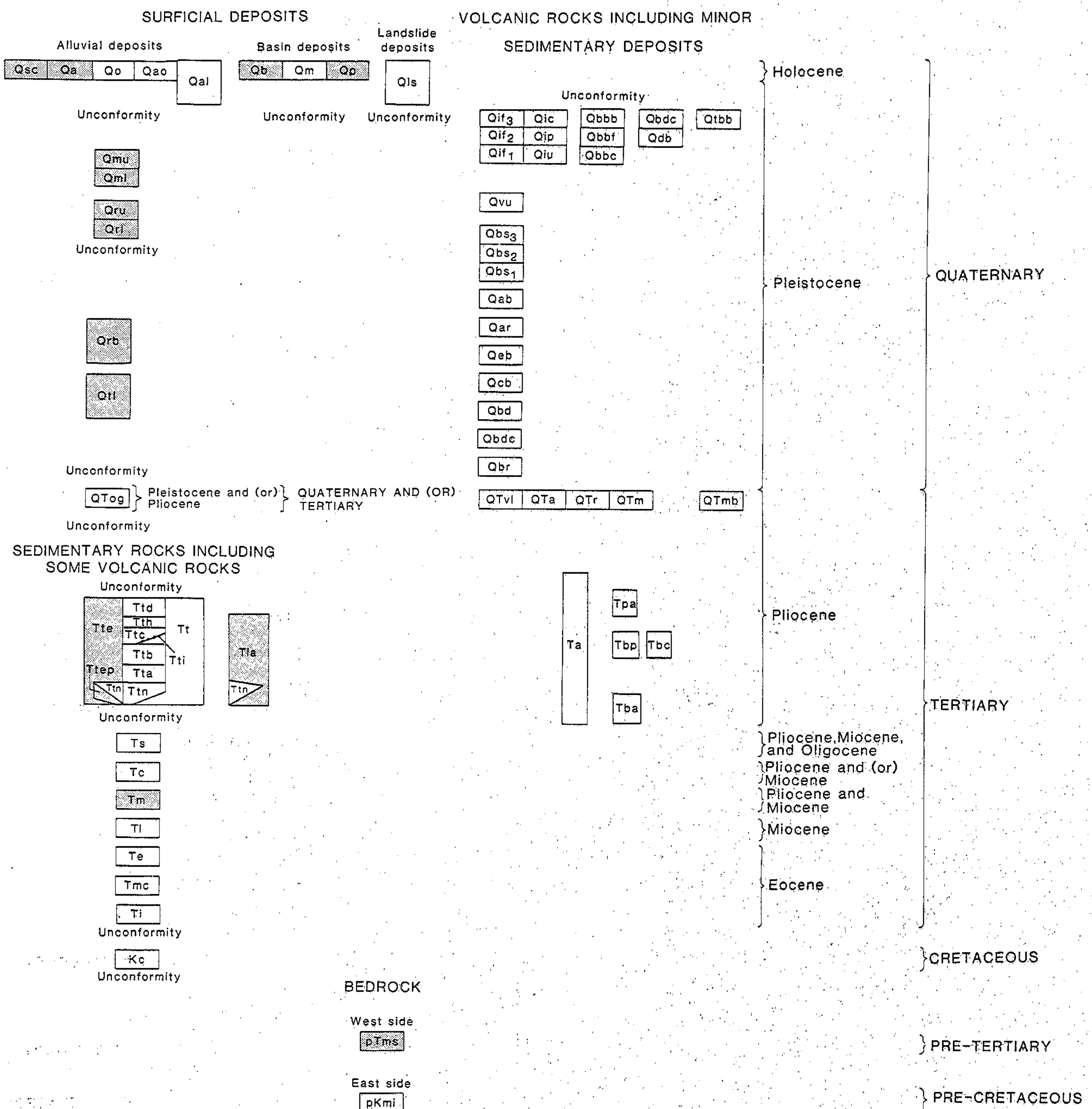
pTms METAMORPHIC, INTRUSIVE, AND SEDIMENTARY ROCKS (PRE-TERTIARY)--Undivided metamorphosed Paleozoic and Mesozoic volcanic and sedimentary rocks intruded by Mesozoic and older granitic rocks in the Klamath Mountains; the Franciscan Complex and the Coast Range ophiolite (discussed in detail by Irwin, 1966, Murphy and others, 1969, and Irwin and others, 1978); and the overlying unmetamorphosed sedimentary rocks of the Great Valley sequence (see Bailey and Jones, 1973)

SOUTHERN SACRAMENTO VALLEY

CORRELATION OF MAP UNITS

SHEET 1

(NOTE – Not all map units occur on every sheet; stippling indicates presence on this map sheet)

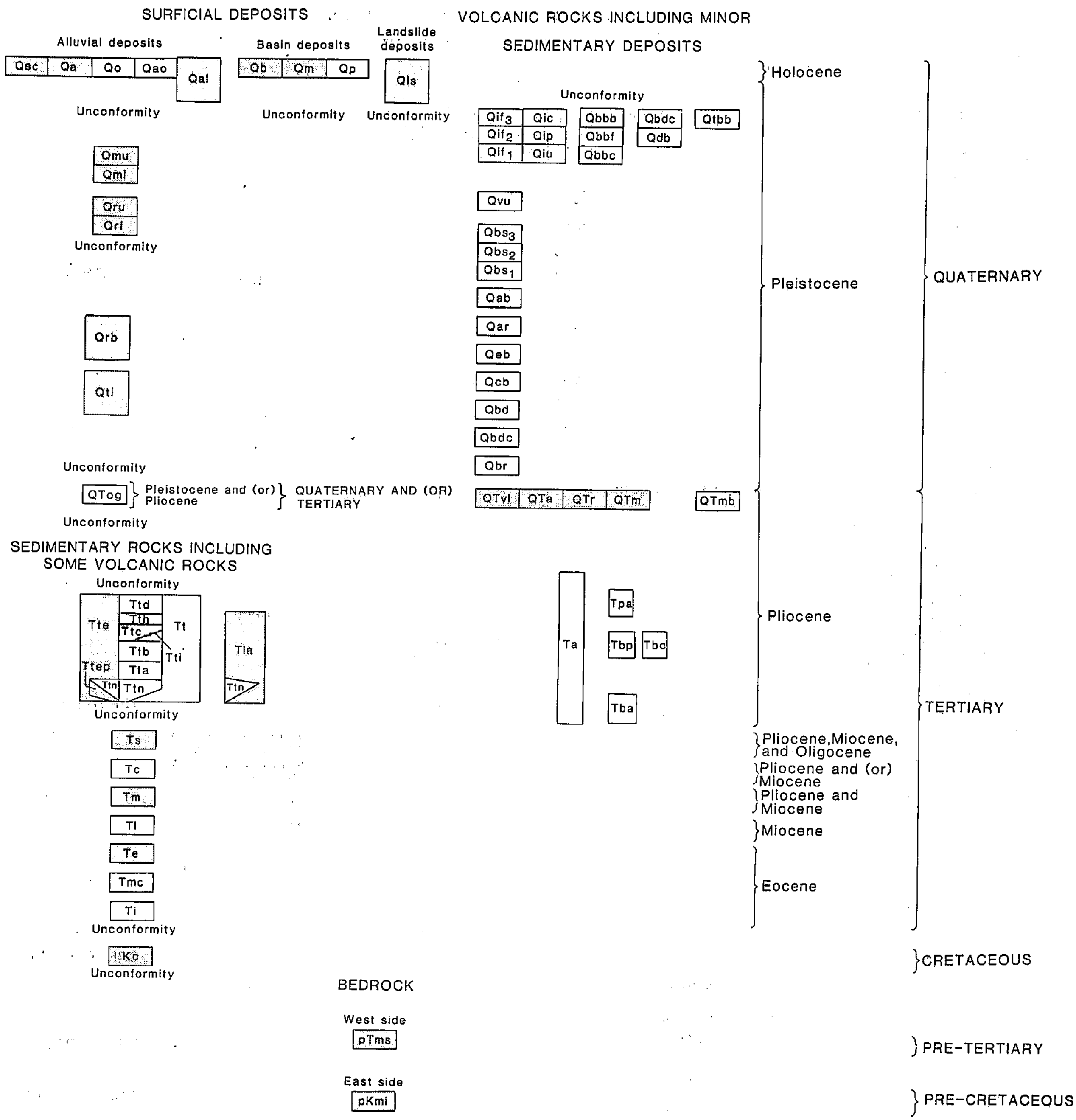


SOUTH CENTRAL SACRAMENTO VALLEY

CORRELATION OF MAP UNITS

SHEET 2

(NOTE – Not all map units occur on every sheet; stippling indicates presence on this map sheet)

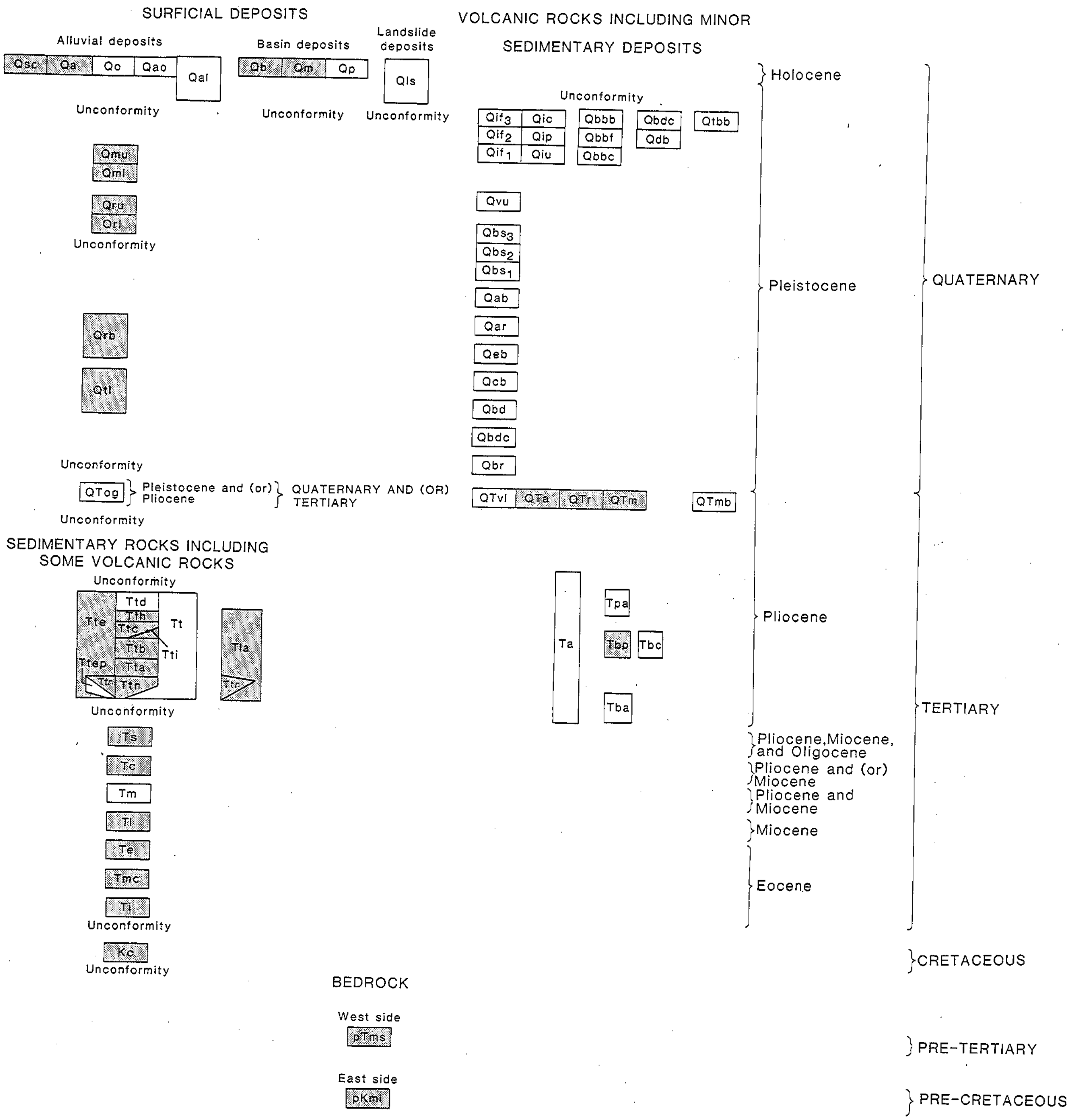


CENTRAL SACRAMENTO VALLEY

CORRELATION OF MAP UNITS

SHEET 3

(NOTE – Not all map units occur on every sheet; stippling indicates presence on this map sheet)

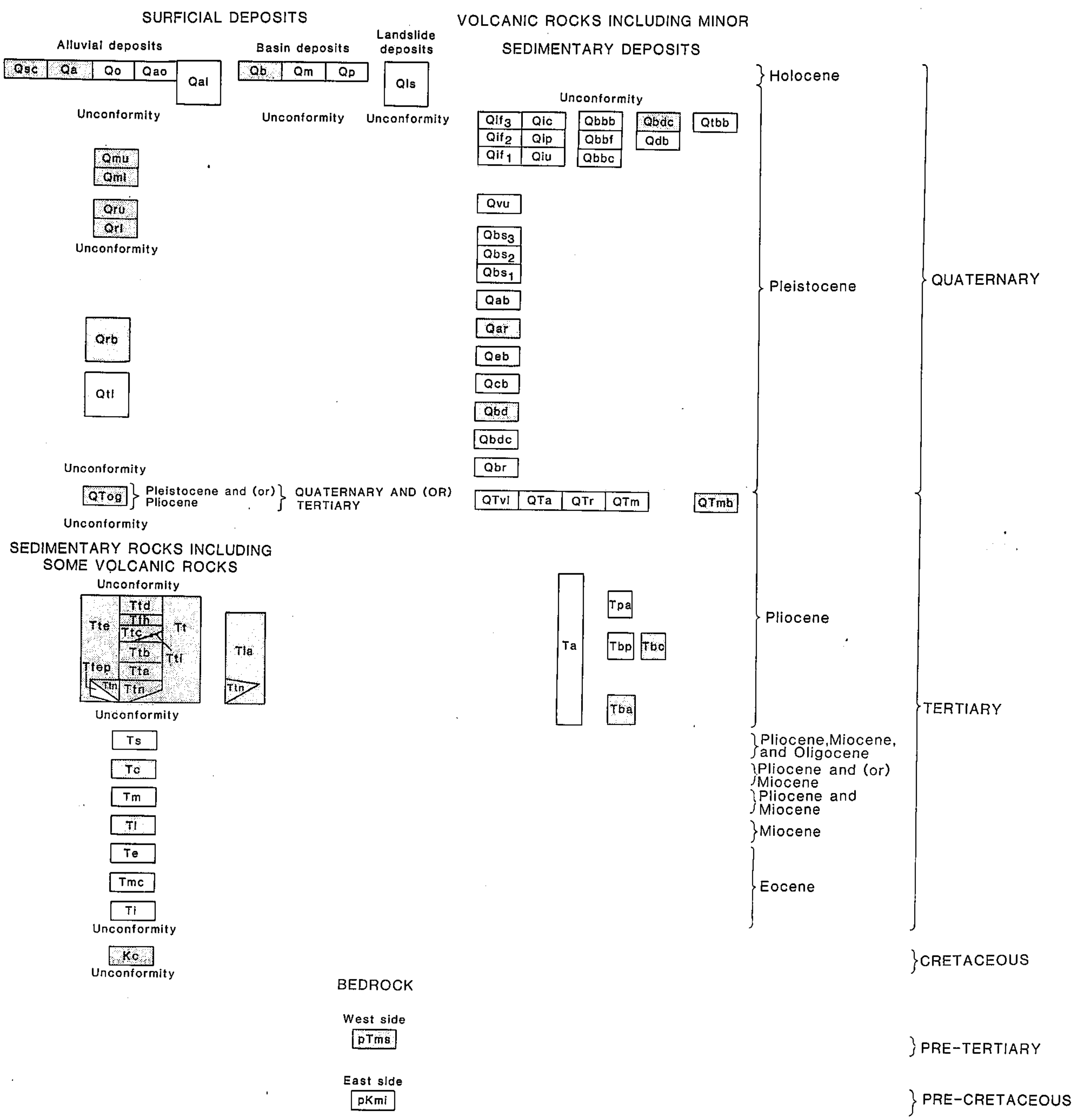


NORTH CENTRAL SACRAMENTO VALLEY

CORRELATION OF MAP UNITS

SHEET 4

(NOTE – Not all map units occur on every sheet; stippling indicates presence on this map sheet)

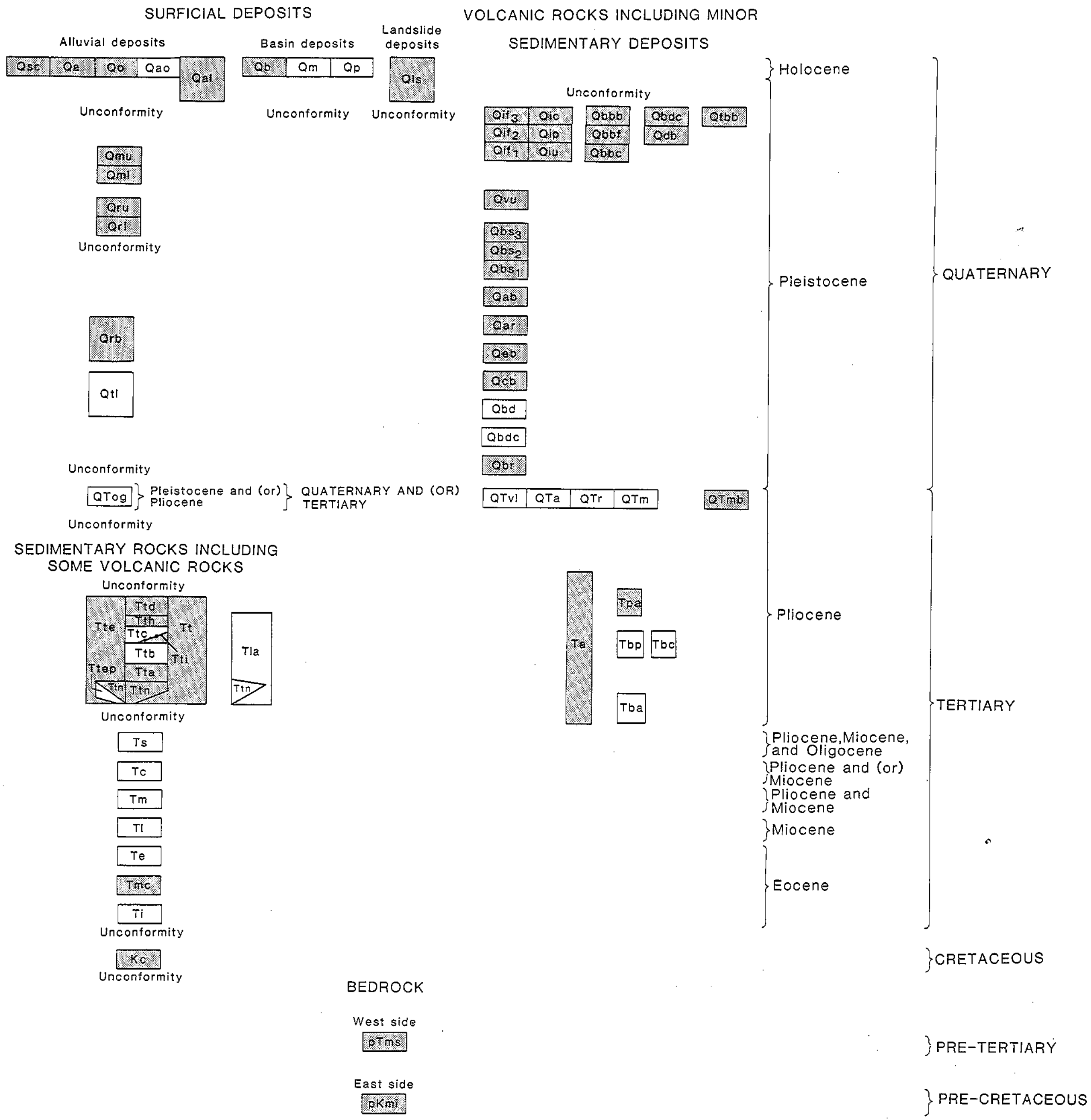


NORTHERN SACRAMENTO VALLEY

CORRELATION OF MAP UNITS

SHEET 5

(NOTE – Not all map units occur on every sheet; stippling indicates presence on this map sheet)



EXPLANATION

CONTACT–Dashed where approximately located

FAULT–Dashed where approximately located; dotted where concealed; U, upthrown side; D, downthrown side

FAULT SCARP–Hachures on downthrown side

FRACTURE PATTERN–On Chico Monocline

VOLCANIC FISSURES OF INSKIP HILL

PHOTO LINEAMENT

FOLDS
- Anticline–Dashed where approximately located
- Syncline–Dashed where approximately located

LANDSLIDE–Arrow indicates direction of movement

TUFF BED

t MAN MADE MATERIALS–Dredge tailings and other disturbed ground