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SEDIMENTOLOGY OF THE LIVERMORE GRAVELS (MIOCENE-PLEISTOCENE), SOUTHERN LIVERMORE VALLEY, CALIFORNIA

By

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ABSTRACT

The Livermore Gravels exposed east of San Francisco Bay are composed of gravels, sandstone, and claystone in varying proportions. The gravels are significant because they record orogenic events that affected the region from the late Miocene through the Pleistocene.

A general stratigraphy of the Livermore Gravels has been developed based on composition of clasts within the gravels. They are here subdivided into two members, the Lower Livermore and the Upper Livermore. The Lower Livermore is composed predominantly of clasts of Cenozoic sandstone, graywacke, and fine-grained vein quartz. Thick, planar cross-bedded sandstone and laterally extensive lenses of siltstone and mudstone surround horizontally bedded gravel. The Lower Livermore represents deposition by sandy braided streams.

The Upper Livermore is composed predominantly of clasts of Franciscan graywacke, lithic sandstone, metamorphic rock, volcanic rock, and traces of fine-grained vein quartz. Thick, horizontally bedded, clast-supported, well imbricated, gravel beds interlayered with planar cross-bedded and trough cross-bedded sandstone intervals are typical. Indistinctly bedded, matrix-supported, cobble to boulder gravel occurs rarely. The Upper Livermore represents deposition by gravelly braided streams on an alluvial fan.

Clast compositions indicate two different source areas. Imbrication of clasts suggests that the paleocurrents for the Lower Livermore were toward the southwest. Trends in maximum clast size for the Lower and Upper Livermore confirm the sediment dispersal pattern suggested by paleocurrent vectors. These dispersal data and the clast compositions suggest that the Lower Livermore was supplied with detritus from the Altamont Hills to the northeast, whereas the Upper Livermore sediment was derived from the central Diablo Range to the southwest. Thus, there was a stream reversal between deposition of the two members.

The Livermore Gravels record uplift of two different portions of the central Coast Ranges. Uplift of the Altamont Hills approximately 8.0 Ma is thought to reflect the inland expression of stress associated with the passage of the Mendocino triple junction. A reversal in stream drainage and the development of the Upper Livermore fan complex indicate uplift of the central Diablo Range. This uplift occurred approximately 2.5 Ma and is thought to reflect major changes in the local stress field. The timing of this compressional event coincides with the change in relative plate motion between the Pacific and Antarctic plates. The Livermore Gravels thus provide a sensitive record of the changing tectonic environment in this part of the California Coast Ranges.

INTRODUCTION

Much of the history of the continental margin of central California is recorded by sedimentary sequences in basins formed along strike-slip faults in the central Coast Ranges. Basin fill within the Livermore Valley (fig. 1) presents an opportunity to study the 8.0 and 2.5 Ma tectonic changes that have affected this inland basin. The Livermore Gravels, composed of nonmarine boulder to pebble gravel, sandstone and fine-grained rocks, were deposited in this basin during the late Miocene and Pleistocene.

The Livermore Valley separates the Diablo Range into a northern range and a central range. The Altamont Hills and Mount Diablo comprise the northern range, and Mount Hamilton comprises a large portion of the central range. Both Mount Diablo and the central Diablo Range are antiformal structures cored by ultramafic rocks and Jurassic and Cretaceous sedimentary rocks with Cenozoic sedimentary rocks flanking the sides (fig. 2). The area of study is situated at the northern end of the central Diablo Range (fig. 1).

The Livermore Valley, which is bounded on the west by the Calaveras fault and on the east by the Greenville fault, is filled with Miocene and younger gravel-bearing formations. Among these are the Livermore Gravels, which are exposed on the northern flanks of the central Diablo Range and buried beneath the valley.

Previous geologic investigations that included the Livermore Gravels focused on regional geology rather than the gravel's record of orogenic events that affected the Livermore Valley. Therefore, a more definitive study of the Livermore Gravels is needed. The purpose of this thesis is to: (1) establish a basis for recognizing and subdividing the Livermore gravels based on objective criteria; (2) determine the provenance of the individual units, map their distribution, and interpret their depositional environments; and (3) use these depositional environments as a basis for interpretation of the tectonic evolution of the Livermore Valley.

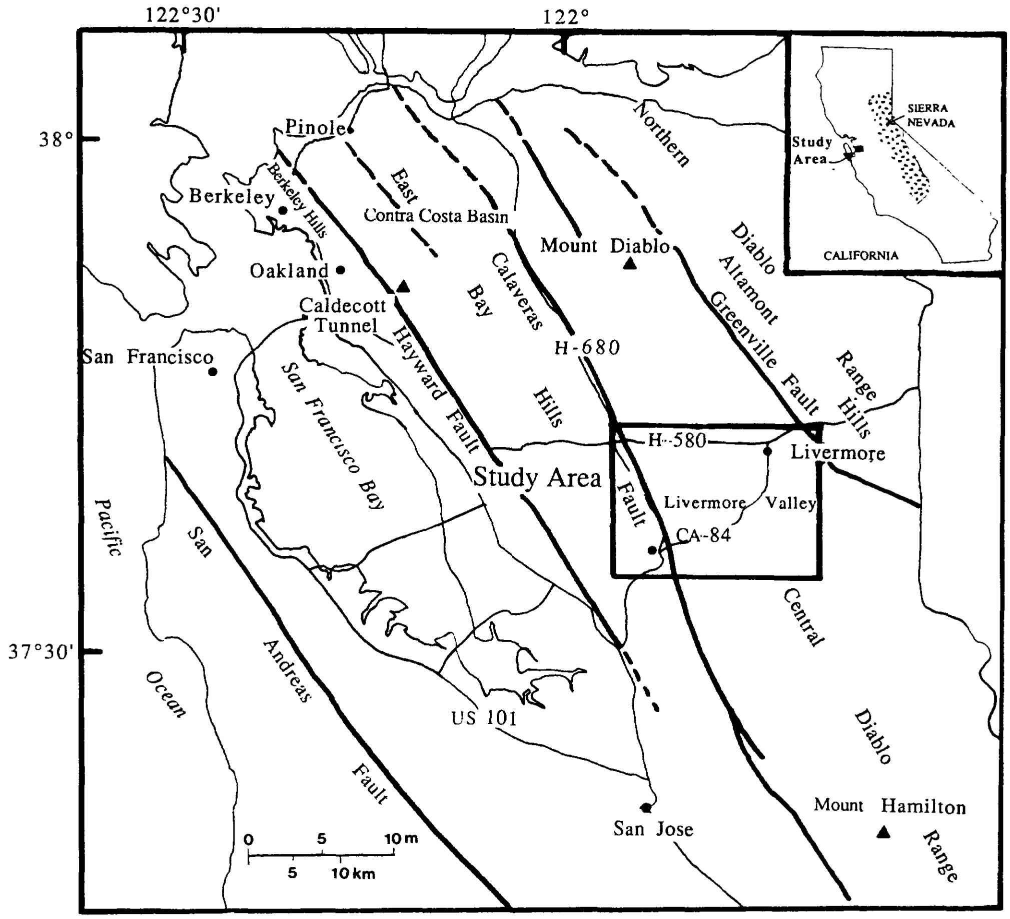
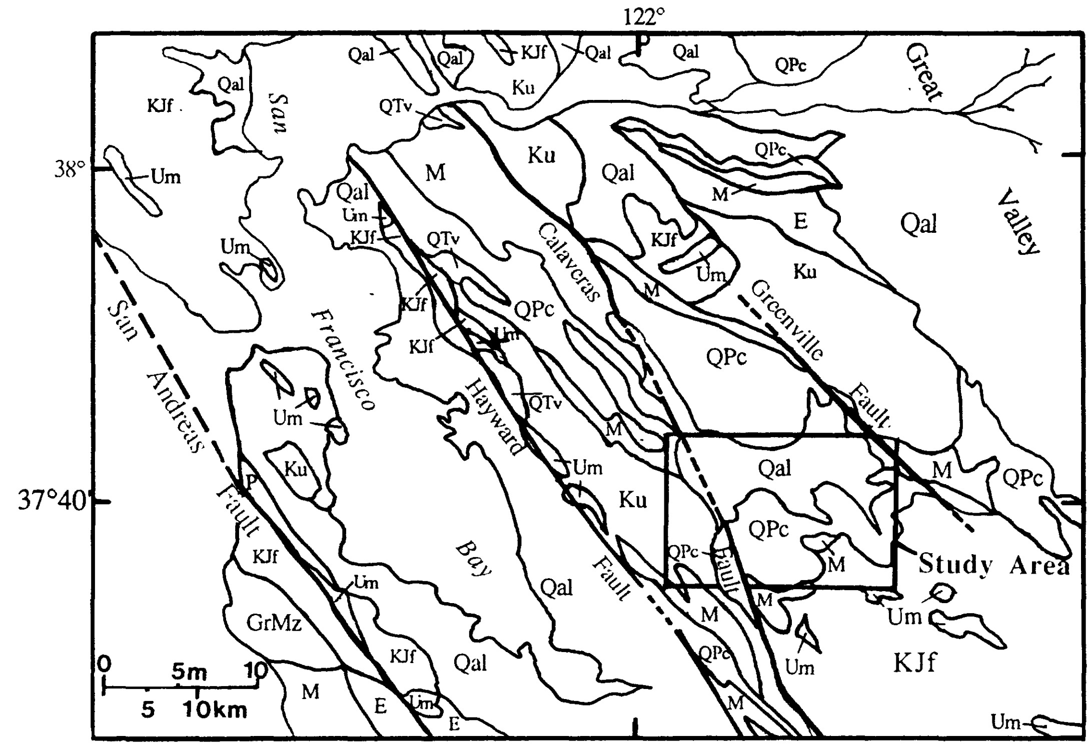


Figure 1. Location of area of study in the San Francisco Bay area, showing major faults (after Schlocker, 1970) and area of plate 1 (outlined).



EXPLANATION

Qal -- Alluvium and terrace deposits, unconsolidated

QTv-- Quaternary and Tertiary volcanics

QPc-- Plio-Pleistocene sandstone, shale, and gravel deposits

P -- Pliocene sandstone, moderately consolidated

M-- Miocene sandstone, shale, moderately consolidated

E -- Eocene sandstone, shale, and conglomerate

GrMz-- Mesozoic granite, quartzmonzonite

Ku -- Great Valley Group:Upper Cretaceous sandstone, shale, and conglomerate

KJf -- Franciscan Complex:Cretaceous Jurassic sandstone, chert, limestone,schist,and conglomerate

Um -- Ultramafic rocks

Figure 2. Generalized geologic map of west-central California, showing area of study (modified from Jennings, 1977).

PREVIOUS STUDIES

Vickery (1924) originally applied the name Livermore gravels to a thick sequence of gravels that form the hills south of the town of Livermore. The name was formally adopted by Clark (1943). Regional geologic studies were performed by Clark (1930), Huey (1948), Hall (1958), California Department of Water Resources (1966), Helley and others (1972), and Herd (1977). In these regional studies, the criteria used in distinguishing the Livermore Gravels from younger alluvial deposits were not consistent. Therefore, the distribution of the gravels differs markedly from one map to another.

More recent studies involving efforts to subdivide the Livermore Gravels have been presented by California Department of Water Resources (1974), Earth Science Associates (1978), Dibblee (1980a, 1980b, 1980c, 1980d), Carpenter and others (1984), and Ollenburger (1986). Figure 3 shows the different nomenclature used for the Livermore Gravels and the new nomenclature proposed.

In 1974, California Department of Water Resources (CDWR) released a geologic study in which the gravels were subdivided into two facies: a claystone facies, TQlc, occurring only in Livermore Valley, and a conglomerate facies, TQl, exposed over broad regions south of Livermore Valley, in limited exposures north of the City of Livermore, and west of Sunol Valley (CDWR, 1974).

Earth Science Associates (1978) also subdivided the Livermore Gravels, but they identified three units. Their lowest unit, QTlgl, is composed of weakly indurated siltstone and silty mudstone interbedded with conglomerate and lithic sandstone. This unit evidently is equivalent to the lower unit of CDWR (TQlc). Overlying the lower unit of Earth Science Associates (1978) is a middle, resistant conglomeratic unit, QTlgm. Their upper unit, QTlgu, is a thick gravel unit that was differentiated from the underlying conglomerate unit in that it is weakly cemented and friable.

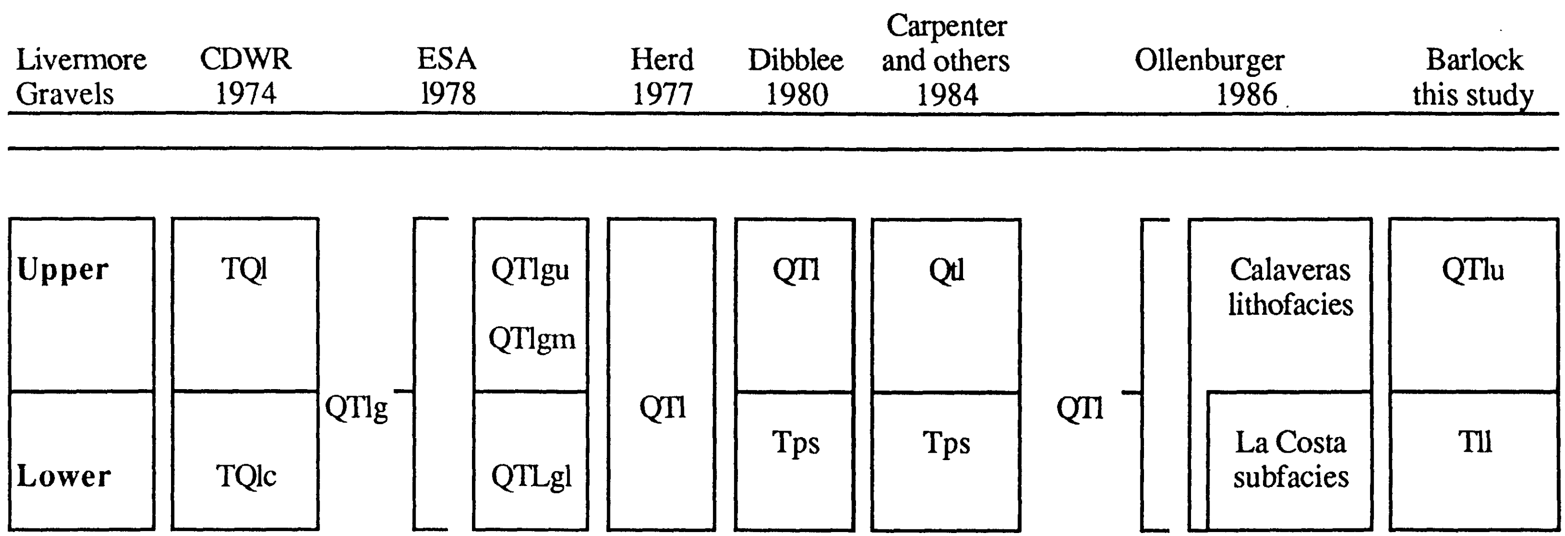


Figure 3. Nomenclature of the Livermore Gravels.

Dibblee (1980a, b, c) mapped all of the Livermore Gravels exposed within Contra Costa County. He divided the nonmarine Tertiary rocks into two units, QTl and Tps. His QTl includes Livermore gravels composed of reddish-gray, cobble and pebble gravel mapped as TQl by CDWR (1974), QTl by Herd (1977), and as Qtlgm and Qtlgu by ESA (1978). His unit Tps (nonmarine sedimentary rocks) is composed of pebble conglomerate, greenish gray clay and sand, and is mapped as being older than QTl. Tps crops out in the southern hills, adjacent to San Antonio Reservoir, and in the hills east of the Lawrence Livermore National Laboratory facility. Although the description of the two units by Dibblee (1980a, b, c, d) suggested equivalency to the two units of CDWR (1974), the map pattern shown by him is considerably different.

Carpenter and others (1984), in a report for the Lawrence Livermore National Laboratory site, referred to the QTl of Dibblee (1980b) as Upper Livermore Gravels and to his Tps as Lower Livermore Gravels. This nomenclature is adopted in this study.

Ollenburger (1986) divided the Livermore Gravels into two units on the basis of composition of clasts in the conglomerate. The two units were referred to as the Calaveras lithofacies and the Verona lithofacies. Most of the Calaveras lithofacies evidently is equivalent to the QTl of Dibblee (1980a), and one of the six internal subfacies, the La Costa subfacies of the Calaveras lithofacies, probably is equivalent to Tps, according to clast composition and distribution. The composition of clasts became a "fingerprint" which was used to distinguish the lithofacies even where the outcrop character is similar. Ollenburger (1986) suggested that the Calaveras gravels were derived from a southern source.

GEOLOGIC SETTING

Tectonic Setting

Livermore Valley is a structural trough within the California Coast Ranges. The area of study is constrained on the west by the Calaveras fault and East Bay Hills and on the east by the Greenville fault and Altamont hills (figs. 1, 2). Faults in the region have mostly strike-slip displacement although some thrust faults have been mapped. Rocks in the hills around the area of study are composed of the Jurassic-Cretaceous Franciscan Complex, the Jurassic-Cretaceous Great Valley Group, and several Cenozoic sedimentary formations.

Stratigraphic Setting

Franciscan Complex

The rocks of the Franciscan Complex, Tithonian to Turonian in age, contain abundant metamorphosed and unmetamorphosed graywacke with fine-grained vein quartz and interlayered, pervasively sheared volcanic rocks, basalt altered to greenstone, highly indurated conglomerate, serpentinite, blueschist and related schists, and multi-colored massive and bedded chert, all in a sheared shale matrix (Dibblee, 1980a, b, c). Outcrops in proximity to the area of study are predominantly to the south (fig. 2).

Great Valley Group

The Great Valley Group, Tithonian through Turonian in age, contains massive and locally concretionary lithic sandstone, graywacke, and grayish-black carbonaceous shale (Bailey and others, 1964). It differs from the Franciscan Complex in that there are no greenstones or chert, except in the basal part, the sequence is less structurally deformed, and there are higher proportions of mudstone and shale, more uniform and thinly bedded lithofacies, higher proportions of conglomerate, and more fossils. Bailey and others (1964) estimated the thickness of the Great Valley Group to be approximately 40,000 feet (12,000 m). The general distribution is illustrated in figure 2.

Tertiary Marine Rocks

Paleogene rocks are not preserved in the Livermore Valley. However, Neogene strata are present with almost all of the marine rocks being exclusively Miocene in age (fig. 2). The Miocene rocks are composed of coarse, pebbly, fossiliferous beds, fine-grained, light-gray sandstone, massive siltstone and claystone, arkosic sandstone, and andesite-pebble conglomerate. CDWR (1964) estimated that the combined thickness of these formations in the Livermore area and surrounding central-bay region is approximately 4,000 feet (1,200 m).

Nonmarine Gravels

There are several gravel units exposed throughout the Livermore Valley with similar lithologies and sedimentary features. These gravels are: (1) the Livermore Gravels, (2) gravels of the Tassajara Formation, (3) terrace deposits, (4) landslide deposits, and (5) alluvium. Of all the gravel units in the Livermore Valley, the landslide and alluvium are easily distinguished from the rest of the gravels because of their unique geomorphic features and lack of deformation.

The landslide deposits are composed of clasts of graywacke, siliceous volcanic rocks, and red chert, an assemblage of clasts similar to that in the Cretaceous Oakland Conglomerate (Dressen, 1979). These deposits therefore are interpreted as detached blocks of Oakland Conglomerate.

Modern alluvium in active channels and on recent terraces is unconsolidated, and it is not deformed. This broad category includes all unconsolidated sand and gravel including recent terrace deposits, stream deposits, and colluvium. Herd (1977) presented a complete description of the lithology of the Quaternary terraces and alluvium throughout the region.

The remaining gravel units are difficult to distinguish in outcrop, and another method is utilized to differentiate between them.

UPPER CENOZOIC GRAVELS

During reconnaissance, four different gravel units tentatively were recognized in the Livermore Valley. These units are the Livermore Gravels, which have two parts, and two other gravel units including a younger terrace deposit in the west and gravels considered to belong to the Tassajara Formation of Dibblee (1980b) on the north. Because previous methods of distinguishing between gravel units have proved inadequate, it seemed necessary to separate these units on the basis of clast composition. The method developed by Cummings (1968) for identifying gravel lithofacies based on clast composition was utilized.

Clast Composition

The method of utilizing composition of clasts in conglomerates, developed by Cummings (1968) and Ollenburger (1986), makes the recognition of gravel lithofacies possible even in areas of poor exposure. This method involves identification of a gravel lithofacies based primarily on its clast composition.

Sample Locations

Areas previously mapped as the Tassajara Formation and Livermore Gravels were sampled in order to ascertain their similarities and differences. At locations where the identification of these conglomerates is disputed, clast compositions have been used as "fingerprints" to distinguish between similar conglomerate units. Fifty two collection sites shown on figure 4 were sampled.

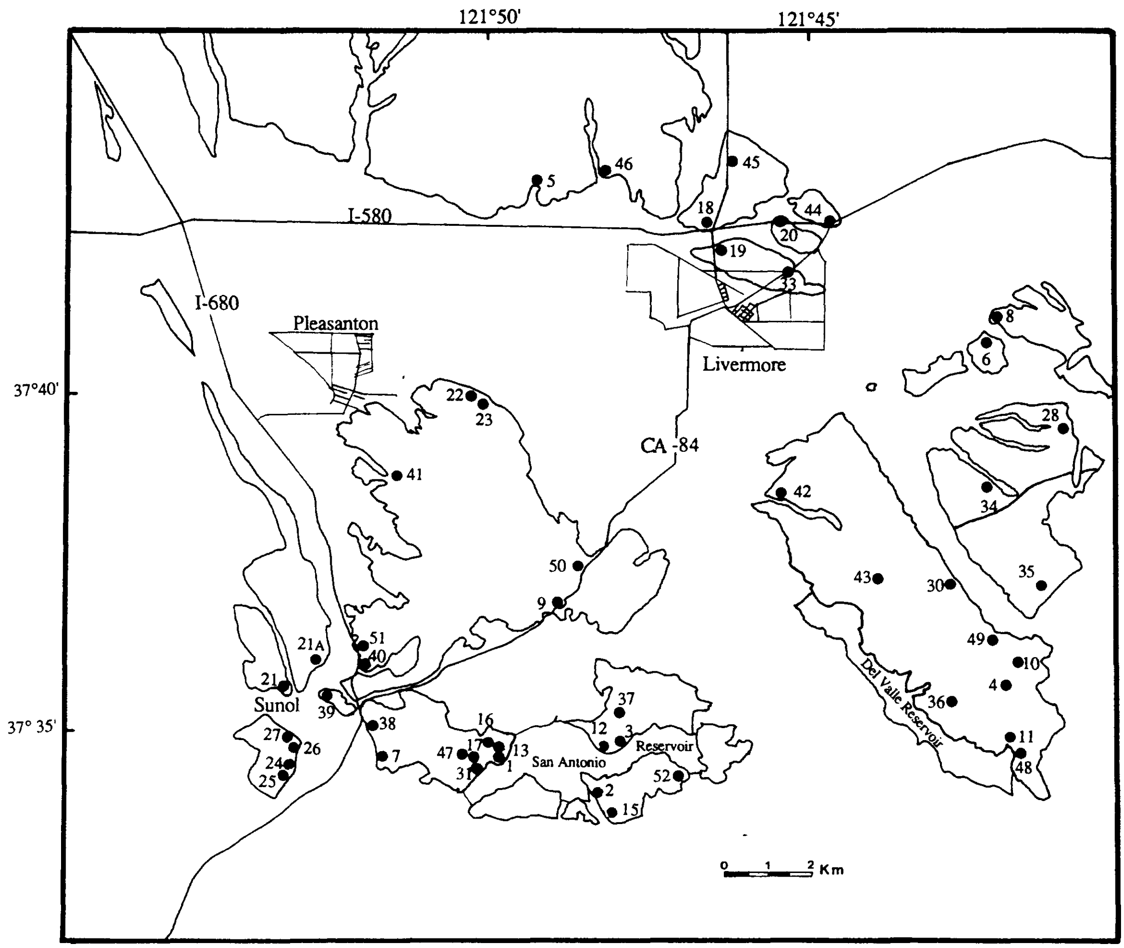


Figure 4. Map showing locations of gravel outcrops sampled for clast compositions.

Method of Collection

In order to obtain a reasonably accurate estimation of the clast composition, one hundred or more clasts were counted at each outcrop. A net with 5-cm mesh (fig. 5) was placed onto an outcrop, and the clast at each intersection of the mesh was counted, identified, and collected. To avoid counting the same clast twice, clasts larger than 5 cm in diameter were counted only once. All clasts counted in the field were brought back to the laboratory to confirm and refine their identification. Thin-section petrographic analysis was done for several clasts, and the remaining clasts were studied using a binocular microscope.

Classification of Clasts

Clasts are classified on the basis of their textural characteristics and mineral assemblages. The main rock divisions are metamorphic, igneous, terrigenous sedimentary, chert, and vein quartz.

Metamorphic. Metamorphic rocks include blueschist, serpentinite, gneiss, greenstone, eclogite, and phyllite. They are lumped under the heading "all types." Slightly metamorphosed clasts are placed under the category of the protolith.

Igneous. The plutonic and volcanic rock clasts are classified using the IUGS (1973) classification. Silicified clasts showing original igneous textures were counted as "silicified igneous rocks" but were tabulated along with unaltered rocks with the same igneous mineral assemblages. All volcanic rocks, altered or not, were tabulated together. Degrees of alteration were noted but not used as the basis for separate rock divisions.

Sedimentary. Terrigenous sedimentary clasts are grouped into categories based on grain size and percentage of lithic

Figure 5. Exposure of Upper Livermore gravels at sample locality #6, showing 5-cm mesh netting used to count clasts. Marker is approximately 15 cm in length.

fragments. Particular attention was given to the sandstones, which were subdivided into three types. The first type, termed "sandstone," is composed predominantly of quartz with minor lithics. Most of these rocks contain well sorted, subrounded grains and calcareous cement. The second type, termed "lithic sandstone," is here defined as one composed of quartz, feldspar, and approximately 2 to 10 percent lithic fragments. The lithic sandstones typically contain moderately to well sorted, subangular grains in a calcareous cement. The third type is termed "graywacke," using the name applied by McBride (1963) to an immature sandstone with an interstitial matrix of more than 15 percent dark grayish-green, microcrystalline phyllosilicates, and containing more than 5 percent feldspar and more than 10 percent lithic fragments. The phyllosilicates are weakly aligned and show a subtle foliation. The rocks tend to be moderately to highly indurated.

Siltstone and mudstone were used primarily as field terms, and the scheme of Picard (1971) for describing fine-grained sedimentary rocks was utilized. If the material yielded a gritty feel when bitten between the teeth, the name siltstone was used. If the material was moderately indurated, had a generally homogeneous appearance, and did not yield a gritty feel when bitten between the teeth, the name mudstone was used.

Eight types of chert were recognized and distinguished on the basis of color. The chert clasts range in color from white to black, and in roundness from angular to well rounded.

Vein Quartz. Two types of vein quartz are recognized, a blocky, coarse-grained, white vein quartz and a fine-grained, moderate-gray, vuggy, vein quartz. The fine-grained vein quartz, being more resistant, survives transport and weathering processes.

Results

More than 5,000 clasts were identified and are summarized in Appendix I. It was found that sedimentary and volcanic clasts are the most abundant and differ markedly in their relative percentages among sample locations. Especially significant are proportions of lithic sandstone and graywacke. Vein quartz also is conspicuous in outcrop. Of the vein quartz identified, the moderate-gray, fine-grained, vein quartz occurs in relatively high amounts in some locations and in lesser amounts in other locations (Appendix I). Therefore, graywacke, sandstone, lithic sandstone, volcanics, and fine-grained vein quartz were chosen to distinguish the various gravel units. Figures 6 and 7 show that the four similar gravel units in the area: (1) Lower Livermore Gravels, (2) Upper Livermore Gravels, (3) Tassajara Formation, and (4) terrace deposits can be separated on the basis of differing clast compositions.

Gravel Units

Lower Livermore

Samples that contain abundant clasts of sandstone and lithic sandstone with subordinate amounts of graywacke, few volcanics, and moderate amounts of fine-grained vein quartz occur consistently in the lower part of the Livermore Gravels (figs. 6, 7). Deposits with this lithology henceforth are termed Lower Livermore. These sampled gravel beds contain a clast composition where the total clast population is typically more than 30 percent total sandstone, less than 30 percent graywacke, and between 20 and 45 percent fine-grained, vein quartz (fig. 7).

Upper Livermore

These gravel beds contain abundant graywacke, and subordinate amounts of sandstone, white, blocky, coarse-grained, vein quartz, blueschist, gneiss, schist, phyllite, plutonic rocks, volcanic rocks, various colored cherts, and eclogite (Appendix I). Samples high in graywacke with very few lithic sandstone clasts, and approximately 5 to 25 percent volcanics (figs. 6, 7) were found to occur stratigraphically above the Lower Livermore Gravels in

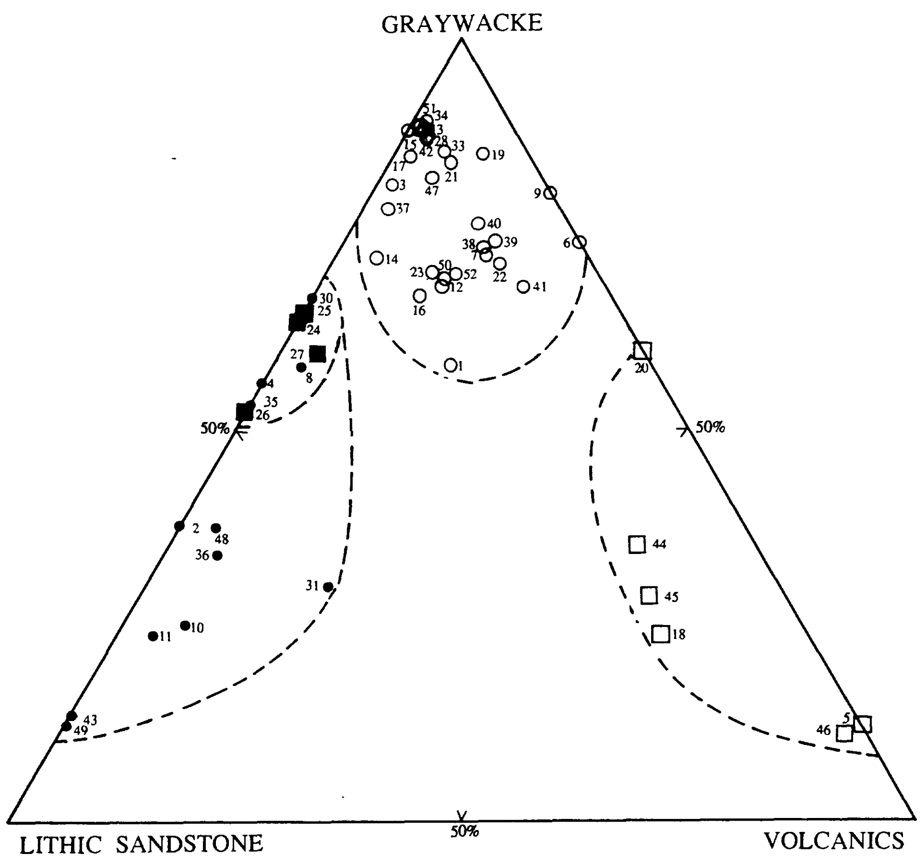


Figure 6. Relative proportions of graywacke, lithic sandstone, and volcanic clasts in gravel from Lower Livermore (filled circles), Upper Livermore (open circles), Tassajara Formation (open boxes), and Terrace deposits (filled boxes).

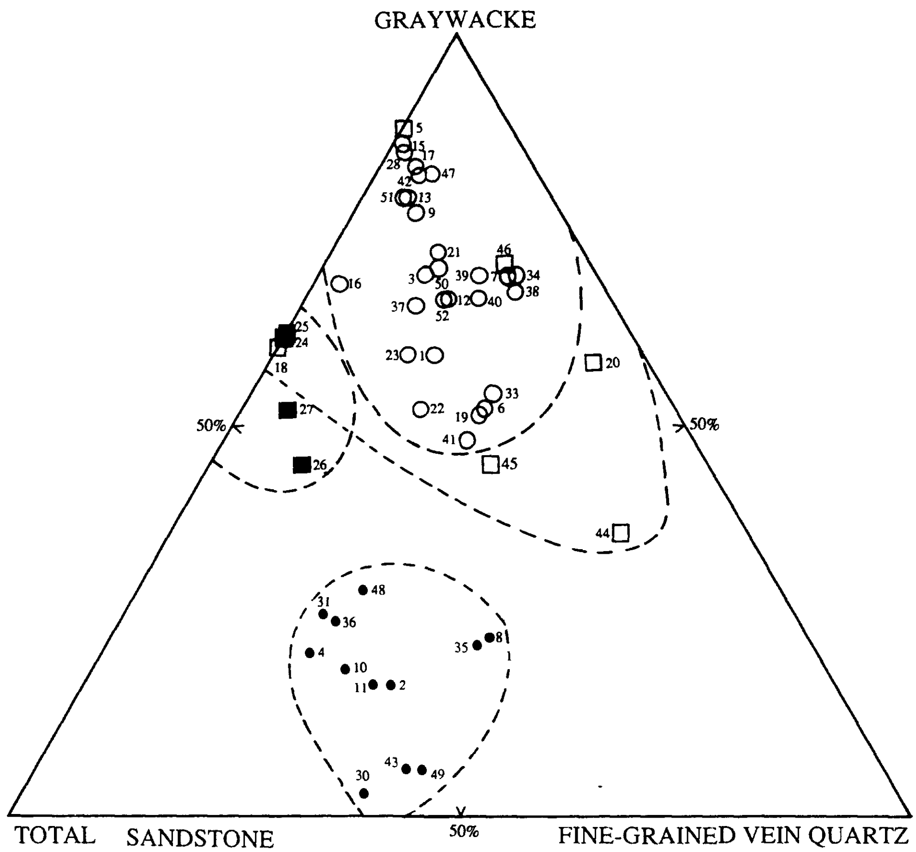


Figure 7. Relative proportion of graywacke, total sandstone, and fine-grained, vein quartz in gravel from Lower Livermore (filled circles), Upper Livermore (open circles), Tassajara Formation (open boxes), and Terrace deposits (filled boxes).

the field and henceforth are termed the Upper Livermore Gravels. Typically the Upper Livermore Gravels contain less than 35 percent total sandstone, more than 49 percent graywacke, and less than 30 percent fine-grained, vein quartz (fig. 7).

Tassajara Formation

One other cluster of clasts illustrated in figures 6 and 7 represents samples from the Tassajara Formation as mapped by Herd (1977). The Tassajara Formation is composed of moderate red claystone and mudstone, interlensed with tuffaceous sediment, small amounts of lithic sandstone, and relatively small proportions of gravel containing clasts of graywacke and limestone (Herd, 1977; Dibblee, 1980b). These gravels have historically been confused with the Livermore Gravels. The six samples (#5, #18, #20, #44, #45, #46), are different in composition from all of the samples from the Livermore Gravels (fig. 6). The Tassajara Formation contains more volcanics and fewer graywackes than the Upper Livermore Gravels and it contains fewer lithic sandstone clasts than the Lower Livermore Gravels (fig. 6), so the Tassajara is here recognized as being very different from the Livermore Gravels.

Terrace Deposit

The clast compositions show that another cluster also is quite distinct (figs. 6, 7). Samples #24, #25, #26, and #27 were collected in the western portion of the study area and on the flanks of the Cretaceous rocks in the vicinity of Sunol (fig. 4). These samples produce a distinct cluster on figure 6 because they contain fewer volcanics and more lithic sandstone than the Upper Livermore Gravels (fig. 6), and much less fine-grained vein quartz than the Lower Livermore Gravels (fig. 7). Although this deposit was previously mapped as part of the Livermore Gravels by Hall, (1958), Herd (1977), Helley and others, (1972), Dibblee (1980c), and Ollenburger (1986), the terrace deposit is not considered to be part of the Livermore Gravels in this report.

LIVERMORE GRAVELS

The objective of this work is to use the gravels as a basis to interpret the geologic history of the Livermore Valley. Clast counts provide a reliable basis for distinguishing the gravels from other gravel units and for separating them into two distinct parts. The two parts are described in detail and their preserved sedimentary features and depositional sequences are used to interpret depositional environments and provenance. The results of these analyses provide constraints on interpretations of the tectonic evolution of the valley.

Stratigraphy

The distinct compositional differences between the Lower and Upper Livermore have allowed a general two-part stratigraphy to be developed. The distribution of the two units has been remapped throughout the valley (Plate 1). The map shows the distribution of the Livermore Gravels as defined here, and it shows the geology of the overlying and underlying units taken largely from previous work. To facilitate mapping, five surface stratigraphic sections were measured (Appendix II; Plate 2).

Lower Livermore

The Lower Livermore Gravels are exposed along road cuts and within gullies and form gentle hills in the southern portion of the area of study (Plate 1). A typical exposure of the Lower Livermore is preserved adjacent to Mendenhall Road, just east of the Del Valle Reservoir (fig. 8). As defined here, the Lower Livermore includes rocks mapped as TQlc by CDWR (1974) in the area east of Greenville Road (Plate 1). This is the only area in which CDWR showed the lower clay facies exposed throughout the

Figure 8. Exposure of typical section of Lower Livermore Gravels along Mendenhall Road leading to Del Valle Reservoir. Abundant massive siltstone and mudstone are interbedded with subordinate gravel and tuffaceous beds.

region. Dibblee (1980b) described a similar sandy and silty unit and mapped the rocks as Tps. Although his description is essentially identical to that of CDWR and this investigation, Dibblee shows no Tps in the area east of Greenville Road, whereas Tps is exposed predominantly south of San Antonio Reservoir. Carpenter and others (1984) concurred with Dibblee's descriptive usage of Tps and referred to those areas with similar lithologies as the lower member of the Livermore Formation, but the contacts on the two maps are very different. The map of Carpenter and others (1984), which was limited to seven square miles around the Lawrence Livermore National Laboratory, has contacts similar in location to those of CDWR (1974) and this investigation.

The silty sandstone and gravel of the Lower Livermore are clearly exposed in the western part of the area of study along the shores of San Antonio Reservoir, and they comprise a small portion of the hills directly above the north shore (Plate 1). This lower member crops out in the southwestern portion of the study area in exposed stream banks, in gullies on the south side of San Antonio Reservoir, in gullies at Indian Creek, and in road excavations along Mendenhall and Greenville roads (Plate 1). The map of the La Costa Valley area by Dibblee (1980a) shows Tps in the hills south of San Antonio Reservoir, whereas Plate 1 of this investigation shows the Lower Livermore along portions of both shorelines and extending several meters up slope (Plate 1). CDWR (1974) has mapped the southern slopes at Del Valle Reservoir as TQl. Dibblee (1980a) has mapped this area and other small exposures along the east slope of Del Valle Reservoir and at sample location #35 as Tps. Exposures descriptively identical to Tps also are seen along Greenville Road, location #8, in the southeast part of the valley, although Dibblee mapped the area as Qtl. In this vicinity Carpenter and others (1984) mapped the rocks as Lower Livermore (fig. 3).

Thickness estimates for the Lower Livermore vary. The columnar section of CDWR (1974) shows a thickness of 500 feet (150 m) for TQlc, which is the sequence beneath a thick conglomerate bed. Carpenter and others (1984) have reported a thickness of approximately 4,000 feet (1,200 m) for Tps. The thickest portion of the Lower Livermore is exposed along Mendenhall Road, from sample location #30 over the road crest at sample location #10 and down to the fault contact with the Franciscan Complex just below sample location #48 (Plate 1). The Lower Livermore is approximately 390 m thick in the measured surface stratigraphic section of Del Valle (Appendix II, Plate 2). From field investigations continued north of the Del Valle measured section an additional 150 m was estimated. Therefore, a total thickness for the exposed Lower Livermore is approximately 540 m.

Upper Livermore

The Upper Livermore Gravels crop out as resistant, cliff-forming ledges. As defined here, this unit includes most of the rocks mapped as QTl by Dibblee (1980a, b, c) and the rocks mapped as Upper Livermore (Qtl) in the area around the Lawrence Livermore National Laboratory by Carpenter and others (1984). Although the general locations of the units of these workers are geographically similar to the locations reported here, the use of clast composition provides a more reliable basis for placement of the contact.

The upper member of the Livermore Gravels occurs in limited exposures throughout the study area. In the west, the gravels crop out as resistant cliffs on the hills and ridge crests along San Antonio Reservoir, the area north of California Highway 84, east of U.S. 680, south of Pleasanton, and east of Sunol (Plate 1). A typical exposure of the Upper Livermore is preserved adjacent to Calaveras Road, just south of the junction of U.S. 680 and California Highway 84 at sample locality #7 (fig. 9). Exposures of this type can be seen along road cuts of California Highway 84, along portions of U.S. 680, and on road escarpments leading into the Arroyo Del Valle (Plate 1). The Upper Livermore in the eastern portion of the area of study is exposed as gentle hill slopes northeast of the city of Livermore, along north Grant Road west of the Lawrence Livermore National Laboratory, and along Tesla Road (Plate 1). At Reuss Road, at sample location # 28 in the southeastern portion of the study area, the upper member is not as cliff-like in appearance and the hills take on a subdued form.

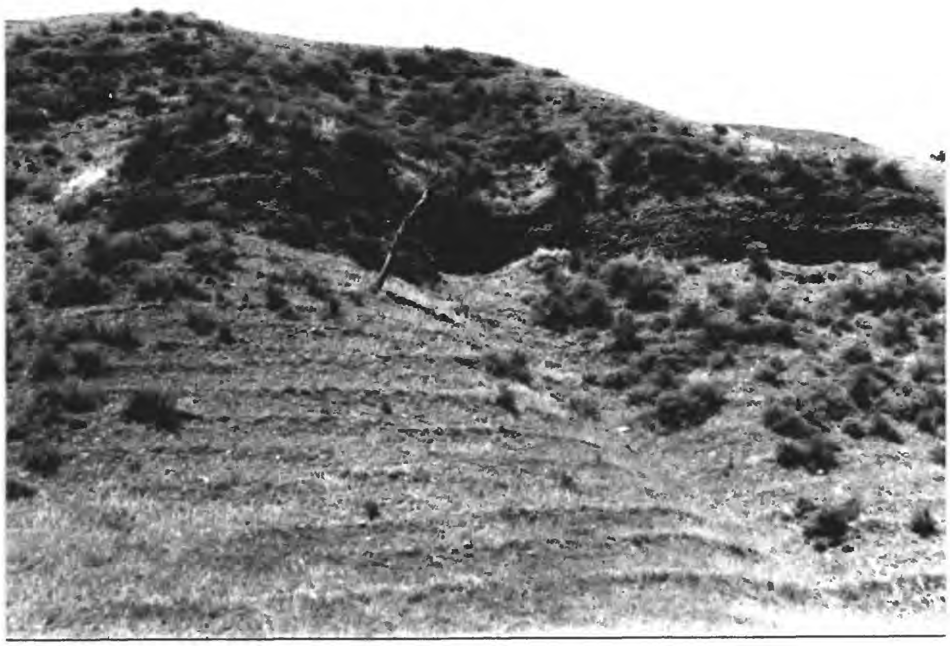


Figure 9. Upper Livermore Gravels along Calaveras Road at location #7. Coarse beds form resistant outcrops. The prominent Gravel bed in the upper half of the hill is approximately 10 m thick.

CDWR (1974) estimated a thickness of 4,000 feet (1,200 m) for their upper unit, TQl. Earth Science Associates (1978), who had sub-divided the gravels into three members, estimated the thickness of their middle conglomeratic unit, QTlgm, to range from 50 to 250 feet (20 to 80 m). Carpenter and others (1984) estimated a thickness of more than 100 feet (30 m). Ollenburger (1986) also mentioned an outcrop thickness for his upper Calaveras lithofacies to range from 45 to 60 m. The measured surface stratigraphic section at San Antonio Reservoir indicates a thickness of 67 m (Appendix II). From the similarity between lithologic descriptions and the thickness estimates, it can be inferred that Earth Science Associates (1978), Carpenter and others (1984) and Ollenburger (1986) described and measured the same unit and that their thickness measurements and the outcrop thickness measurement obtained in this investigation all represent locally measured thicknesses for the Upper Livermore Gravels.

Sedimentary Features

Lower Livermore

Measured surface stratigraphic sections (Plate 2) show that the Lower Livermore is composed of approximately 50 percent sandstone, 40 percent massive siltstone and mudstone, and 10 percent pebble to cobble gravel, with tuff-bearing beds interlayered throughout (fig. 8).

Sandstone is light-brown to light-gray where fresh and very light-gray where weathered. Sandstone is medium to coarse grained. Beds occur in tabular cosets that are 2 to 3 m thick, they exhibit sharp bounding surfaces, and they extend laterally for many meters. Where stratification is visible, the internal sets are medium-scale, planar cross-beds (fig. 10). The sandstone is friable to moderately indurated and composed of moderately sorted, moderately rounded grains. Thin pebble layers define many of the bedding surfaces (fig. 10). At the top of a typical sandstone bed, the contact with the overlying siltstone or mudstone is gradational.

Figure 10. Subtle planar cross-bedding (bracket) dipping to left in 1-m-thick sandstone horizon within the Lower Livermore at Del Valle. Scale marks an 8-cm-thick, oxidized horizon. Scale is 15 cm in length.

Siltstone and mudstone lithofacies are lenticular and laterally extensive for hundreds of meters. Outcrop thickness ranges from 10 to 100 m. Where discernible, the beds are horizontally to finely laminated. The poorly sorted mudstone is dark colored and variegated. The rocks are greenish-gray and dark greenish-gray, with lenticular, organic-rich partings along which the rocks break into fine laminations. Brownish-black carbonaceous material is abundant on many bedding surfaces. Several invertebrate and mammal fossils have been found within the siltstone and mudstone lithofacies (Herd and Brabb, 1980). Siltstone typically overlies sandstone and is overlain by mudstone; transitions between beds are gradational.

Siltstone and mudstone units commonly include packages interpreted as paleosols. The bounding surface at the top of each package is sharp (fig. 11). The paleosol packages typically overlie a basal siltstone bed which is finely laminated to variegated, very light gray in color, and 0.5 to 3 m thick. Bioturbation is common and bedding generally is absent. The transition from the siltstone to the overlying mudstone package is gradational. These packages can be divided into two parts. The basal part is commonly 5 to 10 cm thick, is devoid of stratification and typically includes abundant calcium carbonate. The calcium carbonate commonly occurs as strongly indurated nodules 0.5 to 2 cm in diameter, or as a fine, interstitial precipitate within the mudstone (fig. 11). The beds, interpreted as caliche, occur directly beneath a reddish-brown oxidized layer. Contact with this overlying layer is gradational. The oxidized layer is light brown, 5 to 25 cm thick, irregular, very friable, and contains zones of decomposed plant residue and root casts filled with silt. The upper bounding surface is sharp where overlain by siltstone or sandstone, or it is erosional where truncated by a gravel bed (fig. 12).

Gravel cosets 1 to 3 m thick are light-grey, lenticular, horizontally bedded, moderately indurated, and laterally extensive for 20 to 35 m. The cosets are closely packed in the upper 100 m of the Del Valle measured section. The bounding surfaces of sets within the cosets are undulatory and erosional, and many exhibit a broad, channelform geometry in cross section (fig. 13). The cosets contain medium-scale, horizontally bedded, moderately indurated, upward-fining sets 10 to 100 cm thick and up to 20 m in length.

Figure 11. Exposure of a typical paleosol in the Lower Livermore at location #11. The oxidized upper zone of a paleosol is seen adjacent to scale. Moderate gray shading, indistinct bedding, and bioturbation are common. White calcium carbonate nodules (arrow) occur in a second paleosol overlying the oxidized top of the lower paleosol. Scale is 15 cm in length.

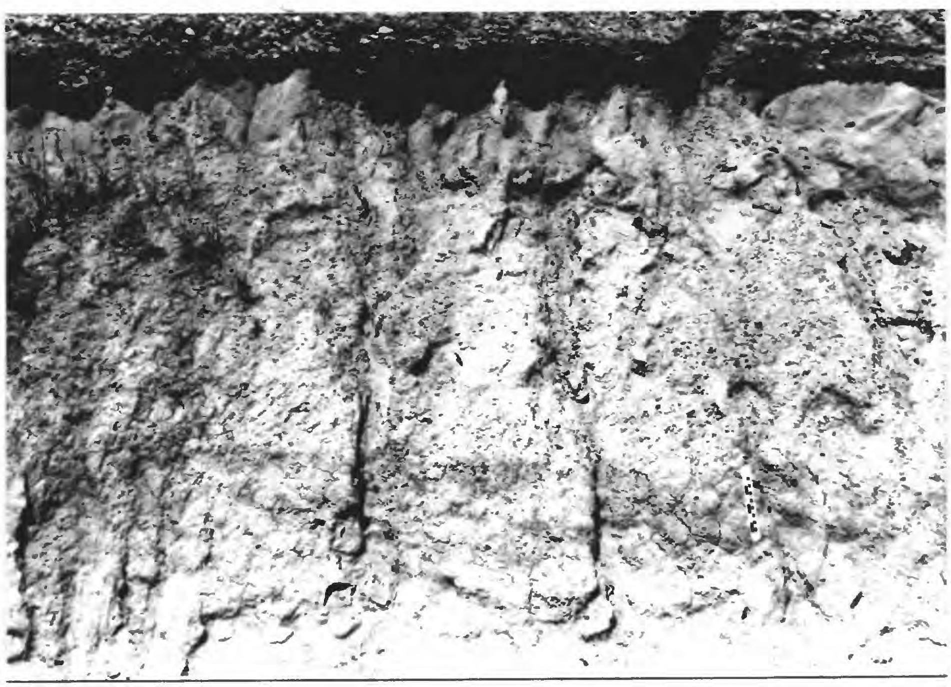


Figure 12. Two paleosols in the Lower Livermore at the Del Valle measured section. The oxidized upper horizon marks the top of each sequence. Upper paleosol is partially truncated by gravel horizon. Scale is 15 cm in length.

Figure 13. Exposure of Lower Livermore at Del Valle section (location #4). Broad, shallow channels truncate the underlying siltstone and sandstone to the left. Gravel bed is approximately 1 m thick.

The sets are bounded by sharp planar contacts (fig. 14). Individual strata within the sets are composed of clast-supported, moderately sorted, subangular to subrounded, imbricated pebbles. Most sets fine upward, with medium pebbles at the base and smaller pebbles or coarse sand at the top (fig. 14). The matrix is a mixture of silt and sand. Pebbles are imbricated parallel to the B-axis. The largest clast measured is 7 cm in diameter.

Several tuffs were found near the base of the Lower Livermore. The tuffaceous beds are fine-grained, finely laminated, well sorted, locally cross-bedded, and 1 to 3 m thick (fig. 15). Some tuffs contain fragments of rounded siltstone and mudstone and are believed to be water-laid and reworked (Sarna-Wojcicki, 1976).

Upper Livermore

The Upper Livermore is composed of 55 percent coarse-grained sandstone and siltstone and 45 percent unconsolidated pebble to boulder gravel beds.

Sandstone is reddish-brown where weathered and light brown where fresh, and it occurs in cosets 2 to 10 m thick. Exposures of the cosets can attain 25 m in thickness. Cosets typically contain small-scale, upward-fining sets about 10 cm thick. The bounding surfaces of the sandstone cosets are roughly horizontal, irregular and sharp and are inferred to be erosional. The internal sets generally are thinly planar cross-bedded and composed of moderately rounded, moderately sorted, coarse sand. The upper and lower bounding surfaces of these sets are sharp and planar. In several locations throughout the region, fossil remains of bison, horse and microtine rodents have been documented (Herd and Brabb, 1980).

Gravel is moderately to weakly indurated and cliff-forming (fig. 9). It occurs in very thick-bedded, horizontal cosets, 1 to 5 m thick, which are separated from each other by 1 to 4 m of coarse-grained sandstone (fig. 16). These cosets of gravel are laterally extensive for 50 to 100 m and have bounding surfaces that are undulatory and erosional. The majority of cosets contain medium-scale, planar-bedded sets (fig. 17). In several sequences the basal

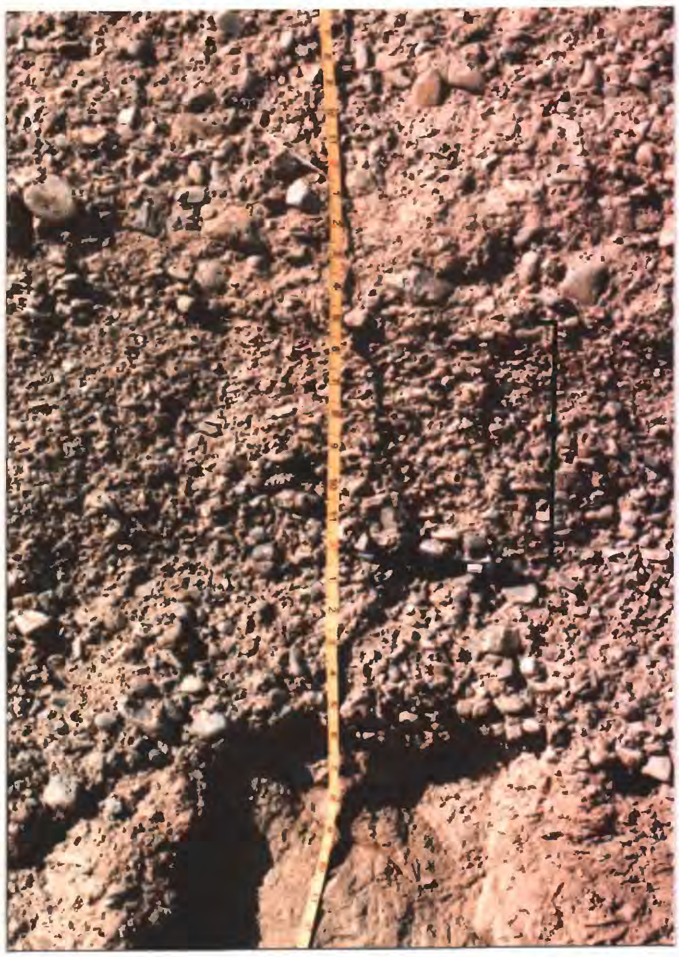


Figure 14. Gravel beds in the Lower Livermore at location #4 along road to Del Valle. A fining upward sequence (bracket) is typical. Imbrication indicates flow from right to left. Pencil is 14 cm in length.

Figure 15. Volcanic tuff, 10 cm thick; white where partially exposed (next to scale). Tuff interbedded with siltstone and sandstone beds of the Lower Livermore at the Del Valle measured section.

Figure 16. Exposure of Upper Livermore Gravels at location #9, along Highway 84, showing nesting of gravel beds (brackets), which is accentuated by preferential growth of vegetation on the sandstone and siltstone beds. Lenses of conglomerate are 1 to 5 m in thickness. White marker is approximately 1 m tall.

Figure 17. Cobble- and pebble-bearing, horizontally-bedded gravel bed (bracket) overlain by coarse, planar cross-bedded sandstone in the Upper Livermore at San Antonio Reservoir. Pencil is 14 cm in length.

set is horizontally bedded and contains moderately rounded, moderately sorted, clast-supported, pebble to boulder clasts, with B-axis imbrication. The overlying set locally is composed of small-scale, planar cross-bedded, coarse-grained, sandstone. Bounding surfaces are parallel and sharp.

Within several cosets, gravel sets occur that are 10 to 20 cm thick, are ungraded and lenticular, and lack obvious stratification. They are matrix-supported and poorly sorted, and they have bimodal grain-size distributions. Subhorizontal clast orientation and the absence of basal erosion are typical (fig. 18).

The majority of the clasts within the Upper Livermore are disc shaped, moderately rounded, and average 10 to 15 cm in diameter, but clasts more than 30 cm in diameter occur locally. Exposures of the Upper Livermore, in measured sections, typically show a gradual upward coarsening. Gravel beds typically are well imbricated (fig. 19). A coarse sand matrix is present between the clasts.

Depositional Environments

Lower Livermore

General Environment. Based upon lithology and stratification sequences, the Lower Livermore is inferred to represent a fluvial environment of deposition. The thickness and repetitiveness of the sandstone, siltstone, and mudstone lithofacies within the Lower Livermore suggest that the depositional processes under which the lithofacies were deposited prevailed for a long period of time. The finely laminated sandstone and siltstone, typical of the Lower Livermore, probably are the result of episodic, overbank floods. The fine-grained sediment and carbonaceous material probably were concentrated in local depressions in the overbank areas, producing the lenticular, variegated siltstone and mudstone beds. Oxidized, dark-reddish-brown beds, bioturbation, silt-filled root casts, and caliche nodules, which form irregular thin beds within these lithofacies, indicate pedogenesis (fig. 11). The presence of numerous caliche beds within the fine-grained

Figure 18. Exposure of indistinctly bedded gravel with bimodal clast size (brackets) in Upper Livermore at location #13 at San Antonio Reservoir. Well-rounded, extremely altered clast at tip of pencil is volcanic. Pencil is 14 cm in length.

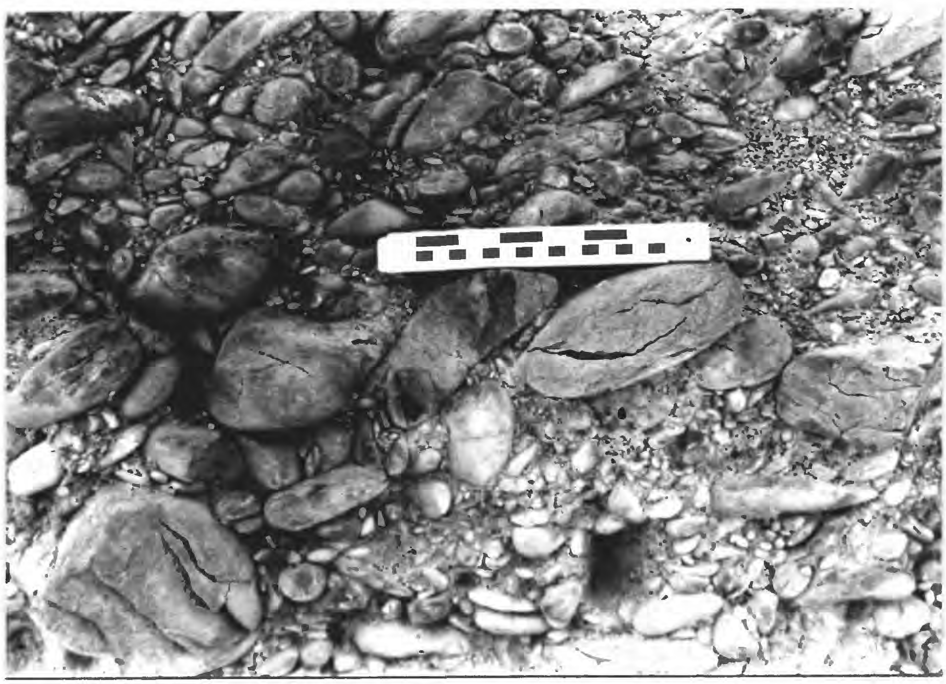


Figure 19. B-axis imbricated, clast-supported, pebble- and cobble-size graywacke clasts exposed at location #7 within the Upper Livermore. Flow was from left to right. Scale is 15 cm in length.

deposits implies that the overbank area was subjected to multiple periods of pedogenesis. Miall (1978) described similar bedding features as representative of floodplain deposits.

The thick, tabular, sandstone cosets with subtly planar-cross-bedded internal sets, moderate sorting and upward-fining sequences (fig. 10) are similar to transverse bar deposits in shallow, sand-dominated, perennial streams (Miall, 1978). The lenticular shape and erosional nature of the basal contact of the scarce gravel cosets (fig. 13) suggest a channel scour and fill structure. Imbrication of the clasts parallel to the B-axis and not the A-axis, and the clast-supported nature of the beds are features typically associated with fluvial bars rather than debris flows (Miall, 1978). The horizontal stratification in the Lower Livermore gravel beds is characteristic of longitudinal bars. Sandstone is rare in beds directly overlying the gravel bars of the Lower Livermore. The absence of sandstone above the gravel beds suggests that the vertical relief on the gravel bar was insufficient to prevent erosion during high flow conditions of any sand that may have been temporarily deposited.

Stream Type. The tabular sandstone cosets with planar cross-bedded sets, rare horizontally stratified gravel beds, the broad, shallow geometry of the channels, and the lack of thick upward-fining sequences in the cosets suggest deposition by a braided stream. These features typically are associated with Platte type braided river systems (Miall, 1978). The morphology of the gravel beds indicates that the stream channels were shallow and broad.

The high proportions of sandstone and siltstone in the interchannel areas indicate that the amount of fine sediment carried in suspension was large. The repetitive paleosols indicate that the overbank areas were relatively stable surfaces subjected to multiple periods of pedogenesis.

Upper Livermore

General Environment. The most conspicuous features of the Upper Livermore are the large-scale, horizontally stratified, non-cyclical cosets of clast-supported, pebble to boulder size, B-axis imbricated gravel (fig. 19). Within these cosets the individual sets are crudely horizontal, weakly cyclical, diminish in grain size upwards, and in a few places contain small-scale planar cross-bedded sandstone that overlies the gravel (fig. 17). Facies with these stratification types and texture have been interpreted by Miall (1978) as features typical of longitudinal bars and of lag deposits formed on channel floors in gravel-dominated braided rivers. In the southwest portion of the area of study (Plate 2) the stream channels are composed of extremely large B-axis imbricated clasts. These sites contain the bedform features interpreted to represent the coarse beds of a longitudinal bar. The overlying sandy planar cross-beds (fig. 17) and parallel laminated sands probably represent deeper channel fill (Miall, 1978).

In a few places, the sequence is interrupted by 10- to 15-cm-thick, ungraded gravel beds that contain non-imbricated, matrix-supported clasts. These have features inferred by Nemec and Steel (1984) to be typical of debris flows.

Figure 16 also illustrates how the channels are nested. The configuration of the channels more closely resembles the geometric arrangement of channels in the braided stream system of the Westwater Canyon Member of the Morrison Formation in New Mexico (Campbell, 1976) than the geometric arrangement of channels and sedimentary features depicted in the excavation of a meandering stream sequence in a portion of the Arkansas River (Steinmetz, 1967). The channels of the Upper Livermore are wide, lenticular, and exhibit cut and fill features with an erosional base. Several channels intersect one another. Their shape and thickness suggest that the channels were wider and deeper than channels of the Lower Livermore. The tight nesting of the channels, the vague upward-fining sequences, the imbrication, the clast-supported beds, and the erosional nature of the basal contact of the cosets are features similar to those inferred by Miall (1978) to result from deposition in a braided stream environment.

The gravel cosets are typically 1 to 5 m thick and are separated by sandstone and siltstone beds 1 to 4 m thick (fig. 16). Stacking of the gravel cosets represents channel migration and the siltstone represents the interchannel deposits.

Stream Type. The measured stratigraphic sections (Plate 2) show that the cosets of the Upper Livermore contain multiple superimposed longitudinal bar deposits. The relatively high proportions of gravel compared to sandstone, the presence of debris flow features, and the presence but scarcity of planar cross-bedded sandstone implies that the sedimentary sequences preserved in the Upper Livermore are similar to Miall's (1978) Scott type braided stream model.

The proximal, medial, and distal parts of an alluvial fan complex are inferred based on the bedforms, clast size, and stratification. Channelform gravel with horizontal stratification, well-developed imbrication, and boulder-size clasts, which represent high-energy streams, is interbedded with matrix-supported, indistinctly bedded units, which indicate debris flows. These features occur together near Calaveras Road and San Antonio Reservoir; this area is inferred to be the proximal part of the fan. The medial part of the fan is inferred to extend from the area of Pleasanton northeast across California Highway 84 toward location #50 (Plate 1). In this area, debris flow deposits are absent, clasts range from pebbles to cobbles, sandstone is more abundant, and the bedding is horizontal and laterally more extensive than in the proximal area. The distal parts of the fan are interpreted to be located near the City of Livermore and east of the Lawrence Livermore National Laboratory. Smaller size clasts, more sandstone and siltstone, and finer bedding features indicate lower-energy flow conditions and greater preservation of interchannel deposits.

Sediment Dispersal

Paleocurrents

Due to the presence of extremely well imbricated clasts in the Upper Livermore and moderately imbricated clasts in the Lower Livermore, paleocurrent analysis was utilized as a method to help constrain sediment dispersal directions and provenance.

Methods. Paleocurrent measurements were obtained from cosets of gravel up to 2 m thick. Each measurement was of the orientation of the B-axis of an individual clast. Some samples include measurements from several different beds within a coset. Five sequences of gravel as much as 10 m thick each contain several cosets, and in some cases several sample localities were identified within each sequence. Because the structural dip of the outcrops studied is less than 20°, a tilt correction was not used.

The orientation and magnitude of the resultant vector for each sample location were determined using calculations modified from Picard and Andersen (1975). The resultant direction is the direction of the vector sum of all of the measurements, and the vector strength is the magnitude of the vector resultant divided by the number of measurements. Summations for each member of the Livermore Gravels use vector statistics, based on a circular normal distribution, to establish the 95% confidence limits.

Results. Paleocurrent directions for all samples from the Livermore Gravels are shown in table 1. Table 1 shows that a major difference exists between the two members.

Figure 20 shows the resultant vector orientations plotted for each sample location in the Lower Livermore. A paleoflow trend from the northeast towards the southwest across the San Antonio Reservoir area is indicated. The histogram in figure 20 was constructed using all of the paleocurrent data for the Lower Livermore. The resultant vector is 204°, and the vector strength is

TABLE 1 . PALEOCURRENT DATA FOR THE LIVERMORE GRAVELS

Sample Number	Number ofMeasurements	Resultant Azimuth	Direction Quadrant	Vector Strength (%)	95% Confidence
LOWER LIVERMORE					
2	7	240°	S60°W		
4	6	194°	S14°W	95	
8	4	240°	S60°W	69	
10	8	157°	S23°E	94	
11	8	211°	S31°W	95	
30	9	186°	S06°W	92	
31	8	254°	S74°W	88	
35	7	233°	S53°W	85	
36	9	191°	S11°W	96	
43	7	257°	S25°W	88	
48	6	187°	S87°W	87	
49	9	153°	S27°E	97	
Totals	**13**	**204°**	**S24°W**	**74%**	**9°**
UPPER LIVERMORE					
1	4	104°	S86°E	94	
3	5	31°	N31°E	99	
6	6	314°	N46°W	89	
7	8	50°	N50°E	95	
9	4	8°	N08°E	100	
12	3	130°	S50°E	98	
13	8	71°	N71°E	95	
15	4	87°	N87°E	96	
16	8	89°	N89°E	94	
17	4	103°	S77°E	97	
19	4	10°	N10°E	99	
23	6	318°	N42°W	95	
28	8	60°	S60°E	90	
29	9	152°	S28°E	98	
33	5	353°	N07°W	92	
37	6	29°	N29°E	99	
38	6	61°	N61°E	95	
39	6	68°	N68°E	93	
40	6	117°	S63°E	98	
41	5	325°	N35°W	96	
42	6	109°	S71°E	96	
47	4	94°	S86°E	99	
50	5	10°	N10°E	100	
51	5	56°	N56°E	97	
52	5	103°	S77°E	99	
Totals	**140**	**59°**	**N59°E**	**61%**	**9°**

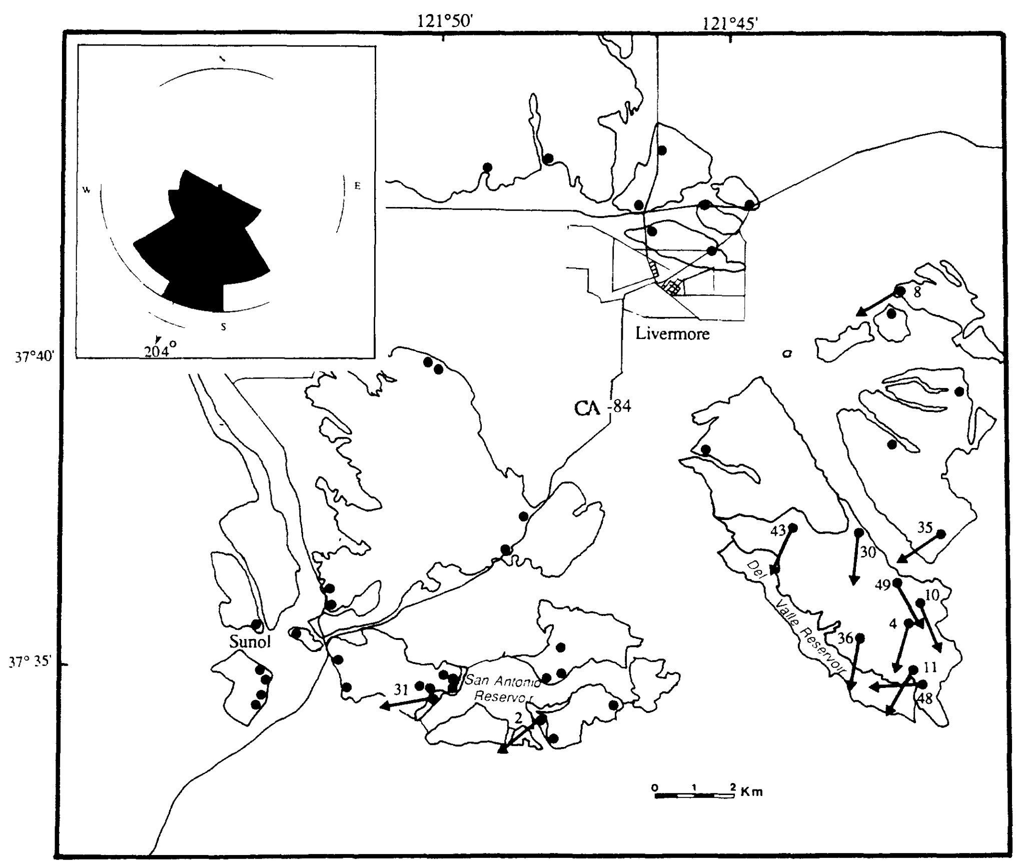


Figure 20. Paleocurrent map of the Lower Livermore Gravels. Each arrow represents resultant vector for an individual sample location. Upper left corner shows a histogram of the 88 individual measurements and the resultant and 95% confidence limits for the Lower Livermore.

74 percent. The resultant vector has a 95 percent confidence limit of 9°.

Figure 21 shows the resultant vector orientations plotted for each sample location in the Upper Livermore. A dominantly northeasterly paleoflow trend is indicated, with minor local components of flow towards the east and northwest. The histogram in figure 21 was constructed using all of the paleocurrent data from the Upper Livermore. The resultant vector orientation is 59°, and the vector strength is 61 percent. The 95 percent confidence limit for the resultant for this member is 9°.

The resultant vectors for the two members are in almost opposite directions. Paleocurrents for the Lower Livermore were from the northeast towards the southwest, and those for the Upper Livermore were from the southwest towards the northeast, or were diverging radially from the southwest. Two different, opposing drainage paths for the Lower and Upper Livermore are inferred.

Maximum Size of Clasts

Within each measured section, a gradual upward-coarsening sequence occurs (Plate 2). Clast size also differs with geographic location in the basin.

Methods. The B-axis dimension of the single largest clast in outcrop at each sample location was measured. A steel tape was used to measure the diameter of the clast.

Results. The size of the largest clast at each location is shown in Table 2. The maximum clast size in the Lower Livermore Gravels range from 2 cm at sample location #2 at Indian Creek to 7 cm at sample location #8 on Greenville Road. The maximum clast size for the Upper Livermore Gravels range from 3 cm at location #33 at the intersection of Portola and Livermore avenues to 33 cm at location #7 along Calaveras Road. The map showing clast size distribution within the Lower Livermore (fig. 22) indicates a

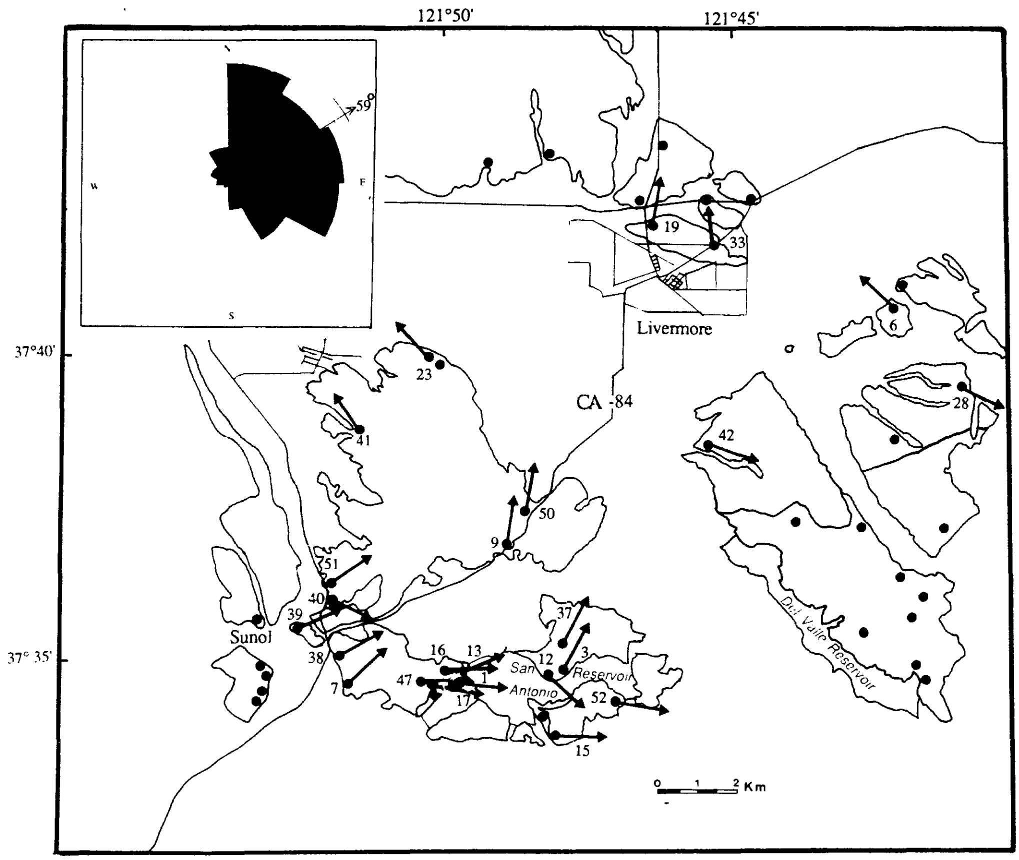


Figure 21. Paleocurrent map of the Upper Livermore Gravels. Each arrow represents resultant vector for an individual sample location. Upper left corner shows a histogram of the 140 individual measurements and the resultant and 95% confidence limits for the Upper Livermore.

TABLE 2. MAXIMUM SIZE OF CLASTS IN THE LIVERMORE GRAVELS

Location Number	Maximum Clast Size (cm)
LOWER LIVERMORE GRAVELS	
2	2
4	4
8	7
10	5
11	3
30	3
31	2
35	5
36	4
43	3
48	3
49	6
UPPER LIVERMORE GRAVELS	
1	8
3	6
6	8
7	33
9	15
12	10
13	18
15	10
16	20
17	18
19	5
22	7
23	7
28	10
33	3
37	7
38	28
39	15
40	18
41	5
42	4
47	13
50	10
51	15
52	6

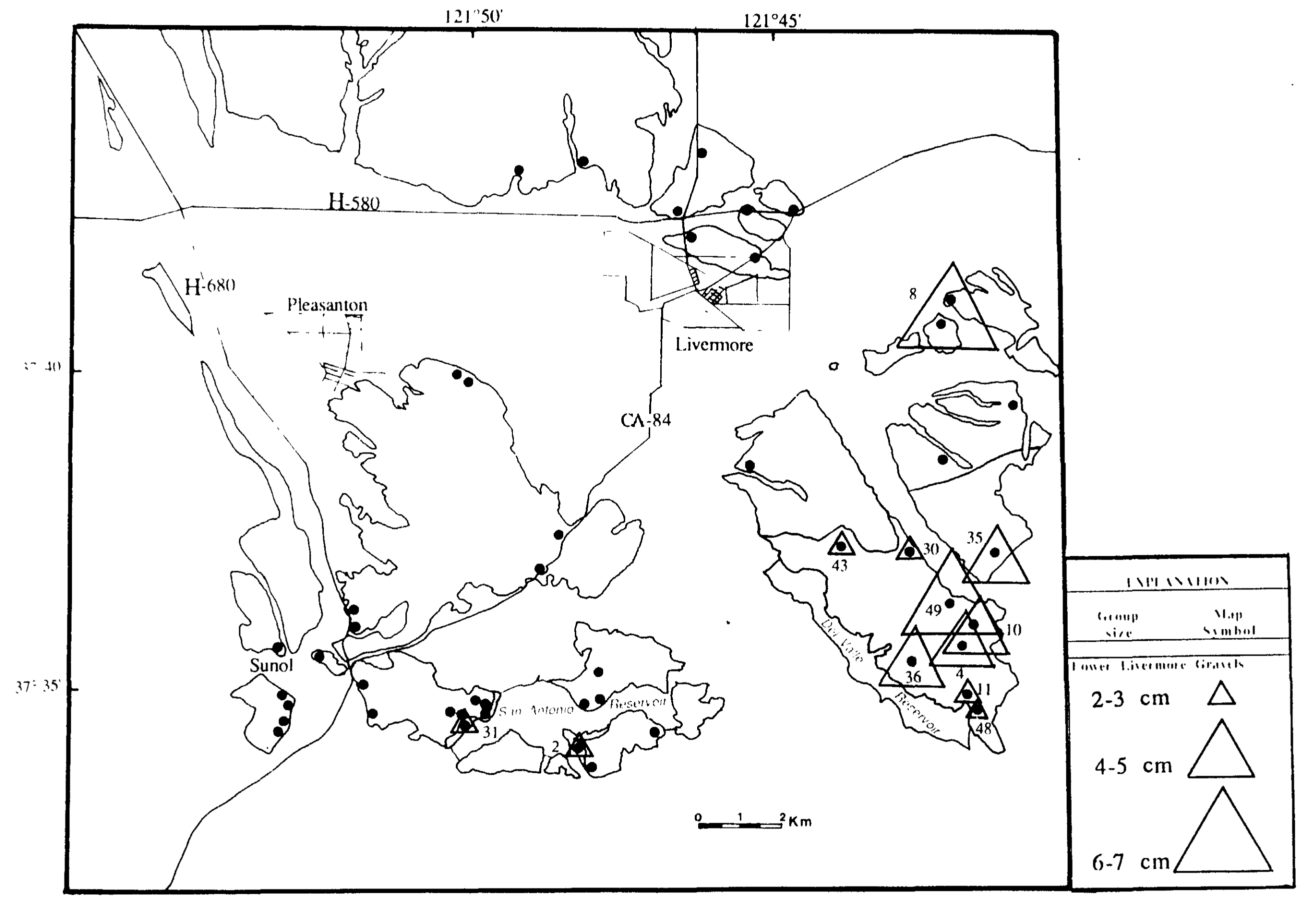


Figure 22. Distribution of maximum clast size in the Lower Livermore Gravels. Size decreases from the area east of Livermore towards San Antonio Reservoir on the south.

decrease in maximum clast size from the northeast towards the southwest. This decrease in clast size is in the same direction as the resultant vector obtained for the Lower Livermore paleocurrents (fig. 20). The map of maximum clast size for the Upper Livermore (fig. 23) illustrates decreasing clast size in several directions. The direction of the dominant trend is from the southwest toward the northeast. This direction also is similar to the resultant vector obtained for the Upper Livermore paleocurrents (fig. 21).

Specific Gravity of Graywacke Clasts

Graywacke occurs in both the Upper and Lower Livermore gravels, but in greater proportions in the Upper. Specific gravity of graywacke clasts from 39 sample locations from the two members was determined.

Methods

For most localities, approximately ten graywacke clasts were analyzed. If fewer than ten clasts were collected at any single location, then all of the graywacke clasts collected were analyzed.

The specific gravities were obtained by using a Mettler balance readable to 0.1 mg. The graywackes were split to samples of approximately 20 g, cleaned with a steel brush, weighed for their dry weight, and weighed submerged in water. Each sample was weighed two or three times in air. The most consistently repeated weight was retained. Samples were then placed into individual bags that were filled with de-ionized water. The samples were left in water overnight to allow trapped air to leave. The deionized water was allowed to equilibrate to room temperature. This was the temperature used to determine the density of water. Wet samples were placed onto a submerged platform that was suspended from the balance and weighed. The submerged weight was measured by this method twice and if agreement between the two measurements was within 10 mg, the

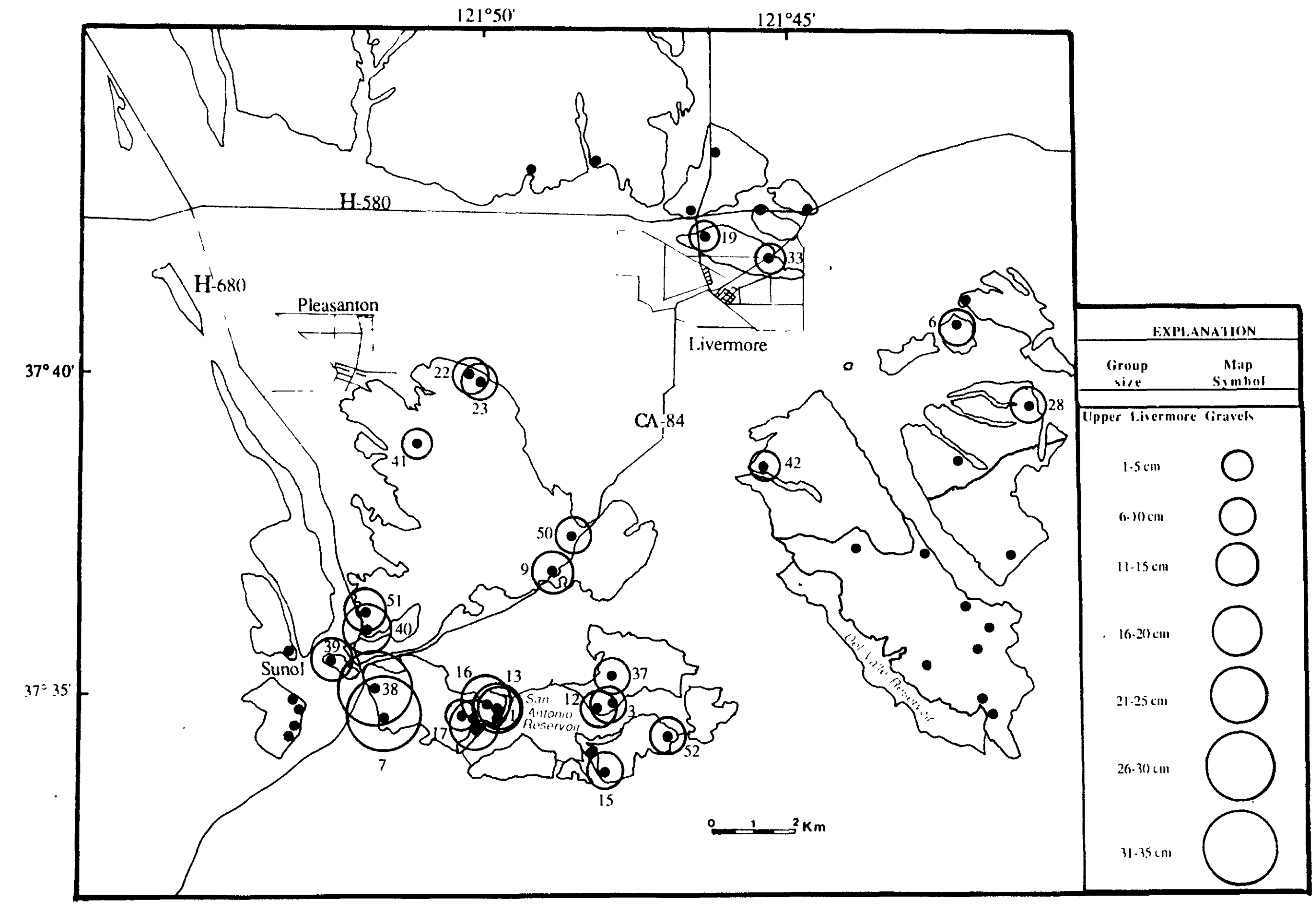


Figure 23. Distribution of maximum clast size of the Upper Livermore Gravels. The decrease in clast size occurs from the Sunol Valley northeast across the city of Livermore and to Pleasanton and Del Valle Reservoir.

average value was used. If not, the sample was measured again. The specific gravity of the sample is calculated using the following formula:

$$\text{SPECIFIC GRAVITY} = \text{Specific gravity of } H_2O \times \frac{\text{Wt-air}}{(\text{Wt-air})-(\text{Wt-water})}$$

The measurements are reproducible to the nearest hundredth.

Results

The specific gravities of all clasts at each sample location are shown in Appendix III. The range in specific gravity for graywackes collected in the Lower Livermore is from 2.62 to 2.81. The range in specific gravity for individual clasts within the Upper Livermore is from 2.51 to 2.77. Individual graywacke clasts within a sample locality have values within about 2 percent of all other clasts at the same locality. The average specific gravities are plotted against the percent of graywacke, measured as a percent of the total clast population (fig. 24).

Samples from the Lower Livermore Gravels have average specific gravities in the range from 2.66 to 2.74, with an average for the entire member of 2.71. The average specific gravity of samples from the Upper Livermore range from 2.60 to 2.69, with an average for the member of 2.66 (fig. 24).

Provenance

Lower Livermore

The Lower Livermore Gravels are characterized by an abundance of sandstone, lithic sandstone, a moderate-gray, fine-grained, vein quartz, and small proportions of graywacke (figs. 6, 7). Lithologically, the sandstone is similar to Tertiary sandstone exposed northeast of the city of Livermore in the area of the

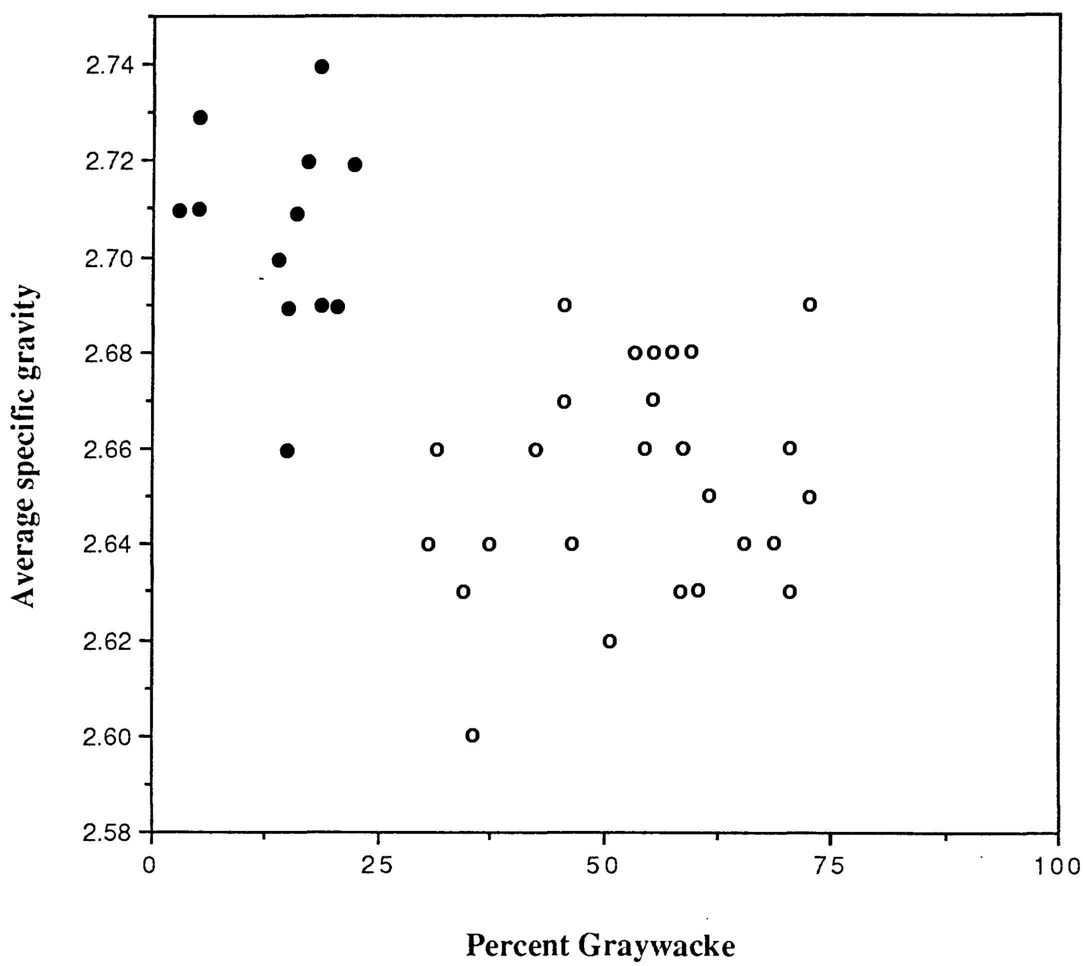


Figure 24. Average specific gravity of graywacke clasts plotted against abundance of graywacke, shown as percent graywacke of total clasts. Lower Livermore is represented by filled circles; Upper Livermore is represented by open circles.

Altamont Hills (fig. 1). However, the fine-grained vein quartz and the graywacke typify the lithologies exposed in the Franciscan Complex of the central Diablo Range to the south (fig. 1). Two differing source areas are inferred.

The resultant vectors from paleocurrent analysis indicate that the dominant flow direction was from the north-northeast (fig. 20), and the maximum-clast-size distribution map indicates a clast-size reduction trend from the northeast towards the southwest (fig. 22). These trends, along with the fact that most of the clasts were derived from Tertiary sandstones (Appendix I) exposed predominantly in the northeast, indicate that the major source for the Lower Livermore was from an area in the northeast.

Similar studies by Isaacson and Andersen (1987) of gravel beds in the middle part of the Miocene Sycamore Formation on the south flank of Mount Diablo (fig. 1) have demonstrated the arrival of reworked andesitic material and clasts of Tertiary sandstone from an uplifted area to the east. Clasts of Franciscan graywacke are present in conglomerates of the Sycamore Formation, but because of sparse clasts of chert and ultramafic rocks the conglomerates do not resemble the Franciscan and ultramafic rocks presently exposed in the core of Mount Diablo (Isaacson and Andersen, 1987). This indicates that Mount Diablo was not exposed in the late Miocene, but that there existed some topographically high source of Tertiary sediment towards the east. The structural feature to the east that is inferred to account for the predominance of Tertiary sandstone clasts contained in both the middle Sycamore Formation and the Lower Livermore is the Altamont Hills anticline.

The results of the specific gravity analysis indicate that the Lower Livermore Gravels contain dense graywacke (fig. 24). The specific gravity of graywackes in the Great Valley Group does not exceed 2.68, and their average specific gravity is 2.57 (Bailey and Irwin, 1959). Franciscan graywackes east of the Hayward fault in the San Francisco Bay area and west of the Hayward fault (coastal belt) average 2.65 and 2.60, respectively. Graywackes with a specific gravity higher than 2.71 are metamorphosed, with plagioclase having been altered to jadeite and lawsonite (Bailey and Irwin, 1959). Jadeite metagraywacke was first reported in the Franciscan Complex by Maddock (1955) in his study of the

Mount Boardman quadrangle. The upper portions of the Franciscan Complex contain graywacke beds with higher specific gravity than the graywacke beds stratigraphically lower in the complex (M.E. Maddock, 1987, personal commun.). A large area of Franciscan graywacke that has been subjected to jadeite metamorphism is located in the central Diablo range from Panoche Valley northward to Livermore (Bailey and others, 1964). Thus, the graywackes in the Lower Livermore must have been derived from the Franciscan because their specific gravity values are similar to the average values obtained by Bailey and others (1964) from those areas hosting Franciscan graywacke, and the values for graywackes from the Great Valley Group are significantly lower than the average values obtained for the Lower Livermore (Appendix III). Therefore, the source for these high-specific-gravity graywackes in the Lower Livermore must be an area hosting Franciscan material. However, the clasts in the Lower Livermore are dominated by a high percentage of Cenozoic sandstone, fine-grained, Franciscan vein quartz, and minor amounts of graywacke (fig. 7). This is not a composition that would result if an area of dominantly Franciscan outcrop had been eroded. Furthermore, the paleocurrent directions (fig. 20) and the distribution of maximum clast size (fig. 22) indicate that the source for the Lower Livermore was to the northeast, an area where the Franciscan Complex is not exposed.

A plausible explanation is that the upper, high-specific-gravity graywacke beds in the Franciscan Complex were exposed and eroded, with the clasts having been carried northward across the basin, then an area of non-deposition, but leaving a veneer of high-specific-gravity graywacke and fine-grained, vein quartz in the area of the present Altamont Hills. Uplift of the Altamont Hills in the northeast caused underlying Tertiary rocks to be eroded and to become the major constituents of the Lower Livermore. The veneer of remnant Franciscan graywacke and fine-grained vein quartz was incorporated with these Tertiary clasts and accounts for the Franciscan contribution to the Lower Livermore.

Isaacson and Andersen (1987) also found evidence that the conglomerate in the lower part of the Sycamore Formation (Miocene) consists of sediment derived from the Mount Hamilton area. The sediment is below the middle conglomerate beds with

Tertiary clasts and reworked Sierran volcanics. This sediment is older than the Lower Livermore Gravels (Isaacson, and Andersen, 1987), which supports the idea that sediment from the south bypassed the Livermore Valley, producing an unconformity, and was available in the north to be reworked southward into the Lower Livermore Gravels.

The combination of clast compositions for the Lower Livermore (Appendix I), paleocurrent directions (fig. 20), the maximum clast size distribution (fig. 22), and the specific gravity data (fig. 24), indicate that the provenance for the Lower Livermore was the Altamont Hills to the northeast.

Upper Livermore

The Upper Livermore Gravels contain abundant Franciscan graywacke, altered volcanics, metamorphic clasts, variously colored cherts, and a few percent lithic sandstones (Appendix I). Compared with the Lower Livermore Gravels, the abundance of metamorphic clasts and the high proportion of graywacke with low-specific-gravity (fig. 24) indicate deeper incision and erosion of a Franciscan source area for the Upper Livermore Gravels. Franciscan material is present in several locations near the study area, including Mount Diablo, areas formerly west of the Berkeley Hills that have been displaced northward along the Hayward Fault, and Mount Hamilton.

Mount Diablo is not a likely candidate for a source area because results from a similar study of clast composition to the north have indicated that the Franciscan detritus in conglomerates is unlike the Franciscan and ultramafic rocks presently exposed on Mount Diablo. This indicates that the Mount Diablo antiform was not a source for the Franciscan debris in the Upper Livermore (Isaacson and Andersen, 1987).

Investigations of clast composition by Graham and others (1984) of similar material in the Berkeley Hills near the Caldecott tunnel suggest that areas west of the Berkeley Hills (fig. 1) are not a likely source for the clasts contained in the Upper Livermore, because clasts include chert and porcelanite derived from the Monterey Formation, and high concentrations of blueschist. This composition is very different from that obtained for the Upper Livermore.

The combination of clast compositions for the Upper Livermore (Appendix I), paleocurrent directions (fig. 21), the maximum clast size distribution (fig. 23), and the specific gravity data (fig. 24) indicate that the source area for the Upper Livermore is the central Diablo Range.

Age

Lower Livermore

Fossils. The earliest mention of fossils from the Livermore Gravels was by Branner (1912), who found fossils of fresh-water invertebrates 10 m above the base of the gravels at Cuesta Blanca on Arroyo Valle Road. No list or age of the assemblage was given.

Stirton (1939) noted the remains of *Pliohippus*, early Hemphillian in age, collected by Toleman from 225 feet (69 m) underground at the Indian Creek excavation for the Hetch Hetchy tunnel. Because the Neroly Formation is exposed at the entrance of the tunnel, the fossils may have been collected from within the Neroly or near the base of the Lower Livermore Gravels.

Herd and Brabb (1980) described a locality (M-1145, Plate 2), located along the banks of San Antonio reservoir, that contains *Equus dolichohippus*, which is Hemphillian to early Irvingtonian in age. This fossil could occur in rocks anywhere in the range from 4.5 to 1.2 Ma.

Locality M-1431 of Herd and Brabb (1980), which is located 30 feet (9 m) above a tuff bed in the Del Valle measured section (Plate 2), contains dentary fossil fragments from *Hypolagus limnetus*. This fossil is Blancan III (mid Blancan) in age, and a possible range of 3.7 to 3.4 Ma was suggested (Herd and Brabb, 1980). Repenning (1987) suggested that the Blancan III mammal age ranges from 3.7 to 3.0 Ma.

Locality M-1432 of Herd and Brabb (1980), 200 feet (60 m) above the tuff bed at the surface measured stratigraphic section of Del Valle (Plate 2), contains *Hypolagus* sp. cf. *H. furlongi*, believed to be of Blancan V (late Blancan) age (Herd and Brabb, 1980). An age range between 2.5 and 1.8 Ma was suggested. Herd and Brabb (1980) mentioned that the record of *Hypolagus* is poor but that the genus is almost exclusively Pliocene, from Hemphillian to Blancan in age.

Radiometric Ages. A K/Ar age of 4.5 ± 0.5 Ma was reported by Sarna-Wojcicki (1976) for a water-laid tuff about 150 m above the base of the formation in the Del Valle measured section (Plate 2). Geochemical analysis indicated a correlation of the tuff with the Lawlor Tuff, K/Ar dated at 3.96 ± 0.16 Ma (Sarna-Wojcicki, 1976). The best estimate for the time of deposition of the tuff at Del Valle probably is about 4 Ma.

Age of Base. At Del Valle, the base of the Lower Livermore is unconformable on the Franciscan Complex, and the Lawlor tuff occurs approximately 150 m above the unconformity. Approximately one third of the measured section lies beneath this K/Ar dated tuff (Plate 2). It is unclear how long it took for this Lower Livermore detritus to be deposited, but a significant amount of time is inferred.

The Pinole tuff is not recognized on the south side of the Livermore Valley, but it is on the north (Sarna-Wojcicki, 1976) in strata assigned to the Sycamore Formation. Below the Pinole tuff in the north, Isaacson and Andersen (1987) reported detritus inferred to be derived from the Mount Hamilton area, a southern source. This lithofacies is unlike the material in the Lower Livermore. Because the source of this part of the Sycamore is south of the Livermore Valley, it is inferred to be older than the Livermore Gravels. The age of the Sycamore lithofacies is bracketed by the underlying Blackhawk fauna, which is middle Hemphillian and suggested to be 8 Ma (Savage, 1951), and the overlying Pinole tuff, at 5.2 Ma (Sarna-Wojcicki, 1976). This was a time of erosion and sediment bypassing in the south and a time of deposition in the north. Evidence for non-deposition in the south is supported by the existence of a major unconformity between the Lower Livermore and the underlying Franciscan Complex and

Cenozoic sandstones. Therefore, it is suggested that the basal Livermore is no older than late Hemphillian (about 5 Ma) in age.

Age of Unit. The fossil and radiometric ages suggest that the lower Livermore could range in age from late Hemphillian to middle or late Blancan. The material comprising the Lower Livermore is suggested to be Pliocene in age, and probably was deposited between about 5.0 and 2.5 Ma.

Upper Livermore

Fossils. The number of fossil localities in these coarse-grained rocks is limited. Locality M-1442 of Herd and Brabb (1980), along California Highway 84 (Plates 1, 2) contains fossils similar to those of the Hagerman fauna of Idaho, believed to represent a Blancan III (mid Blancan) age (Herd and Brabb, 1980). The Hagerman fauna has been estimated to have an age of 3.7 to 3.3 Ma (Herd and Brabb, 1980). The youngest records for two fossils within the assemblage are Blancan in age, with an age as young as 2.6 Ma suggested for *Hypolagus vetus*, and a range of 3.8 to 2.5 Ma for *Hypolagus limnetus*. A Blancan age, within the range from 3.8 to 2.5 Ma, is suggested for the Livermore locality (Herd and Brabb, 1980).

Locality M-1441 of Herd and Brabb (1980), within the Upper Livermore along north Livermore Avenue (Plate 1), is host to an assemblage of young fossils, all of which are very young except for *Neodon meadensis*. *Neodon* is a microtine rodent that is now extinct. The oldest date obtained for *Neodon* is from the Cudahy fauna of Kansas. That faunal assemblage, which includes *Neodon*, is located at the base of a 600,000 year old volcanic ash. An invasion of microtine rodents into the United States around 450,000 years ago is believed to be the cause for *Neodon's* annihilation. These constraints suggest that the north Livermore fauna is between 600,000 and 450,000 years old (Herd and Brabb, 1980), an age of late Irvingtonian (Repenning, 1987).

Savage (1951) reported an assemblage of vertebrate fossils (V-4901) located in an excavation for Interstate Highway 580, near Livermore and location 20 (Plate 1). Four of the five fossils are of Blancan age, and the fifth fossil, *Bison*, suggests a Rancholabrean age. The fossil assemblage was inferred to be present in the Livermore Gravels (Savage, 1951) and was assigned an age of Pleistocene by Herd and Brabb (1980). Clasts from location 20 (figs. 6, 7) indicate that the area is composed of material similar to that of the Tassajara Formation and not the Livermore Gravels, so this fossil assemblage should be considered to be from the Tassajara Formation (Plate 1).

Radiometric Ages. Herd and Brabb (1980), using soil and oxygen isotope stage correlations developed by Shlemon and others (1980), inferred that the oldest terrace deposits unconformably overlying the Upper Livermore may be 300,000 to 350,000 years old.

Age of Base. The age at the base of the Upper Livermore is constrained by the oldest fossil locality contained in the Upper Livermore and the youngest dates suggested for the Lower Livermore. Fossil locality M-1442, assigned a Blancan age (3.8 to 2.5 Ma), occurs within rocks of the Upper Livermore. The youngest location in the Lower Livermore is at San Antonio Reservoir and is Blancan in age, with the range suggested to be 4.5 to 1.2 Ma. At Del Valle, the youngest range for the Lower Livermore also is late Blancan, 2.5 to 1.8 Ma. The mammal ages suggest that the base of the Upper Livermore is middle to late Blancan in age and probably is no older than about 2.5 Ma.

Age of the Top. The age for the top of the Upper Livermore is constrained by the dates imposed for the youngest fossils in the Upper Livermore at fossil locality M-1441, probably no younger than 450,000 years old, and the oldest date obtained from alluvial terraces unconformably overlying the Upper Livermore, probably at least 300,000 years old. Thus the top of the Upper Livermore gravels is probably about 450,000 years old.

Age of Unit. Material comprising the Upper Livermore was deposited between middle Blancan and middle Irvingtonian time. An age range of Pliocene to Pleistocene, possibly 2.5 to 0.45 Ma, is suggested.

Contact Between The Members

Observations

The contact between the Lower and Upper Livermore is in places unconformable, and in other locations the contact is placed within a gradational stratigraphic sequence.

At the Indian Creek measured section, the compositions of clasts collected from the gravel and underlying pebble beds are noticeably different (fig. 7). The thick-bedded, coarse sandstone and pebble to cobble gravel of location #15 overlies thin-bedded, coarse sandstone and interlayered pebble gravel of location #2 and a subtle angular relationship is suggested by the map pattern (Plate 1). The maximum clast size is substantially larger in the Upper Livermore than in the Lower Livermore (Table 2). The paleocurrent directions are also dissimilar (Table 1). From the evidence in the outcrop, the contact was placed at the base of the cobble gravel bed (Plate 2).

Along the northwest slope of San Antonio Reservoir between locations #17 and #31, the contact was also placed at the erosional base of a gravel bed that overlies thinly bedded sandstone and siltstone. As at Indian Creek, clast compositions at these two sample locations also are noticeably different (fig. 7). The contact here is inferred to be unconformable.

Elsewhere, the transition is found to occur within gradational sequences. One such gradational sequence has been measured at San Antonio Reservoir (Plate 2). At location #1 the clast composition is intermediate between typical Lower Livermore Gravel and typical Upper Livermore Gravel (figs. 6, 7), and the maximum clast size is significantly lower than most measurements in the Upper Livermore (Table 2). The ratio of sandstone to gravel is much greater than at the Calaveras measured section, and the beds are thinner and laterally more extensive than at Calaveras Road (Plate 2). The compositions and paleocurrent trends obtained several tens of meters above and below location #1 (locations #16 and #31) are Upper and Lower Livermore, respectively (fig. 6, table 1). The gravel compositions show that there is no interfingering of Upper and Lower Livermore Gravels in this area.

In the Del Valle measured section, the contact between the two members is not exposed. All the gravel beds analyzed within this section have been determined to be the Lower Livermore (fig. 7).

Interpretations

The contact between the two members is unconformable from Calaveras Road eastward along portions of the northwest slopes of San Antonio Reservoir (Plate 1). These deposits occur only in material of the Upper Livermore and are inferred to be in the proximal area of an alluvial fan complex.

At location #1, in the San Antonio Reservoir measured section, downstream from the proximal area, intermediate clast compositions indicate an area of sediment mixing. Sediment from two geometrically opposed source areas was mixed in the medial to distal parts of the fan. Detritus from the Altamont Hills was incorporated with sediment from the central Diablo Range, thus accounting for the intermediate clast composition (fig. 6). A contact developed by intertonguing, although possible, has not been seen. Therefore, within a gradational sequence, the contact was placed at the base of the gravel bed with a clast composition that is more typical of the Upper Livermore (figs. 6, 7).

At Del Valle where there is no Upper Livermore it is inferred that it has been either removed by erosion, or a portion of the region was isolated from the prograding fan by a topographic high at Rocky Ridge to the west (Plate 1).

GEOLOGIC HISTORY

Tectonic Events Prior To 5.0 Ma

Beginning approximately 13 Ma, uplift west of the Hayward fault, near the present location of Berkeley, formed a clastic wedge that shed detritus from a recycled subduction complex and older forearc basin eastward (Graham and others, 1984). At this time, Sierran volcaniclastic sediment was shed westward and now crops out in the northeast Diablo Range as the Neroly Formation, which is mostly marine in the Mount Diablo area, but is nonmarine farther south (Bartow, 1987).

Evidence of continued tectonic uplift south of Livermore Valley is preserved in the Carbona Formation. Bartow (1987) has demonstrated through the preservation of an unroofing sequence that the central Diablo Range was being uplifted around 10 Ma.

Marine deposition of Sierran detritus in the region south of present day Mount Diablo (fig. 1) gave way to dominantly fluvial deposition of Coast Range detritus composed of rocks eroded from the central Diablo Range. These sediments were shed northward across the Livermore Valley and are now preserved as conglomerate in the lower portions of the Sycamore Formation above the Blackhawk fauna and below the Pinole Tuff (Isaacson and Andersen, 1987) This terrigenous detritus crossed the Livermore region and represents a period of sediment bypass from the south, producing the unconformity between the Livermore Gravels and the underlying Cenozoic rocks. Remnant high-specific-gravity Franciscan graywacke and its fine-grained vein quartz was left behind as a thin veneer on top of the eroded Briones Sandstone and Neroly Formation.

Between 8 and 7 Ma, the Mullholand Formation was deposited in the Contra Costa basin north of Livermore Valley (fig. 1) and is composed of estuarine, lacustrine and fluvial sediments (Liniecki and Andersen, 1988). The presence of estuarine ostracodes, and the lack of Sierran material in the basal members of the formation, indicate that this area was near sea level and that some topographic barrier existed to the east. Perkins (1987) demonstrated that this barrier diverted large proportions of Sierran volcanics southward to the Etchegoin Formation.

Thus, an elevated terrain west of the Sierran arc and east of the Berkeley Hills diverted streams southward (Perkins, 1987) and prevented the influx of Sierran material into the Contra Costa basin (Liniecki and Andersen, 1988). With uplift of this barrier, Tertiary sediments were eroded and deposited in the northern Livermore basin approximately 7 Ma (Isaacson and Andersen, 1987). This material reached the southern Livermore basin around 5.0 Ma. This uplifted terrain is in the area presently occupied by the Altamont Hills. Thus, stresses generated after the passage of the Mendocino triple junction (Graham and others, 1984) influenced the areas as far inland as the Altamont Hills by about 5.0 Ma.

Events Between 5.0 and 2.5 Ma

Preservation of reworked Tertiary rocks in the Lower Livermore, beneath and overlying the Lawlor tuff (4.0 Ma, Sarna-Wojcicki, 1976), have yielded paleocurrent directions and sedimentary sequences, which record the erosion and transportation of Tertiary material from the northeast into the southern Livermore basin by sand-dominated braided streams as a result of uplift in the Altamont Hills.

Tectonic Conditions Since 2.5 Ma

Gravel beds distinctly different with respect to clast composition (figs. 6, 7) and specific gravity (fig. 24), and abrupt changes in paleocurrent direction between the Lower Livermore and the Upper Livermore, which document a major sediment stream reversal, indicate the uplift of the central Diablo Range. A clastic wedge of Franciscan debris was shed northeastward off the flanks of Mount Hamilton out into the Livermore basin over the sediments of the Lower Livermore.

The uplift of Mount Hamilton occurred at 2.5 Ma. This coincides with the change in relative motion of the Pacific and Antarctic plates between magnetic chrons 2A and 3, approximately 2.5 to 3.0 Ma (Harbert and Cox, 1986). The stresses initiated by this tectonic reorganization event affected the inland Livermore basin.

The result of such stress was a major sediment stream reversal and the production of a different depositional environment. Preservation of predominant gravel bar sequences and matrix-supported, cobble to boulder gravel in the Upper Livermore record the development of an alluvial fan complex by Scott type braided streams and debris flows, which transported Franciscan detritus northward over the Lower Livermore

The basin has been filled with continental detritus since the late Miocene and it continues to be filled with sediment today. Since deposition of the Livermore Gravels, deformation has synclinally warped the gravels and tilted recent terrace deposits up to 10 ° (Herd, 1977). This indicates that deformation of the basin margins has continued in response to continuing compression along this active plate margin.

CONCLUSIONS

Detailed studies of the composition of clasts in gravels in the Livermore region have allowed the distinction between various gravel units, specifically within the Livermore Gravels. The Livermore Gravels have been divided into two parts.

Composition of Lower Livermore clasts is characterized by an abundance of Tertiary sandstone, fine-grained vein quartz, and a small percentage of graywacke with an average specific gravity of 2.71. The Lower Livermore is composed of abundant planar cross-bedded sandstone that represents multistory transverse bars. Finely laminated and variegated siltstone and mudstone are overbank and small pond deposits. B-axis imbricated, horizontally stratified gravel indicates the development of rare longitudinal bars. The high ratio of sandstone to gravel indicates that the Lower Livermore developed under continental fluvial conditions within and adjacent to a Platte type braided steam system. Paleocurrents indicate that the braided streams flowed from the northeast to the southwest. Constraints imposed by fossil and radiometric age data indicate that the Lower Livermore is Miocene to Pliocene in age and was probably deposited between 5.0 and 2.5 Ma.

Clasts in the Upper Livermore include abundant graywacke with subordinate amounts of fine-grained vein quartz, sandstone, volcanics, and metamorphics. The Upper Livermore is composed of abundant horizontally bedded gravel cosets, and very little sandstone. The cosets indicate deposition by longitudinal bar processes. The Upper Livermore was deposited by Scott type braided streams on an alluvial fan. Unconformable contacts are seen in the proximal part of the fan. In the distal portions of the fan the contact has been placed within gradational sequences. These sequences indicate areas of sediment mixing.

Paleocurrent directions and variations in clast size indicate that the streams in the Upper Livermore flowed from the southwest. The average specific gravity of graywacke in the Upper Livermore is 2.66. The source for the clasts contained in the Upper Livermore is in the area of Mount Hamilton. Fossils and radiometric age data for the Upper Livermore suggest an age range of Pliocene to Pleistocene, 2.5 to 0.45 Ma.

The Livermore Gravels record uplift in the central Coast Ranges. Uplift of the Altamont Hills (8 to 7 Ma) probably developed as the result of stresses associated with the passage of the Mendocino triple junction. Approximately 2.5 Ma, uplift of the central Diablo Range produced the major sediment stream reversal between the two members. The timing of this event coincides with the reorganization of the Pacific-Antarctic plates, approximately 2.5 to 3.0 Ma. Evidence of continued stress is seen by the synclinally warped Livermore Gravels and recent terrace deposits.

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APPENDIX I: CLAST COMPOSITION

SampleNumbers	1	2	3	4	5	6	7
METAMORPHIC ROCKS							
All types		2	2	3		4	3
PLUTONIC ROCKS							
Granite	1				1	2	
Diorite							
Gabbro							
VOLCANIC ROCKS							
Rhyolite	10		2		30	6	6
Andesite	3				17	4	6
Basalt					6	2	1
TERRIGENOUS SEDIMENTARY ROCKS							
Sandstone		20	5	43	1	13	
Lithic Sandstone	15	24	15	17			8
Greywacke	39	15	71	22	7	33	53
Siltstone		2					
Mudstone	1	1					
CHERTS							
Pale yellow					5		
Light red							
Black	4						
Moderate brown	2					1	
Grayish green	5		2	7		5	
Red-banded		2	1	4		2	
Moderate green				2			
Black-white-banded							
VEIN QUARTZ							
Coarse-grained white quartz		2		4	3	4	2
Fine-grained gray quartz	12	31	12	25		17	16
TOTALS	**92**	**99**	**110**	**127**	**70**	**93**	**95**
Total Metamorphic	0	2	2	3	0	4	3
Total Plutonic	1	0	0	0	1	2	0
Total Volcanic	13	0	2	0	53	12	13
Total Terrigenous	55	62	91	82	8	46	61
Total Chert	11	2	3	13	5	8	0
Total Vein Quartz	12	33	12	29	3	21	18

Note *= Sample collected outside of study region

CLAST COMPOSITION continued

SampleNumbers	**8**	**9**	**10**	**11**	**12**	**13**	**14***	**15**
METAMORPHIC ROCKS								
All types		1	6	3		2	2	1
PLUTONIC ROCKS								
Granite		3			1			
Diorite		1				3	4	3
Gabbro							4	
VOLCANIC ROCKS								
Rhyolite		4	3	2	8		1	
Andesite	1	9			1	1	2	
Basalt		2						
TERRIGENOUS SEDIMENTARY ROCKS								
Sandstone	18	12	1			5	3	1
Lithic Sandstone	15		30	36	12	7	15	10
Greywacke	22	59	11	12	44	59	47	72
Siltstone	2		4	4	5	7	2	13
Mudstone						1		1
CHERTS								
Pale yellow								
Light red	1							
Black		1	2	1	7	2	1	
Moderate brown	1	2	3				2	1
Grayish green	5	6		1	1	4	1	
Red-banded	4	2	2		3	2	4	
Moderate green								
Black-white-banded								
Coarse-grained white quartz	6		1		2			
Fine-grained gray quartz	39	6	16	23	11	4	14	1
TOTALS	**114**	**108**	**79**	**82**	**95**	**97**	**102**	**103**
Total Metamorphic	0	1	6	3	0	2	2	1
Total Plutonic	0	4	0	0	1	3	8	3
Total Volcanic	1	15	3	2	9	1	3	0
Total Terrigenous	57	71	46	52	61	79	67	97
Total Chert	11	11	7	2	11	8	8	1
Total Vein Quartz	45	6	17	23	13	4	14	1

Note *= Sample collected outside of study region

CLAST COMPOSITION continued

SampleNumbers	16	17	18	19	20	21	22	23
METAMORPHIC ROCKS								
All types	2			1	6	1	1	
PLUTONIC ROCKS								
Granite				1	1		2	
Diorite	2			3	2		3	2
Gabbro								
VOLCANIC ROCKS								
Rhyolite	8	1	14		3	1		
Andesite			16		7	4		
Basalt	1		1	4	2	1	4	4
TERRIGENOUS SEDIMENTARY ROCKS								
Sandstone	5			13	2	8	6	4
Lithic Sandstone	16	9	8	2		7	2	6
Greywacke	50	58	12	35	18	68	15	23
Siltstone	16	7		2	1	6		1
Mudstone	1				1	2	3	1
CHERTS								
Pale yellow					10		1	
Light red				1	7			
Black	3		4	3	6			
Moderate brown		1	2		8	3		
Grayish green	1		8	10	5	3	3	3
Red-banded	3	1			14		1	1
Moderate green			12	3	2		2	
Black-white-banded				2				
Coarse-grained white quartz	1	1		6	6			
Fine-grained gray quartz	2	3		18	11	12	6	6
TOTALS	**111**	**81**	**77**	**104**	**112**	**116**	**49**	**51**
Total Metamorphic	2	0	0	1	6	1	1	0
Total Plutonic	2	0	0	4	3	0	5	2
Total Volcanic	9	1	31	4	12	6	4	4
Total Terrigenous	88	74	20	52	22	91	26	35
Total Chert	7	2	26	19	52	6	7	4
Total Vein Quartz	3	4	0	24	17	12	6	6

Note *= Sample collected outside of study region

CLAST COMPOSITION continued

Sample Numbers	24	25	26	27	28	29*	30	31	32*
METAMORPHIC ROCKS									
All types					1	2			2
PLUTONIC ROCKS									
Granite	1	1						3	4
Diorite			6						4
Gabbro									
VOLCANIC ROCKS									
Rhyolite				1	1			3	29
Andesite				1				9	17
Basalt					1			3	5
TERRIGENOUS SEDIMENTARY ROCKS									
Sandstone	2	3	2	6	2	5	75	8	
Lithic Sandstone	14	14	23	18	7	5	2	38	7
Greywacke	25	27	25	29	60	57	4	23	14
Siltstone	3			5	5		3	2	
Mudstone	1			1			1	1	
CHERTS									
Pale yellow									
Light red				1		1	1		
Black						2	4		6
Moderate brown							1	4	
Grayish green	2	3		1		5	3		2
Red-banded			1		3	7	3		
Moderate green						2			
Black-white-banded									
Coarse-grained white quartz					1	1	1	4	3
Fine-grained gray quartz			5	3	2	10	50	20	7
TOTALS	**48**	**48**	**62**	**66**	**83**	**97**	**148**	**118**	**100**
Total Metamorphic	0	0	0	0	1	2	0	0	2
Total Plutonic	1	1	6	0	0	0	0	3	8
Total Volcanic	0	0	0	2	2	0	0	15	51
Total Terrigenous	45	44	50	59	74	67	85	72	21
Total Chert	2	3	1	2	3	17	12	4	8
Total Vein Quartz	0	0	5	3	3	11	51	24	10

Note *= Sample collected outside of study region

CLAST COMPOSITION continued

SampleNumber	33	34	35	36	37	38	39	40	41
METAMORPHIC ROCKS									
All types	1		4	4	2	4	2	1	2
PLUTONIC ROCKS									
Granite	2						1	2	4
Diorite									4
Gabbro									
VOLCANIC ROCKS									
Rhyolite				3		5	4	4	
Andesite	2	2			2	7	2	1	
Basalt						1	3	2	10
TERRIGENOUS SEDIMENTARY ROCKS									
Sandstone	9	2	10	5	5			1	12
Lithic Sandstone	4	7	12	32	15	9	10	12	4
Greywacke	37	71	13	18	60	58	55	59	30
Siltstone	2	7		4	3				
Mudstone									
CHERTS									
Pale yellow									
Light red	2								
Black	2	1		3					
Moderate brown	1			2			3	1	
Grayish green	12		7		3		1		10
Red-banded		3	3	2	1				4
Moderate green	2		3			1			2
Black-white-banded									
Coarse-grained white quartz	6	4	4	1		3	5	4	
Fine-grained gray quartz	18	23	25	18	12	19	15	17	17
TOTALS	**100**	**120**	**81**	**92**	**103**	**107**	**101**	**104**	**99**
Total Metamorphic	1	0	4	4	2	4	2	1	2
Total Plutonic	2	0	0	0	0	0	1	2	8
Total Volcanic	2	2	0	3	2	13	9	7	10
Total Terrigenous	52	87	35	59	83	67	65	72	46
Total Chert	19	4	13	7	4	1	4	1	16
Total Vein Quartz	24	27	29	19	12	22	20	21	17

Note *= Sampe collected outside of study region

CLAST COMPOSITION continued

SampleNumber	42	43	44	45	46	47	48	49	50
METAMORPHIC ROCKS									
All types			5				3	2	3
PLUTONIC ROCKS									
Granite		1	4		1				5
Diorite									
Gabbro									
VOLCANIC ROCKS									
Rhyolite			10	10	47	4	2		7
Andesite	1		2	22					6
Basalt	1			1	6				
TERRIGENOUS SEDIMENTARY ROCKS									
Sandstone	2	20						8	
Lithic Sandstone	7	45	3	9	1	9	35	52	16
Greywacke	60	7	8	17	7	60	22	7	65
Siltstone	5	4	1			7	7	8	
Mudstone		1	2					2	
CHERTS									
Pale yellow									
Light red	1		1		13			1	
Black	2	5	7	4	13		1	4	8
Moderate brown	1	1	10	2		2	7	1	1
Grayish green	2	3	5	8	7		3	3	1
Red-banded		3	14	2		1		4	4
Moderate green		1	3				1	1	
Black-white-banded									
Coarse-grained white quartz	1	1			7	1		2	3
Fine-grained gray quartz	3	50	11	12	2	4	19	50	12
TOTALS	**86**	**142**	**86**	**87**	**104**	**88**	**100**	**145**	**131**
Total Metamorphic	0	0	5	0	0	0	3	2	3
Total Plutonic	0	1	4	0	1	0	0	0	5
Total Volcanic	2	0	12	33	53	4	2	0	13
Total Terrigenous	74	77	14	26	8	76	64	77	81
Total Chert	6	13	40	16	33	3	12	14	14
Total Vein Quartz	4	51	11	12	9	5	19	52	15

Note *= Sample collected outside of study region

CLAST COMPOSITION continued

Sample Number	51	52
METAMORPHIC ROCKS		
All types	3	
PLUTONIC ROCKS		
Granite	3	1
Diorite		
Gabbro		
VOLCANIC ROCKS		
Rhyolite		6
Andesite	1	3
Basalt		
TERRIGENOUS SEDIMENTARY ROCKS		
Sandstone	5	2
Lithic Sandstone	7	10
Greywacke	59	44
Siltstone	7	5
Mudstone	1	
CHERTS		
Pale yellow		
Light red		
Black	2	7
Moderate brown	4	
Grayish green	2	1
Red-banded		3
Moderate green		1
Black-white-banded		
Coarse-grained white quartz		3
Fine-grained gray quartz	4	11
TOTALS	**98**	**97**
Total Metamorphic	3	0
Total Plutonic	3	1
Total Volcanic	1	9
Total Terrigenous	79	61
Total Chert	8	12
Total Vein Quartz	4	14

APPENDIX II: MEASURED SECTIONS

Section 1- Calaveras and 680,
Alameda County, California
T4S, R1E

The section was measured along the south facing cliff within a gully perpendicular to the Calaveras Road. Base of the section is located approximately 915 m south of the intersection of Calaveras Road and Interstate 680 and at the intersection of three bearings taken from Bench Marks (BM) in the area. BM 274- N20°E, BM 323- S19°W, and BM 544- S20°E, located in the La Costa Valley 7 1/2 minute quadrangle, California. Strike and dip are N62°W 5°NE.

Unit	Description	Thickness (Equivalents) Meters	Feet
	Top of section: Modern soil, vegetated, sandy.		
	Upper Livermore: (Pliocene and Pleistocene)		
4.	Gravel, moderate-reddish-brown, medium-scale, moderate to high-angle, planar cross-beds, cobble to pebble, poorly sorted, moderately indurated; consists of a sandy-siltstone matrix, locally slumped.	4.5	15.0
3.	Gravel, moderate-brown, large-scale, horizontally bedded sets; composed of well imbricated, poorly sorted, subrounded, boulder to cobble size clasts of phyllite, blueschist, altered volcanic, chert, graywacke and lithic sandstone clasts. Maximum clast size is 33 cm. Contact with unit 4 is gradational. (location # 7)	1.0	3.5
2.	Gravel, light-brown, medium-scale, horizontally bedded sets, indistinct and graded bedding, cobble to pebble, poorly sorted, subangular; interbedded with sandstone, light-brown, medium-scale, planar cross-sets, coarse-grained, moderately sorted, subangular, friable; consists of a heterogeneous mixture of quartz, chlorite and abundant mica,		

siliceous, Contact with unit 3 is unconformable.		
	6.1	20.0
1. Heavily vegetated from the intermittent stream up to break in slope 34 m up section. Contact with unit 2 is unconformable.		
	34.1	112.0
Partial thickness of Upper Livermore Gravels at Calaveras and 680 Measured Section		
	45.7	151.8

Section 2- Highway 84
Alameda County, California.
T4S, R1E.

This section was measured along the south facing road cut of Highway 84, 3 km northeast of the entrance to the Vallecitos Atomic Laboratory. The measured section begins at the intersection of two Bench Mark (BM) bearings. BM 789- N49°E, BM 747- N49°W. Located in the La Costa Valley 7 1/2 minute quadrangle, California.
Strike and Dip are N85°E 20°NW.

Unit	Description	Thickness (Equivalents) Meters	Feet
Top of section:	Modern soil, pebbly and sandy.		
Upper Livermore:	(Pliocene and Pleistocene)		
4.	Siltstone, reddish-brown, indistinctly bedded, friable; interlayered with sandstone, reddish-brown, indistinctly bedded to planar cross-bedded, coarse-grained, moderately sorted, subangular, siliceous, friable; with lenses and individual strata composed of pebble size metamorphic, altered volcanic, chert, and graywacke clasts.	7.9	26.0
3.	Gravel, dark-yellowish-brown to moderate-reddish-brown, large-scale, planar cross-bedded, cobble to boulder size clasts, subrounded, poorly sorted, moderately indurated, well imbricated; consists of altered volcanic and metamorphic rocks and abundant graywacke. Matrix of coarse sand. Maximum clast size 15 cm. (location #9)	4.6	15.0
2.	Gravel, moderate-yellowish-brown to dusky-red, medium-scale, planar bedded sets, pebble to cobble size, subrounded, moderately sorted, moderately indurated; consists of altered volcanic, metamorphic, chert, and graywacke clasts; interbedded with sandstone, yellowish-brown, medium-scale, planar cross-bedded, coarse grained, moderately sorted, subrounded,		

	siliceous, moderately indurated; interbedded with siltstone, dark-brown, friable laterally discontinuous. Fossil locality (M-1442) *Hypolagus limnetus* 3.8 to 2.6 Ma (Herd and Brabb, 1980). Contact with unit 3 is unconformable.	18.3	60.0
1.	Gravel, pale-yellowish-brown to pale-reddish-brown, horizontally bedded; interlayered with sandstone, reddish-brown, planar bedded, coarse-grained; interbedded with siltstone, pale-brown, thinly bedded and laterally discontinuous. Contact with unit 2 is unconformable.	19.0	62.0
Partial thickness of Upper Livermore Gravels at Highway 84 Measured Section		49.8	163.0

Section 3: San Antonio Reservoir Section,
Alameda County, California
T4S, R1E.

This section was measured along the south facing slope of the north side of San Antonio Reservoir 1.6 km northeast of the north end of the James H. Turner Dam. The measured section begins at the shoreline of the reservoir at the intersection of three Bench Mark (BM) bearings. BM 323- S60°E, BM 299- N47°E, and BM 1792- N54°E. Located in the La Costa Valley 7 1/2 minute quadrangle, California.
Strike and dip are N48°E 15°NW.

Unit	Description	Thickness (Equivalents) Meters	Feet
	Top of section: Modern soil, sandy		
	Upper Livermore: (Pliocene and Pleistocene)		
11.	Gravel, moderate-reddish-brown, medium-scale, low-angle, planar cross-beds, cobble and pebble in size, moderate to poorly sorted, sub angular, well imbricated, clast-supported; composed of graywacke, metamorphic, and altered volcanic clasts, 4-20 cm in diameter. Contact is with modern soil. (location #16)	1.7	5.6
10.	Covered interval	12.2	40.0
9.	Siltstone, light-brown, horizontally bedded to variegated. Contact with unit 10 is covered.	1.7	5.6
8.	Sandstone, pale yellowish-orange, medium-scale, low-angle, planar cross-beds and occasional trough cross-beds; medium-grained, well-sorted, subrounded, siliceous. Contact with unit 9 is gradational.	17.1	56.0
7.	Gravel, light-olive-gray to light-brown, large-scale, medium-angle, planar cross-beds, pebble to cobble clasts, moderately		

sorted, upward-fining, clast-supported, subrounded; composed of metamorphic, graywacke, altered volcanic, and red chert clasts. Maximum clast size 18 cm. Contact with unit 8 is gradational. (location #13)

15.5 51.0

6. Sandstone and Siltstone; Same as unit 3. Contact with unit 7 is unconformable.

6.7 22.0

5. Gravel, moderate-brown, medium-scale, planar cross-beds, cobble-pebble in size, clast-supported, moderately sorted, subrounded, weakly indurated; composed of sandstone clasts, high-grade metamorphics, red-banded and black chert, and some fine-grained vein quartz with pebbles and cobbles as much as 8 cm in diameter; interbedded with sandstone, grayish-brown, medium-scale, planar bedded sets, fine to medium-grained, moderately sorted, subrounded, friable; interbedded with siltstone, light-olive, friable, lenticular, with shale partings. Contact with unit 6 is gradational. (location #1)

12.0 39.5

Lower Livermore: (Late Miocene and Pliocene)

4. Sandstone, yellowish-orange, medium-scale, low-angle, planar cross-beds, fine-grained, well sorted, subrounded; interbedded with siltstone, light-gray, indistinctly bedded; interlayered with shales, dark-green to dark-gray, variegated, lenticular, friable. Calcareous nodules and pedogenic features locally. Contact with unit 5 is gradational.

69.0 226.0

3. Covered section; Lithologies not identifiable. Contact with unit 4 is gradational.

26.0 85.0

2. Shale, light-brown, indistinctly bedded to finely laminated; interbedded with siltstone, light gray, indistinctly bedded to planar bedded, well sorted, friable, calcareous nodules and root casts locally. Fossil locality (M-1145) *Equus*

	dolichohippus sp. Horse, 4.5-1.2 Ma (Herd and Brabb, 1980). Collected approximately 10 m above shoreline. Contact with unit 3 is covered.	17.1	56.0
1.	Gravel, very light-gray, medium-scale, planar cross-beds, cobble-pebble size, well sorted, well rounded, moderately indurated, imbricated; consists of clasts of sandstone, fine-grained vein quartz, graywacke, and few metamorphics. Maximum clast size 2 cm. Contact with unit 2 is gradational. (location #31)	0.7	2.4
	Partial thickness of Livermore Gravels at San Antonio Reservoir Measured Section	179.7	589.1

Section 4. Indian Creek Section,
Alameda County, California.
T4S, R1E.

This section was measured at the southwest facing cliff face parallel to Indian Creek, located on the south side of San Antonio reservoir. The measured section begins at the base of the cliff face adjacent to the ephemeral stream at the intersection of three Bench Marks (BM). BM 1792- N44°W, BM 510- S7°E, and BM 747- S47°W. Located in the La Costa Valley 7 1/2 minute quadrangle, California.
Strike and dip are N78°E 10°NW.

Unit	Description	Thickness (Equivalents) Meters	Feet
	Top of section: Modern soil, sandy and pebbly.		
	Upper Livermore: (Pliocene and Pleistocene)		
3.	Gravel, moderate brown to dark-yellowish-orange, indistinctly bedded to horizontally bedded, medium-scale, medium-angle, planar cross-bedded sets, with cobble and pebble size clasts, poorly sorted, subrounded, well imbricated; consists of blueschist, graywacke, altered volcanic, chert, and lithic sandstone clasts. Maximum clast size 10 cm. Matrix is a heterogeneous mixture of medium-grained sand and silt with abundant mica (location #15).	12.8	42.0
	Lower Livermore: (Late Miocene and Pliocene)		
2.	Gravel, yellowish-gray, indistinctly bedded, large-scale, low-angle, planar cross-beds, cobble-pebble size clasts, moderately sorted, subrounded, well imbricated clasts of lithic sandstone, and fine-grained vein quartz, in a coarse sand matrix; interbedded with sandstone, light-olive-gray, horizontally bedded, medium-grained, moderately sorted, Maximum clast size is 2 cm. Contact with unit 3 is unconformable (location #2).	7.6	25.0

1.	Shale, grayish-olive-green to dusky-yellowish-green, organic detritus interlensed between shale partings; interbedded with siltstone, medium-gray to brownish-gray, indistinctly bedded; overlain by a paleosol, moderate reddish-brown, 15 cm thick, oxidized, bioturbated, calcareous. Sequence typically 2 m thick and repeats for 23 meters. Contact with unit 2 is unconformable.	22.9	75.0
	Partial thickness of Livermore Gravels at Indian Creek Measured Section	43.3	142.0

Section 5 Del Valle Reservoir,
Alameda County, California.
NW1/4, NW1/4, SE1/4, Sec.18, T4S, R3E

This section was measured at the south facing road-cut east of the Del Valle Recreational Park entrance at the southern end of the Del Valle Reservoir. The measured section begins at the contact of the Franciscan Complex which is 150 meters east of the park entrance. Located in the Mendenhall Springs 7 1/2 minute quadrangle, California.
Strike and dip are N81°E 15°NW.

Unit	Description	Thickness (Equivalents) Meters	Feet
	Top of section: Modern soil, sandy.		
	Lower Livermore: (Late Miocene and Pliocene)		
16.	Gravel, pale-yellowish-brown, indistinctly bedded to horizontally bedded, cobble-pebble in size, moderately sorted, subrounded, imbricated, moderately indurated, matrix of medium-grained sand.	2.4	8.0
15.	Gravel, medium-light-gray to pale-yellowish-brown, medium-scale planar cross-bedded sets, cobble to pebble size clasts, moderately sorted, subrounded, well imbricated; consists of sandstone, fine-grained vein quartz, schist, and traces of volcanic, and graywacke clasts. Matrix of medium-grained sand, light-gray to moderate-gray, poorly sorted. Clasts range in size from 1-5 cm in diameter. Contact with unit 16 is gradational. (location #10)	4.0	13.0
14.	Shales, grayish-yellow-green, indistinctly bedded to finely bedded; interbedded with sandstone, light-brown, indistinctly to horizontally bedded, coarse to medium-grained, well sorted. Sandstone occurs in cyclical paleosol sequences similar to unit 2. Spacing of individual sandstone lenses is tighter. Contact with unit 15 is unconformable.	25.9	85.0

13.	Gravel, light-gray to light-brownish-gray, medium-scale, planar bedded sets, poorly sorted, sub-angular, subrounded, well imbricated; consists of lithic sandstone, metamorphic, fine-grained vein quartz, and graywacke clasts. Maximum clast size 4 cm in diameter. Contact with unit 14 is gradational. (location #4)	2.0	6.4
12.	Siltstone and mudstone; Same as unit 5, except there is an increase in the proportion of fine sand, and an increase in clast size up section. Located within the siltstone and mudstone, approximately 61 meters above the Lawlor tuff, is a fossil vertebrate locality (M-1432), *Hypolagus sp. H. Furlongi*, (Herd and Brabb, 1980). Contact with unit 13 is unconformable.	145.0	475.0
11.	Tuff, light-gray, finely laminated, calcareously cemented. Approximate location of vertebrate fossil assemblage with *Hypolagus limnetus* (Herd and Brabb, 1980).	0.3	1.0
10.	Tuffaceous claystone, yellowish-gray to very light-gray, indistinctly bedded with rare laminations and siltstone partings.	7.6	25.0
9.	Tuff, light-gray, weathered, vitric-lithic ash tuff, well bedded, finely laminated, well sorted, calcareously cemented. K/Ar dated at 4.5 ± 0.5 million years (Sarna-Wojcicki, 1976).	0.9	3.0
8.	Same as unit 6.	38.1	125.0
7.	Gravel, light-gray to light olive-brown, medium-scale, planar bedded sets, pebble size, poorly sorted, well imbricated, moderately rounded; consists of sandstone, graywacke, and fine-grained, vein quartz.		

	Clasts range in size from 1-3 cm in diameter. Contact with unit 8 is unconformable. (location #11)	1.2	4.0
6.	Same as unit 2, except a lesser amount of siltstone and more medium-grained sand.	24.1	79.0
5.	Covered interval,	85.4	280.0
4.	Same as unit 2, except laminations are more prominent within the paleosol sequence.	15.2	50.0
3.	Gravel, yellowish-gray to light olive-brown, horizontally bedded, cobble to pebble in size, moderately sorted, subrounded, imbricated, moderately indurated; consists of lithic sandstone, moderate gray, fine-grained vein quartz, graywacke, and metamorphic clasts in a sandy matrix. Maximum clast size is 3 cm. Contact with unit 4 is gradational. (location #48)	0.30	1.0
2.	Shale, grayish-olive-green, blackish-red, pale-red, purple, indistinctly bedded, variegated to finely laminated, 1.2 m thick; grades upward to siltstone, grayish-green to pale-olive, finely laminated, calcareous nodules and bioturbation occurs locally, 0.6 m thick; grades upward to paleosols, moderate-red to moderate-reddish-orange, oxidized, burrowed, root casts, organic matter, and caliche, locally 0.2 m thick. This 2 meters thick sequence is repeated throughout the entire section but is locally uninterrupted for 38 meters. Contact with unit 3 is unconformable .	38.1	125.0
Partial thickness of Lower Livermore at Del Valle Measured Section		390.4	1280.4

Fault contact with greenish graywacke of Franciscan Complex marked by distinctive change in lithology.

APPENDIX III: SPECIFIC GRAVITY OF GRAYWACKE CLASTS IN THE LIVERMORE GRAVELS

Lower Livermore

S.G.	AVERAGE S.G	SAMPLE#	S.G.	AVERAGE S.G	Sample #
2.66	2.66	2	2.67	2.69	31
2.71			2.71		
2.63			2.69		
2.71			2.76		
2.64			2.62		
2.63			2.68		
2.63					
2.66			2.71	2.71	35
2.68			2.69		
			2.70		
2.73	2.72	4	2.71		
2.71			2.68		
2.73			2.73		
2.72			2.72		
2.76			2.71		
2.71					
2.69			2.65	2.69	36
2.68			2.73		
			2.68		
2.80	2.74	8	2.67		
2.73			2.72		
2.80			2.71		
2.81			2.69		
2.72			2.70		
2.71					
2.62			2.72	2.71	43
2.72			2.73		
			2.68		
2.72	2.70	10	2.66		
2.70			2.65		
2.69			2.76		
2.73			2.71		
2.65			2.73		
2.71					
2.69			2.75	2.72	48
2.74			2.74		
2.69			2.73		
			2.72		
2.67	2.69	11	2.68		
2.72			2.69		
2.72			2.70		
2.69					
2.69			2.77	2.73	49
2.73			2.73		
2.66			2.71		
2.67			2.68		
			2.75		
2.72	2.71	30	2.72		
2.73					
2.76					
2.69					
2.70					
2.63					
2.70					
2.71					

SPECIFIC GRAVITY continued

Upper Livermore

S.G.	AVERAGE S.G	SAMPLE#	S.G.	AVERAGE S.G	Sample #
2.64	2.66	1	2.68	2.66	15
2.67			2.68		
2.71			2.66		
2.67			2.67		
2.74			2.62		
2.60			2.69		
2.72			2.66		
2.62			2.64		
2.59	2.64	3	2.69	2.69	16
2.67			2.72		
2.64			2.66		
2.66			2.64		
2.61			2.71		
2.70			2.69		
2.57			2.71		
2.65			2.67		
2.60	2.60	6	2.75	2.69	17
2.59			2.66		
2.64			2.70		
2.62			2.69		
2.56			2.69		
			2.67		
2.69	2.68	7	2.70		
2.67			2.70		
2.65			2.65		
2.69					
2.70			2.67	2.63	19
2.73			2.61		
2.65			2.62		
2.65			2.62		
2.69	2.67	9	2.65	2.66	22
2.69			2.65		
2.71			2.65		
2.69			2.69		
2.51					
2.70			2.63	2.67	23
2.68			2.65		
2.69			2.67		
			2.66		
2.65	2.64	12	2.63		
2.66			2.59		
2.67			2.76		
2.58			2.77		
2.66					
2.62			2.63	2.65	28
			2.69		
2.63	2.65	13	2.56		
2.65			2.63		
2.67			2.65		
2.69			2.69		
2.69			2.65		
2.62			2.66		
2.68					

SPECIFIC GRAVITY continued

Upper Livermore continued					
S.G.	AVERAGE S.G	SAMPLE#	S.G.	AVERAGE S.G	Sample #
2.69	2.68	29	2.69	2.68	40
2.60			2.69		
2.71			2.71		
2.69			2.58		
2.70			2.68		
2.68			2.66		
2.64			2.70		
2.69			2.71		
			2.63	2.64	41
2.63	2.64	33	2.77		
2.63			2.59		
2.66			2.65		
2.64			2.63		
			2.65		
2.65	2.63	34	2.71		
2.63					
2.58			2.65	2.63	42
2.65			2.64		
2.66			2.66		
2.63			2.57		
2.61			2.59		
2.59			2.63		
			2.65		
2.67	2.66	37	2.64		
2.65					
2.69			2.66	2.64	47
2.72			2.63		
2.66			2.63		
2.63			2.62		
2.60			2.69		
2.62			2.62		
			2.65		
2.65	2.66	38	2.63		
2.69					
2.64			2.69	2.62	50
2.63			2.69		
2.65			2.55		
2.71			2.51		
2.68			2.59		
2.66			2.67		
			2.66		
2.65	2.68	39			
2.66			2.65	2.63	51
2.72			2.66		
2.69			2.67		
2.67			2.48		
2.69			2.59		
2.68			2.61		
2.64			2.73		
			2.66	2.67	52
			2.71		
			2.63		
			2.66		
			2.68		