

Preliminary Geologic Map of the Los Angeles 30' x 60' Quadrangle, California

Version 2.1

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Introduction

The Los Angeles 30' x 60' quadrangle covers approximately 5,000 km² including much of the densely populated urban and suburban areas of the southern California megalopolis. The quadrangle is about 90 km east-west and about 55 km north-south, extending from Fillmore and Thousand Oaks in the west to Acton in the northeast and Montebello in the southeast. It covers the urban San Gabriel Valley and San Gabriel Mountain foothill communities from Monrovia to Pasadena, as well as Glendale, downtown Los Angeles, Hollywood, Santa Monica, Malibu, and all the communities in the San Fernando Valley, Simi Valley, and the upper Santa Clara River Valley. Population of these urban and suburban areas, as listed in the 2000 Census, totals approximately 5.6 million, and property value is estimated to total hundreds of billions of dollars. The quadrangle also includes large areas of wilderness in the Angeles and Los Padres National Forests, the Santa Monica Mountains National Recreation Area, and the Sespe Condor Sanctuary. The relief in the quadrangle ranges from about a hundred meters subsea (in Santa Monica Bay) to more than 2,000 meters above sea level at Pacifico Mountain in the high San Gabriel Mountains. Residents and visitors are subject to potential hazards from earthquakes, debris flows and other landslides, floods, wildfires, subsidence from ground water and petroleum withdrawal, and swelling soils; and coastal areas are exposed to flooding and erosion by storm and tsunami waves. This geologic map is intended to illustrate the distribution of the rocks and surficial deposits of the area and their structural and stratigraphic relations to one another. It provides a regional geologic framework as an aid to better evaluations of the potential for hazard from active earth processes. As a digital product it includes some areas mapped in greater detail than others; however, it is not sufficiently detailed to serve as a basis for site-specific evaluations.

Sources of geologic mapping

The map has been compiled from many scientific studies in different parts of the quadrangle, and represents the work of many geologists. Compilation of the Los Angeles 30' x 60' quadrangle was completed by Yerkes and Campbell (2005) and published by the U.S. Geological Survey. That map, which can be considered version 1.0 of the digital geologic map of the Los Angeles 30' x 60' quadrangle, involved digitization of original field mapping, and digitization and assembly of numerous published and unpublished source geologic maps. This effort, led by Robert Yerkes between 1985 and completion of the map in 2005, provides a foundation for the additions and further refinement presented here.

This map, version 2.0 of the digital geologic map of the Los Angeles 30' x 60' quadrangle, represents an update of the map by Yerkes and Campbell with extensive revisions and additions. Many of these revisions and additions resulted from studies by the California Geological Survey to define Seismic Hazard Zones, where development must consider the potential hazards from liquefaction and earthquake-induced landslides. The listing of sources of geologic mapping below includes geologic maps that were used by Yerkes and Campbell (2005), additional geologic maps included in this compilation, and reports describing the liquefaction zoning and earthquake-induced landslide zoning for each quadrangle. Although the Seismic Hazard Zone Reports referenced below are focused on the details of delineation of the hazard zones, virtually all reports resulted in revised mapping of some geologic units. Revised mapping of younger Quaternary units, including the contact between late Quaternary alluvium and bedrock, was a focus of the seismic hazard zoning effort because these contacts can define the boundaries of Liquefaction Hazard Zones. New mapping of Quaternary units was generally based on geomorphic

expression, supplemented by descriptions of the subsurface materials in numerous boreholes from throughout the valley areas (Wills and Hitchcock, 1999, Hitchcock and others, 1999). Quaternary units are designated using the terminology of Matti and Cossette (2007).

The process of creating earthquake-induced landslide zoning resulted in compilation of bedrock units that in some cases differed from the compilation of Yerkes and Campbell (2005). This effort also included re-mapping of landslides for the region, except for areas within National Forests. In preparing this compilation, we have used the compilations from the Seismic Hazard Zonation Program, reconciled those with the source maps used by Yerkes and Campbell (2005), added additional detail based on source maps not used by either the Seismic Hazard Zonation Program or Yerkes and Campbell (2005) and added selected landslides mapped by the Seismic Hazard Zonation Program. Due to the scale of this map, most small landslides and all landslides considered “questionable” in the original landslide inventories are not shown. CGS landslide inventory maps, and related 1:24,000-scale maps, show a more complete depiction of landslides. Landslides that are too small to show on 1:24,000-scale maps can be hazardous and damaging, so no regional map should be used to evaluate the landslide hazard to a particular location or parcel.

In addition to revisions to geologic contacts based on the Seismic Hazard Zonation Program, this map includes extensive revisions to the crystalline bedrock of the San Gabriel Mountains. Yerkes and Campbell (2005) completed a generalized compilation of the San Gabriel Mountains. In their compilation, they modified the nomenclature of the basement rock units to conform with the IUGA Subcommittee on Systematics of Igneous Rocks (Streckheisen, 1973), and to provide continuity with the compilation in the San Bernardino 30' x 60' quadrangle (Morton and Miller, 2003), which adjoins the Los Angeles 30' x 60' quadrangle on the east. They did not, however, attempt to reconcile the various more detailed maps of this area. For this compilation, we have attempted to use as much detailed original mapping as possible and describe the units in as much detail as possible. Where the detailed mapping and unit descriptions are from a single source, such as within the anorthosite complex described by Carter (1980, 1982), this map represents a complete, consistent interpretation. In other areas, detailed mapping and description of map units are lacking or are provided by different authors who had differing interpretations. In some cases, we have extended units described by one author based on contacts by another. Although the resulting compilation is more detailed than that by Yerkes and Campbell (2005), there are significant areas where map unit boundaries, descriptions, and correlations could be improved by new mapping.

In addition to the major updates noted above, CGS has updated numerous other local areas based on map sources not used in the map by Yerkes and Campbell (2005). These more local updates include new mapping of parts of the active Hollywood, San Cayetano, and Simi Faults, updates to mapping and stratigraphy of the Plio-Pleistocene sedimentary rocks of the Ventura basin (see Appendix A), and updates to the Tertiary units in the Soledad basin.

The major sources of mapping are listed below by the 7.5-minute quadrangles shown in Figure 1. Sources are underlined if they are a major source of geologic unit boundaries shown on this compilation, and in italics if they were not used in the compilation by Yerkes and Campbell (2005). Seismic Hazard Zone (SHZ) Reports for each quadrangle are also listed, along with landslide inventory maps that resulted from the Seismic Hazard Zonation Program, which are published as part of the CGS Landslide Inventory Map Series (LSIM).

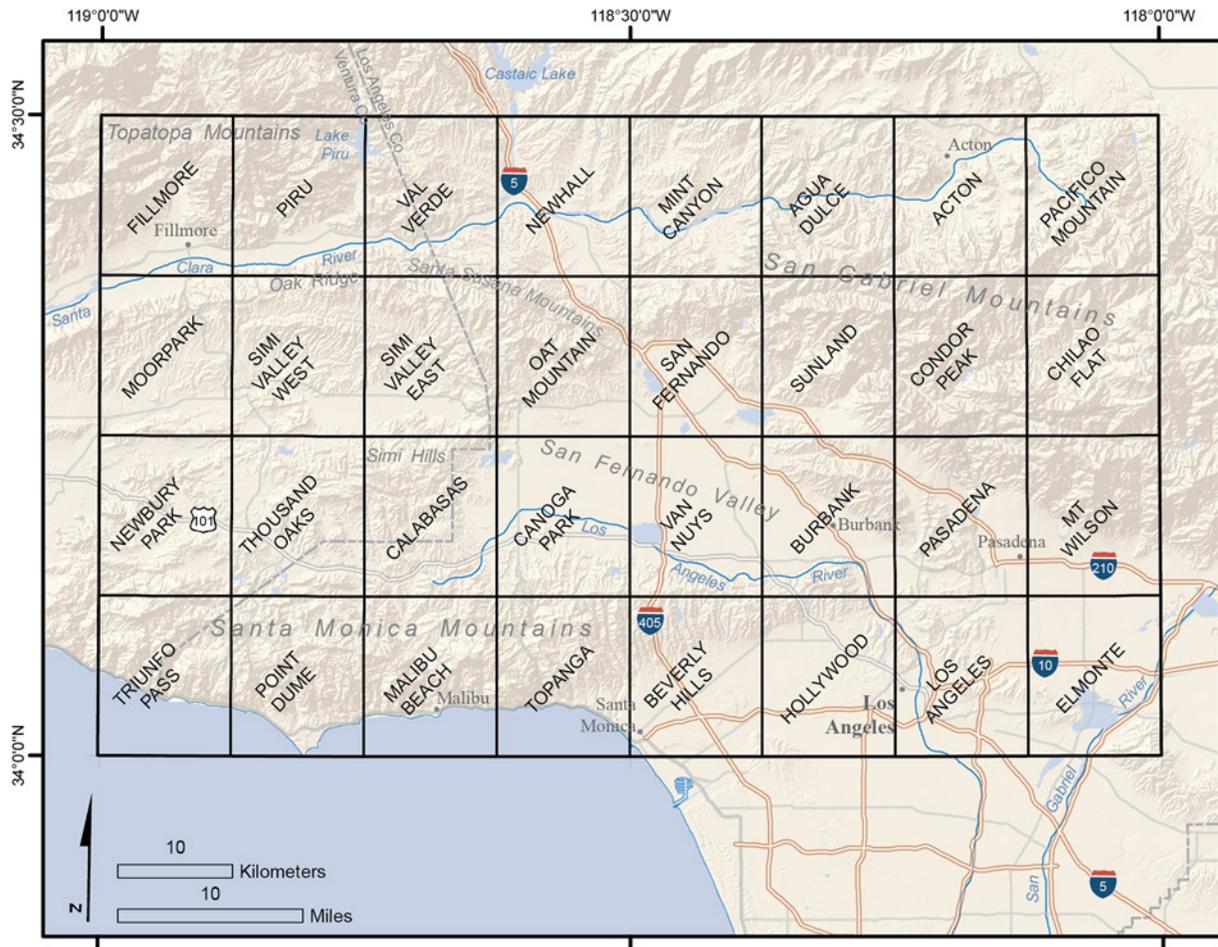


Figure 1. Index map of 7.5 minute quadrangles within the Los Angeles 30'x60' quadrangle.

Acton: Carter, 1980; Dibblee, 1996a; Ehlig, 1981; Jahns and Muehlberger, 1954; Morton and Streit, 1969.

SHZ Reports: Mattison, and Hernandez, 2003a; Wilson, and Hernandez, 2003a, LSIM Series: Hernandez, 2006a.

Agua Dulce: Carter, 1980; Dibblee, 1996b; Jahns and Muehlberger, 1954; Morton and Streit, 1969; Oakeshott, 1958.

SHZ Reports: Mattison and others 2003a; Wilson and others, 2003a; LSIM Series: Hernandez, 2006b.

Beverly Hills: Dibblee, 1991a; Hoots, 1931; Hsu and others, 1982; Poland, and others, 1959; Tinsley and others, 1985.

SHZ Reports: DeLisle 1998; Silva and Irvine, 1998a.

Burbank: Dibblee, 1991b, 1991e; Hitchcock and Wills, 2000; Hoots, 1931; Jennings and Saul, 1969; Lamar, 1970; Neuerburg, 1953; Weber, 1980.

SHZ Reports: Wills and Barrows, 1998a; Silva and others, 1998; LSIM Series: Treiman and Wills, 2013.

Calabasas: Hitchcock and Wills, 2000; Squires, 1983a; Weber, 1984; Yerkes and Showalter, 1993.

SHZ Reports: Wills and Barrows, 1997a; McCrink and others, 1997c.

Canoga Park: Hitchcock and Wills, 2000; Hoots, 1931; Soper, 1938; Weber and Frasse, 1984; Weber, 1983; Yeats and Shields, 1977b; Yerkes and Campbell, 1995a.
SHZ Reports: Wills and Barrows, 1997b; Silva and Irvine, 1997.

Chilao Flat: Carter, 1980; Barth, unpublished; Dibblee, 2002a; Ehlig, 1981; Powell and others, 1983; Morton and Streitz, 1969.

Condor Peak: Carter, 1980; Crook, and others, 1987; Dibblee, 2002b; Ehlig, 1981; Morton and Streitz, 1969; Powell and others, 1983; Weber, 1982.
SHZ Reports: Mattison and others, 2003b; Wilson and others, 2003b.

El Monte: Bullard and Lettis, 1993; Daviess and Woodford 1949; McCalpin 1988; Quarles, 1941; Tan, 1997; Treiman, 1991.
SHZ Reports: Loyd, 1998; Perez and others, 1998.

Fillmore: Bailey, 1951; Dibblee, 1990a; Cemen, 1977; Eschner, 1969; Kahle, 1986; Morton, 1972.
SHZ Reports: Loyd and Barrows, 2002a; Silva and others, 2002a.

Hollywood: Dibblee, 1991a; Hernandez and Treiman, 2014; Hoots, 1931; Hsu and others, 1982; Lamar, 1970; Neuerburg, 1953; Tinsley and others, 1985.
SHZ Reports: Mattison and Loyd, 1998a; Silva and Irvine, 1998b; LSIM Series: Irvine, 2013.

Los Angeles: Bullard and Lettis, 1993; Hsu and others, 1982; Lamar, 1970; Land and others, 2004; Tinsley and others, 1985.
SHZ Reports: Mattison and Loyd, 1998b; Silva and others, 1998.

Malibu Beach: Yerkes, and others, 1971; Yerkes and Campbell, 1980.
SHZ Reports: Woods, 2001a; Silva and Irvine, 2001a.

Mint Canyon: Carter, 1980; Dibblee, 1996c; Jacobson, 1990; Jahns and Muehlberger, 1954; Saul and Wootton, 1983; Saul, 1985; Weber, 1982.
SHZ Reports: Haydon, 1998; Wilson and Haydon, 1998.

Moorpark: DeVecchio and others, 2012b; Irvine, 1995; Weber, 1972; William Lettis and Associates, 1999.
SHZ Reports: Loyd, 2000a; Silva and Irvine, 2000a.

Mount Wilson: Bryant, 1978; Crook and others, 1987; Ehlig, 1981; McCalpin, 1988; Morton, 1973b; Powell and others, 1983; Saul, 1976.
SHZ Reports: Loyd and Wills, 1998; Wilson and Wills, 1998a; LSIM Series: Treiman and Wills, 2007a.

Newbury Park: Dibblee and Ehrenspeck, 1990a; Sonneman, 1975; Weber, 1972; Weber, 1984; Yerkes and Campbell, 1997b.
SHZ Reports: Loyd, 2002; Silva and Rosinski, 2002.

Newhall: Smith, 1984; Stitt, 1979; Allan E. Seward Engineering Geology Inc., 2008, Treiman, 1986; Treiman 1987a; Weber, 1982; Winterer and Durham, 1962.
SHZ Reports: Haydon and Barrows, 1997; Wilson and others, 1997.

Oat Mountain: Dibblee 1992c; Evans and Miller, 1978; Hitchcock and Wills, 2000; Saul, 1979; Treiman, 1987b; Winterer and Durham, 1962.
SHZ Reports: Wills and others, 1997; Schlosser and others, 1997.

Pacifico Mountain: Barrows and others, 1985; Barth, unpublished; Carter, 1980; Dibblee, 2001; Ehlig, 1981; Ehlig, unpublished; Jahns and Muehlberger, 1954; Morton and Streitz, 1969.
SHZ Reports: Mattison and Hernandez, 2003b; Wilson and Hernandez, 2003b.

Pasadena: Byer, 1968; Crook and others, 1987; Ehlig, P.L., 1981; Lamar, 1970; McCalpin, 1994(?); Morton and Streitz, 1969; Powell and others, 1983; Smith, 1982; Winterer and Durham, 1962.
SHZ Reports: Wills, 1998b; Wilson and Wills, 1998b; LSIM Series: Treiman and Wills, 2007b.

Piru: Huftile and Yeats, 1995; Morton, 1972; Olson, 2012.
SHZ Reports: Loyd and Barrows, 2002b; Silva and others, 2002b.

Point Dume: Campbell, and others, 1996.
SHZ Reports: Woods, 2001b; Silva and Irvine, 2001b.

San Fernando: Barrows, and others, 1974; Hitchcock and Wills, 2000; Oakeshott, 1958; Oakeshott, unpublished; Weber, 1982.
SHZ Reports: Wills, 1998c; Schlosser and Haydon, 1998a.

Simi Valley East: Butler, 1977; Dibblee 1992d; Hanson, 1981; Haydon and Loyd, 1997; Irvine, 1990; Squires, 1983a; Treiman, 1998; Weber, 1972; Winterer and Durham, 1962.
SHZ Reports: Haydon and Loyd, 1997; McCrink and others, 1997a.

Simi Valley West: Dibblee 1992e; Ehrenspeck, 1972; Hanson, 1981; Haydon and Loyd, 1997; Irvine, 1990; Ricketts and Whaley, 1975; Squires, 1983a; Treiman, 1998.
SHZ Reports: Haydon and Loyd, 1997; McCrink and others, 1997a.

Sunland: Barrows and others, 1974; Carter, 1980; Hitchcock and Wills, 2000; Oakeshott, 1958; Oakeshott, unpublished; Smith, 1978; Weber, 1982.
SHZ Reports: Wills, 1998d; Schlosser and Haydon, 1998b.

Thousand Oaks: Blackerby, 1965; Squires, 1983a; Weber, 1984; Yerkes and Campbell, 2005.
SHZ Reports: Loyd, 2000b; Silva and Irvine, 2000b.

Topanga: Hoots, 1931; McGill, 1989; Yerkes and Campbell, 1980; Yerkes and Campbell, 1995b.
SHZ Reports: Wills and McCrink, 1997; McCrink and others, 1997b.

Triunfo Pass: Guynes, 1959; Sonneman, 1975; Yerkes and Campbell, 2005.
SHZ Reports: Woods, 2002; Silva and Wieggers, 2002.

Val Verde: Barrows, 1986; Morton 1972; Allan E. Seward Engineering Geology Inc., 2008; Yeats and others, 1985.
SHZ Reports: Loyd and Barrows, 2002c; Silva and Hernandez, 2002.

Van Nuys: Dibblee, 1991a, 1991d; Hitchcock and Wills, 2000; Hoots, 1931; Tan, 1995.
SHZ Reports: Wills and Barrows, 1997c; Irvine and Silva, 1997.

Geologic Summary

The Transverse Ranges and the San Andreas Fault

Nearly all of the Los Angeles quadrangle lies within the south-central part of the Transverse Ranges geomorphic province, a band of west-trending mountain ranges and valleys, varying from 50 km to 130 km in width that extends about 400 km from Point Arguello on the west to the eastern San Bernardino Mountains on the east (Fig. 2). The east-west grain of the Transverse Ranges Province presents a stark and abrupt interruption of the general northwesterly trends of the Peninsular Ranges Province (including the California Continental Borderland) to the south and the northwesterly to northerly grain of the California Coast Ranges, the Great Valley, the Sierra Nevada, and the Mojave Provinces to the north. The southeastern corner of the Los Angeles quadrangle includes the northern part of the Los Angeles basin, which lies at the northern end of the Peninsular Ranges Province. The northwestern quarter of the Los Angeles quadrangle includes the eastern part of the Ventura basin and its southeastern extension, the San Fernando basin. These basins were the sites of very thick accumulations of marine sediments in the late Miocene and Pliocene. The southern boundary of Transverse Range structures is commonly placed at the Anacapa-Santa Monica-Hollywood-Raymond-Cucamonga zone of interconnected north-dipping thrust faults. West of Santa Monica, the southern limit of Transverse Range structures is the offshore Anacapa Fault, which lies a few kilometers south of the southern boundary of the quadrangle. Northwesterly trending faults in the Peninsular Ranges Province, such as the Newport-Inglewood zone, the Elsinore-Whittier Fault, and several faults in the offshore Continental Borderland, appear to be truncated by the east-west zone of interconnected faults, although the apparent step between the Hollywood and Santa Monica Fault zones along the projection of the Newport-Inglewood Fault suggests that the boundary has been modified locally.

The Transverse Ranges are a major anomaly embedded across the general grain of the North American Continent and, although middle Miocene and younger tectonism is responsible for much of the present rock distribution and physiographic relief, the distributions of different crystalline basement rocks, and their Cretaceous and Paleogene superjacent strata, suggest the influence of earlier tectonic episodes. The geologic history remains imperfectly understood, and many interpretations concerning specific aspects are actively disputed among earth scientists (e.g., Campbell and others, 1966; Dibblee and Ehrenspeck, 1993). The distinctive physiographic and structural characteristics of the provinces are superimposed on a preexisting framework of Proterozoic through early Cretaceous igneous and metamorphic basement rocks, which occur chiefly in fault-bounded blocks. This simple relationship has been modified in places so that rocks that are commonly associated with one province can be found in an adjacent province. For example, strata found south of the Malibu Coast Fault and west of the Newport-Inglewood zone of faulting and folding include probable Catalina Schist basement overlain by Miocene volcanics and Monterey facies sedimentary strata in a sequence best correlated with that of the Palos Verdes Peninsula-Santa Catalina Island area of the northern Peninsular Ranges. Although Catalina Island and the Palos Verdes Peninsula are dominated by northwesterly trending structures, and are included in the Peninsular Ranges Province, an east-trending band, bounded by the Malibu Coast Fault on the north and the offshore Anacapa-Santa Monica Fault, is characterized by east-trending folds and north-over-south thrust faults and, therefore, is included in the Transverse Ranges province. Some province-bounding faults take advantage of pre-existing structures in places, but not everywhere.

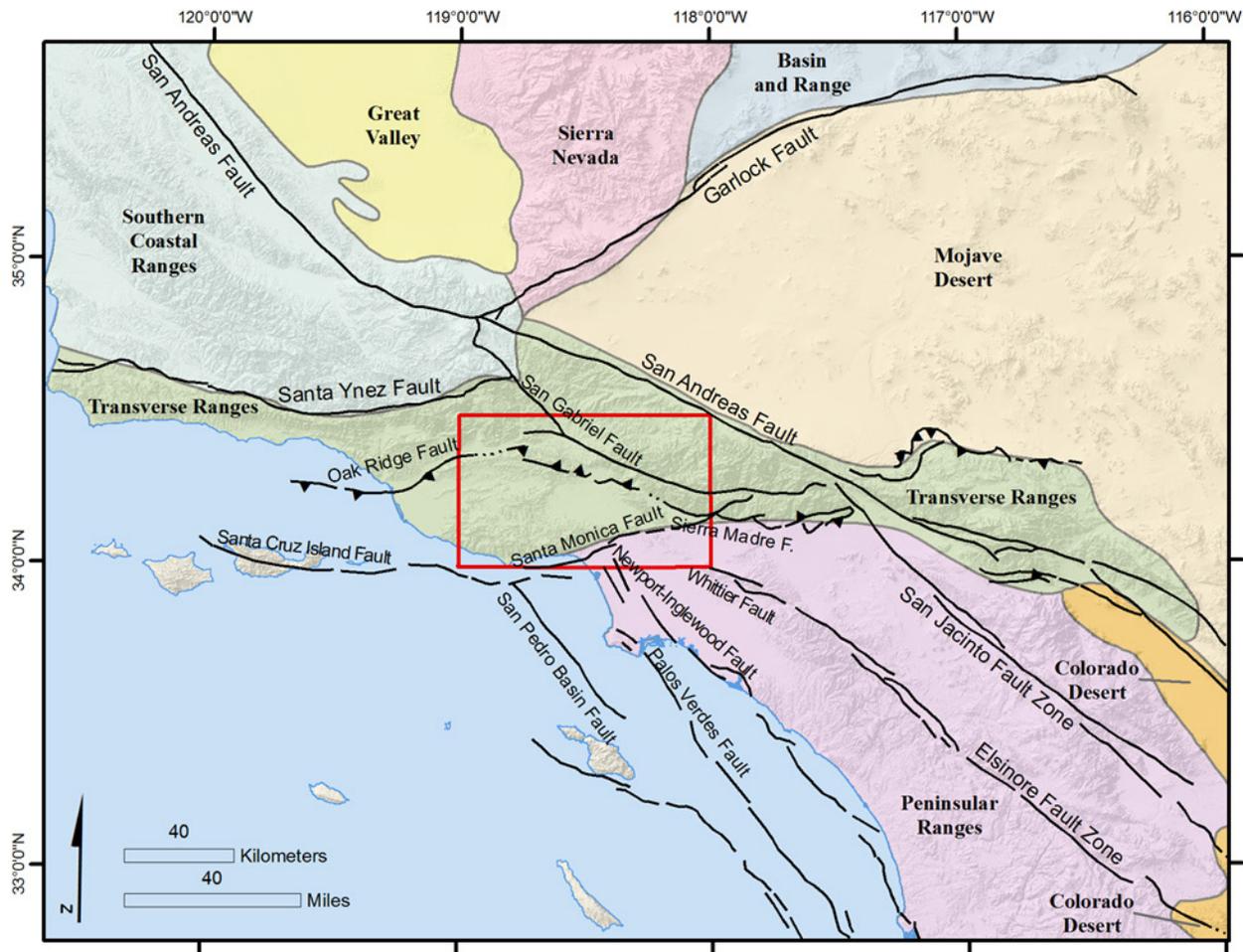


Figure 2. Area of the Los Angeles 30' x 60' quadrangle in reference to geomorphic provinces of southern California.

Major basement rock boundaries are not confined to the margins of the Transverse Ranges, but are also found within the province. For example, the northwest-trending Verdugo Fault separates the cratonic Precambrian to Cretaceous crystalline basement of the San Gabriel Mountains from the oceanic Jurassic metasedimentary basement of the Santa Monica Mountains. Similarly, the Raymond-Cucamonga segment of the southern frontal fault system of the Transverse Ranges approximates the boundary between the San Gabriel Mountains crystalline basement and the oceanic Jurassic basement in the Santa Ana Mountains (northern Peninsular Ranges). The Santa Monica Slate resembles similar Jurassic rocks in the Santa Ana Mountains. Although Jones and others (1976) note that sparse Jurassic fossils from the Santa Monica Mountains are younger than Jurassic fossils from the Santa Ana Mountains, both sections are very thick and represent millions of years of accumulation of pelitic sediment in abyssal to bathyal environments, and they are probably broadly correlative. This relatively simple pattern is further complicated by evidence that the cratonic rocks of the San Gabriel Mountains have been thrust over the Pelona Schist, for which the protolith is inferred to be Jurassic oceanic crust (Ehlig, 1981).

Many workers have attempted to reconstruct the rock distribution in the region as it was before the middle Miocene beginning of major structural deformation (e.g., Campbell and Yerkes, 1976; Crouch, 1979; Hornafius and others, 1986; Powell, 1993; Wright, 1991; Yeats, 2004) using recognized

translations and rotations of fault-bounded blocks. The paleomagnetic evidence that the western Transverse Ranges were rotated approximately 60 degrees clockwise in Miocene time (Kamerling and Luyendyk, 1979) should be kept in mind with regard to descriptions of pre-Pliocene sedimentary and structural trends. For example, northeasterly-trending faults that are truncated by the base of the Modelo and older units have been rotated from initial northwesterly orientations after their last movements. Similarly, north-trending shorelines and pinch-outs in Paleogene and Miocene strata (Yerkes and Campbell, 1976) have been rotated from westerly trends (McCulloh and others, 2002; McCulloh and Beyer, 2004). It seems logical that reconstruction should result in an unbroken western margin for the North American Continent that connects the rocks and structure to the north with those to the south of the Transverse Ranges. However, the pre-middle Miocene positions of individual fault blocks have not been comprehensively established. Partial reconstructions using extensive subsurface data, precise age dating, and well-established minimum fault movements and rotations have demonstrated the difficulty in accurately modeling the early Miocene margin of the North American continent (McCulloh and Beyer, 2004).

The San Andreas Fault crosses the Transverse Ranges Province with an east-southeasterly trend, in sharp contrast to its northwesterly trends to the north, in central California, and to the south, along the east side of the Salton Sea and the Imperial Valley. From Tejon Pass to Wrightwood, the San Andreas approximates the northern boundary of the Transverse Ranges (San Gabriel Mountains), and a short segment of the fault crosses the extreme northeastern corner of the Los Angeles quadrangle. Farther east it separates the San Gabriel Mountains from the San Bernardino Mountains, emerging from the south side of Cajon Pass to mark (approximately) the southern boundary of the Transverse Ranges (San Bernardino Mountains), and continues on that trend for another 45 km (approximately) southeasterly to the vicinity of North Palm Springs.

The presently recognized trace of the San Andreas Fault was probably not a single continuous fault before the end of the (Miocene-Pleistocene) tectonism that resulted in the modern Transverse Ranges Province. Some segments that are now connected show displacements that probably predate the late Miocene. The San Gabriel Fault probably was a major strand of the San Andreas in late Miocene through early Pliocene time that is now much less active (Crowell, 1952). The modern through-going San Andreas Fault consists of connected segments of varying ages and tectonic origins, and may be linked by fault segments that did not exist before the opening of the Gulf of California in the late Pliocene. Although the San Andreas Fault is seen only in the extreme northeast corner of the Los Angeles quadrangle, it is an important component of the geologic structure in the quadrangle, and is probably the principal control for the north-south compressive stress field presently imposed on the central Transverse Ranges. The ongoing deformation and associated earthquakes (Working Group on California Earthquake Probabilities, 2008) are generally considered to be the result of the northwest-trending right-lateral movement of the North American Plate relative to the Pacific Plate as constrained in upper crustal rocks by the geometry of the modern San Andreas Fault.

Geologic units in depositional basins and structural blocks

The geologic map units are divided into several columns in the explanation and brief description of map units on the map sheet, reflecting different sequences of units in different depositional basins. The units are arranged in a single sequence in the "Description of Map Units" below. The designations of different units in different areas is partly semantic; that is, different authors may have used different names for correlative strata in different parts of the quadrangle; or have used the same names for map

units that may be only partly correlative. However, real differences in lithologic character are also represented by the use of different names for strata of correlative ages. We have not been able to identify all the map unit names that should be extended and those that should be restricted. However, it seems clear that the present distribution of rock units is the result of the convergence of tectonic elements of diverse geologic histories. The subdivision of the unit abbreviations and brief descriptions into different columns on the map sheet is our attempt to illustrate the spatial diversity as objectively as possible, while retaining the stratigraphic elements shared in common.

Rocks of the Transverse Ranges Province are subdivided into geographic areas where similar rock sequences are exposed, these geographic areas reflect, at least in part, fault-bounded structural blocks: (1) Topatopa Mountains and the eastern Santa Ynez Range, (2) Oak Ridge, Santa Susana Mountains, Simi Hills, and Santa Monica Mountains, (3) Castaic Valley-Soledad Canyon and western San Gabriel Mountains (Figure 3). The rocks of the northern Peninsular Ranges Province are described in a frame of two middle Miocene and older structural blocks: (1) eastern Los Angeles basin, and (2) western Los Angeles basin. Within the Oak Ridge, Santa Susana Mountains, Simi Hills, Santa Monica Mountains block, middle Miocene and older strata are described separately for the Santa Susana Mountains-Simi Hills area and the central and western Santa Monica Mountains, chiefly because of large changes in thickness of the Conejo Volcanics and nomenclatural differences that represent relatively minor facies changes in the middle Miocene and older rocks. In the central Santa Monica Mountains, the strata in the upper plate of the Malibu Bowl Detachment Fault include a number of tongues of the Conejo Volcanics that have not been specifically correlated with the lithologic subdivisions of that unit in the lower plate. The eastern and western Los Angeles basin blocks correspond to the Northwestern and Central structural blocks of Yerkes and others (1965).

The bedrock units of the area are commonly described in two principal groups: 1) Basement rocks – early Cretaceous and older, crystalline metamorphic and igneous rocks; and 2) The superjacent sequence of late Cretaceous and Tertiary strata. The greatest contrast in basement character is at the boundaries of the San Gabriel Mountains-Soledad basin block. The San Gabriel Mountains form a basement massif that includes components of Proterozoic, Paleozoic, and pre-middle-Cretaceous Mesozoic metamorphic and plutonic rocks. These are the oldest basement rocks in the Los Angeles quadrangle and appear to represent old continental crust at the western margin of the North American craton that has been thrust over Jurassic oceanic crust of a different metamorphic facies than is found in adjacent blocks. In the eastern Los Angeles basin, to the south of the San Gabriel Mountains, and in the Santa Monica Mountains, to the west of the San Gabriel Mountains, the basement rocks are metasedimentary and metavolcanic rocks of Jurassic age that were probably deposited on a Jurassic oceanic crust and accreted to the margin of the North American craton. They have been intruded by early Cretaceous granitic bodies of the same age as similar rocks in the San Gabriel Mountains, but the relationship between these granite bodies is not clear. The basement rocks of the western Los Angeles basin also are associated with a Jurassic oceanic crust; however, their metamorphic character is significantly different, including blueschist facies schists that represent metamorphism in a subduction zone. The basement in the Topatopa Mountains block is unknown, but in the Santa Ynez Mountains, a few miles to the west, the basement is Franciscan Formation, including schists very much like those of the western Los Angeles basin basement rocks.

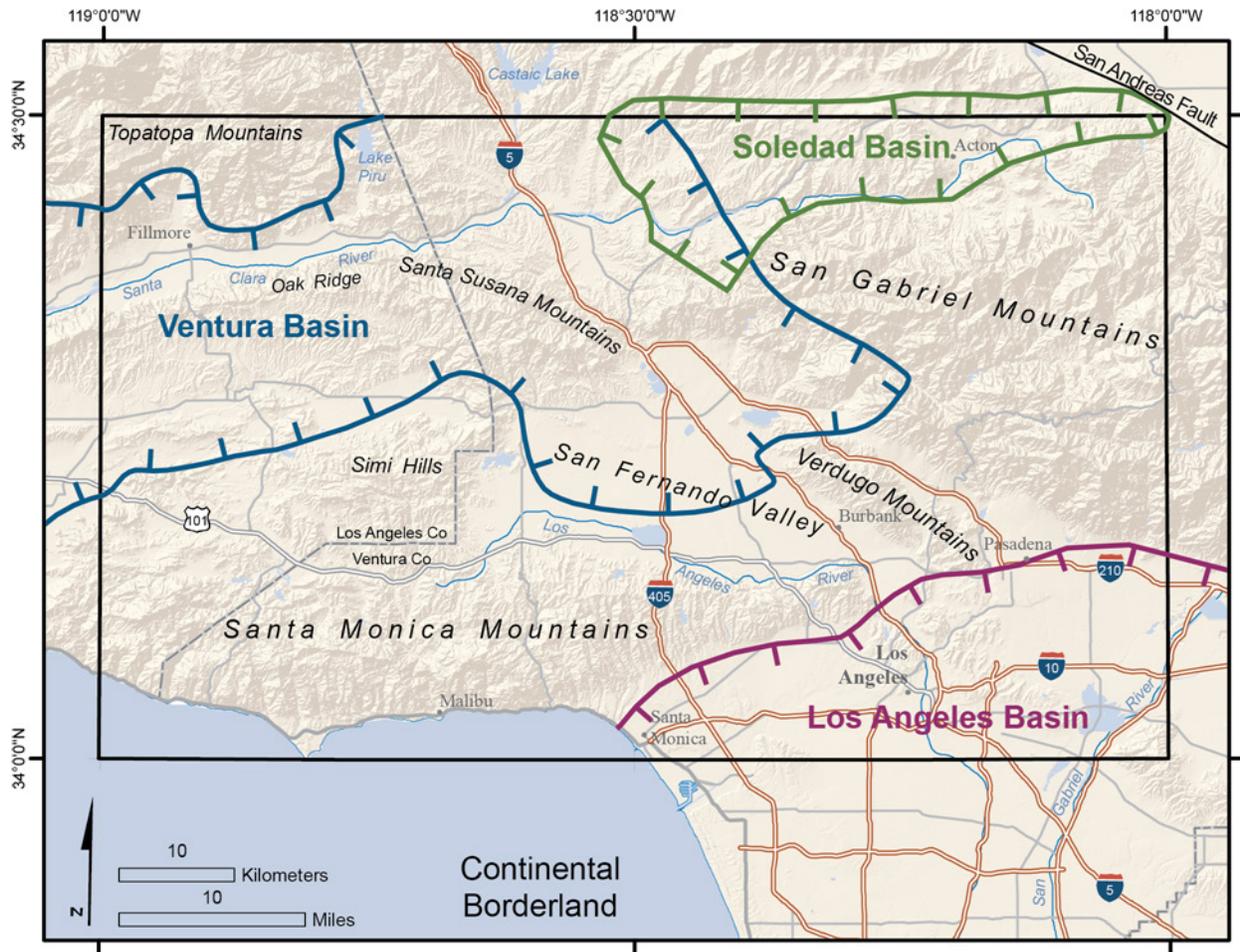


Figure 3. Principal late Tertiary to Quaternary depositional basins and upland areas where bedrock units are exposed within the Los Angeles 30°x60' quadrangle. The Soledad basin is represented by Miocene strata, which are truncated to the southwest by the San Gabriel Fault and subsequently overlapped by Pleistocene deposits of the Ventura basin; the Ventura and Los Angeles basin boundaries represent the limits of associated Pliocene and Pleistocene formations.

The superjacent sequence consists of Upper Cretaceous and Tertiary sedimentary and volcanic strata that rest unconformably on the crystalline basement. The regional unconformity at the base of the Upper Cretaceous is expressed only in the central Santa Monica Mountains, where the Trabuco Formation overlies basement rocks. Another regional unconformity, at the base of the Paleogene section, can be seen in the western Santa Monica Mountains and the Simi Hills where the Simi Conglomerate overlies the Upper Cretaceous sequence. The middle Miocene disruption of the pre-middle Miocene sequence and the formation of more localized basins is expressed by more restricted unconformities at the bases of late-middle Miocene and younger strata and extreme variations in thickness of late Miocene and younger units.

Description of map units

The arrangement of map unit descriptions on the map sheet illustrates the correlation of map units among different depositional basins. The map area straddles two major physiographic provinces, the Transverse Ranges and the Peninsular Ranges, and the southwest margin includes rocks commonly associated with the Southern California Borderland. The modern provinces are largely the products of Neogene tectonics, volcanism, and sedimentation, but each province contains fault-bounded blocks of Paleogene and older rocks that correlate over a larger area.

Similarities and differences among rock units are incompletely reflected in the nomenclature and labeling of the rock units, which evolved from many geologic investigations over the past century. The majority of the units on this map have been adopted from the source maps used in compilation. Named Formations of sedimentary strata are made up of multiple episodes of individual depositional events and each event need not be distributed over exactly the same area. This can lead to significant differences in the age range of a rock stratigraphic unit from one area to another.

Map labels are abbreviations that indicate age and origin of surficial deposits, or age and formally recognized names of formations and members. Where stratigraphic assignment is tentative, a query (?) is added to the label in the database. Where informal subunits are represented by subscripted numbers, numbers increase with decreasing age (i.e., of subunits 1-4, 4 is the youngest and 1 is the oldest). Quaternary deposits are found in all provinces and subareas; however they are relatively local in extent, and deposits are commonly associated with distinctive geomorphic features such as fans, flood plains and terraces. For a complete listing of geologic units and the 7.5' quadrangles on which they occur, refer to Appendix B.

- af Artificial fill (late Holocene)**—Deposits of sand silt and gravel resulting from human construction, mining or quarrying activities; includes compacted engineered and noncompacted nonengineered fill. Only large deposits are shown. Fills emplaced after source maps were completed are generally not shown.
- Qa Alluvium (late Holocene)**—Unconsolidated gravel, sand and silt in active or recently active floodplains, locally including related alluvial fans and streambeds where those are not mapped separately; chiefly stream deposited, but includes some debris-flow deposits. Locally corresponds with or encompasses areas of historic flooding, including deposits behind flood-control structures.
- Qw Wash deposits (late Holocene)**—Unconsolidated gravel, sand and silt in active or recently active streambeds; chiefly stream deposited, but includes some debris-flow deposits; episodes of bank-full stream flow are frequent enough to inhibit growth of vegetation.
- Qb Beach deposits (late Holocene)**—Loose fine- and medium-grained sand of active beaches chiefly between elevations of lower-low water and storm strands).
- Qe Eolian deposits (late Holocene)**—Loose, fine- to medium- grained sand, silty sand and silt; forms transitory dunes against beach-facing cliff.
- Qf Alluvial fan (Holocene)**—Unconsolidated bouldery, cobbly, gravelly, sandy, or silty alluvial deposits on active and recently active alluvial fans and in some connected headward channel segments.

- Qls** **Landslide deposits (Holocene and late Pleistocene?)**—Only selected landslide deposits shown on this map as described below. Deposits represent rock detritus from bedrock and surficial materials, broken in varying degrees from relatively coherent large blocks to disaggregated small fragments, deposited by landslide processes. Most deposits are Holocene, some dissected landslides may be as old as late Pleistocene. Landslide deposits shown on this map were compiled primarily from landslide inventories prepared by CGS for the Seismic Hazard Zonation Program. For this map, only landslides described as definite or probable and larger than 50,000 square meters are shown to preserve the clarity of the underlying bedrock geology. Selected historically active landslides between 10,000 and 50,000 square meters are shown, but no landslides smaller than 10,000 square meters are shown on this map. Exceptions to these rules include small or questionable landslides surrounded by larger probable or definite landslides.
- Qya** **Young alluvium, undivided (Holocene and late Pleistocene)**—Unconsolidated, generally friable, stream-deposited silt, sand and gravel on flood plains, locally including related alluvial fans and streambeds where those are not mapped separately. Deposits are clearly related to depositional processes that are still on-going. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation. Includes:
- Qya₄** **Young alluvium, Unit 4 (Holocene)**—Youngest of as many as 4 subunits of Qya that can be distinguished in some areas.
- Qya₃** **Young alluvium, Unit 3 (Holocene and late Pleistocene)**—Older young alluvium, older than Unit 4, younger than Unit 2.
- Qya₂** **Young alluvium, Unit 2 (late Pleistocene)**—Older young alluvium, older than Unit 3, younger than Unit 1.
- Qya₁** **Young alluvium, Unit 1 (late Pleistocene)**—Oldest young alluvium.
- Qyf** **Young fan deposits, undivided (Holocene and late Pleistocene)**—Unconsolidated gravel, sand and silt, bouldery along mountain fronts; deposited chiefly from flooding streams and debris flows. Deposits are clearly related to depositional processes that are still on-going. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation. Includes:
- Qyf₅** **Young alluvial-fan deposits, Unit 5 (Holocene)**—Youngest of four subunits of Qyf that can be distinguished in some areas. Designated Qyf₅ because of continuity with young alluvial fan designated Qyf₅ on map of San Bernardino 30'x60' quadrangle to east.
- Qyf₃** **Young alluvial-fan deposits, Unit 3 (Holocene to late Pleistocene)**—Young fan deposits, older than Unit 5, younger than Unit 2.
- Qyf₂** **Young alluvial-fan deposits, Unit 2 (Holocene to late Pleistocene)**—Older young fan deposits, older than Unit 3, younger than Unit 1.
- Qyf₁** **Young alluvial-fan deposits, Unit 1 (Holocene to late Pleistocene)**—Oldest of as many as four subunits of Qyf that can be distinguished in some areas.
- Qoa** **Old alluvium undivided (late to middle Pleistocene)**—Unconsolidated to moderately indurated gravel, sand and silt deposited on flood plains, locally including related alluvial fans

and streambeds where those are not mapped separately. Deposits have been uplifted or otherwise removed from the locus of recent sedimentation. Surfaces may be dissected in varying degrees; and can show moderately to well-developed pedogenic soils. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation. Includes:

- Qoa₃** **Old alluvium, Unit 3 (late Pleistocene)**—Youngest of as many as three subunits of Qoa that can be distinguished in some areas.
- Qoa₂** **Old alluvium, Unit 2 (late Pleistocene)**—Intermediate of as many as three subunits of Qoa that can be distinguished in some areas.
- Qoa₁** **Old alluvium, Unit 1 (middle Pleistocene)**—Oldest of as many as three subunits of Qoa that can be distinguished in some areas.
- Qof** **Old fan deposits, undivided (late to middle Pleistocene)**—Slightly to moderately consolidated silt, sand and gravel deposits on alluvial fans. Deposits have been uplifted or otherwise removed from the locus of recent sedimentation. Morphology of original alluvial fan surface usually well preserved, though dissected in varying degrees; surfaces can show moderately to well-developed pedogenic soils. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation. Includes:
- Qof₄** **Old fan deposits, Unit 4 (late Pleistocene)**—Youngest of as many as four subunits of Qof that can be distinguished in some areas.
- Qof₃** **Old fan deposits, Unit 3 (late Pleistocene)**—Intermediate subunit of Qof that can be distinguished in some areas, older than Qof₄ and younger than Qof₂.
- Qof₂** **Old fan deposits, Unit 2 (late Pleistocene)**—Intermediate subunit of Qof that can be distinguished in some areas, older than Qof₃ and younger than Qof₁.
- Qof₁** **Old fan deposits, Unit 1 (late Pleistocene)**—Oldest of at least four subunits of Qof that can be distinguished in some areas.
- Qoft** **Alluvial fan deposits on wave-cut surface (late Pleistocene to Holocene)**—Unconsolidated to moderately indurated, clay, silt, sand, and angular gravel including clasts to boulder size; chiefly debris-flow deposits, but probably includes some stream-deposited material; surfaces can show slight to moderate pedogenic soil development. Overlies elevated wave-planed bedrock and marine terrace deposits along the coast.
- Qom** **Old shallow marine deposits on wave-cut surface (late Pleistocene)**—Unconsolidated (but with small areas locally calcite-cemented) sand, silty sand and gravel; commonly overlies wave-cut bedrock surfaces at two or more altitudes above present sea level; surfaces can show slight to moderate pedogenic soil development; locally carries molluscan fauna referred to the late Pleistocene (Addicott, 1964).
- Qoab** **Old alluvium and breccia (late Pleistocene to Holocene)**—Deposit of angular shale chips and colluvium derived from Modelo Fm. Mapped adjacent to San Fernando Fault, age relationships with other alluvial units unknown.

- Qob** **Old breccia, (late Pleistocene to Holocene)**—Fine to coarse sand with well-rounded pebble gravel and shale chips and colluvium derived from Modelo Fm. Mapped adjacent to San Fernando Fault, age relationships with other alluvial units unknown.
- Qvoa** **Very old alluvium, undivided (middle to early Pleistocene)**—Slightly to moderately consolidated silt, sand and gravel deposits. Deposits have been uplifted or otherwise removed from the locus of recent sedimentation. Environment of deposition may include axial valley, floodplain or alluvial fan, but morphology of original deposit may not be preserved. Surfaces may be significantly dissected and show well-developed pedogenic soils. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation.
- Qvoa₂** **Very old alluvium, (middle to early Pleistocene)**—Younger subunit of Qvoa that can be distinguished in some areas.
- Qvoa₁** **Very old alluvium, (middle to early Pleistocene)**—Older subunit of Qvoa that can be distinguished in some areas.
- Qvof** **Very old alluvial-fan deposits (middle to early Pleistocene)**—Slightly to moderately consolidated silt, sand and gravel deposits on alluvial fans. Deposits have been uplifted or otherwise removed from the locus of recent sedimentation. Morphology of original alluvial fan surface preserved to some extent. Surfaces may be significantly dissected and show well-developed pedogenic soils. Subunits are distinguished by relative ages based on geomorphic relationships, relative degree of surface dissection and soil formation.
- Qvof₂** **Old alluvial-fan deposits, Unit 3 (late Pleistocene)**—Subunit of Qvof with distinct alluvial fan morphology, overlies and is therefore younger than Qvoa₁.
- Qpa** **Pacoima Formation (middle Pleistocene)**—Fanglomerate or sedimentary breccia with a dark-brown to reddish-brown clayey sand matrix; weakly indurated; crudely bedded; poorly sorted with angular, pebble- to boulder-size clasts composed primarily of crystalline rock locally derived from the San Gabriel Mountains, as described in the type area at the mouth of Pacoima Canyon. The Pacoima Formation exposed in the Mint Canyon quadrangle contains more rounded clasts than the type area and the color varies to light yellowish brown; farther west in the Newhall quadrangle the overall clast size decreases and clast composition varies as a result of facies changes associated with greater distance from the San Gabriel Mountain source area and influx of sedimentary clasts shed from the uplifting Santa Susana Mountains to the south (Treiman and Saul, 1986). The Pacoima Formation is an unconformity bounded unit deposited in the eastern Ventura basin that is typically gently inclined; distinguished from the underlying Saugus Formation by poorer bedding and sorting, clast angularity, and angular discordance in most areas; distinguished from younger terrace deposits and overlying older alluvium primarily by degree of erosion and weathering, and the occurrence of locally intense folding and faulting. The maximum thickness is about 500 to 1,000 ft. (152 to 305 m). The Pacoima Formation was initially described by Oakeshott (1952) and subsequently mapped by Oakeshott (1958) and Barrows and others (1974) in the northern San Fernando Valley and south of the San Gabriel Fault in the eastern Santa Clarita Valley area. Saul (1979, 1990) and Saul and Wootton (1983) followed this usage in mapping of the Mint Canyon quadrangle, and Treiman (1986, 1987a)

extended the formation into the Newhall quadrangle in place of older alluvial deposits mapped by Kew (1924) and Winterer and Durham (1962). The Pacoima Formation is younger than about 0.4 Ma based on the estimated youngest age of the underlying Saugus Formation studied in the Santa Clarita Valley by Levi and others (1986) ~~and~~ Treiman and Saul (1986) estimated that deposition of the Pacoima Formation was essentially completed by about 0.3 Ma.

Eastern Ventura Basin, including San Fernando Basin

QTs/Qs Saugus Formation, undivided (late? Pleistocene to late Pliocene)—Weakly to moderately cemented, medium- to coarse-grained, light-gray to yellowish-gray sandstone and pebble conglomerate and light greenish-gray sandy siltstone deposited in the Ventura basin; moderately sorted; commonly cross bedded and channeled; interbedded with moderate-brown to reddish-brown poorly sorted sandy mudstone and local claystone seams in the type area and other portions of the eastern Ventura basin, reflecting overbank deposits and paleosols; fluvial near the basin axis, transitioning to alluvial fan environment near the basin margins; interfingers with shallow marine sands to the west. The Saugus Formation is chiefly nonmarine as defined by Hershey (1902b) and Winterer and Durham (1962), but mapping compiled herein may locally include shallow marine interbeds. Transitional to brackish water deposits at the base of the section observed in the eastern Ventura basin are assigned to the Sunshine Ranch Member. This formation has a gradational to interfingering conformable contact with underlying shallow marine strata of the Pico Formation near the axis of the Ventura basin, but the contact is time transgressive and is progressively younger to the west. Near the basin margins, the base is unconformable with the Pico Formation and locally overlaps older strata and basement rock. The upper contact shows distinct angular discordance with the overlying Pacoima Formation in most areas, but discordance is more subtle west of Valencia and middle Pleistocene deposition in this area may be nearly continuous. The thickness varies greatly across the Ventura basin; Kew (1924) reports a thickness of 2,000 ft. (610 m) but Winterer and Durham (1962) report that up to 12,000 ft. (3,660 m) of Saugus strata were encountered in a well southeast of San Fernando Pass; a thickness of 2,000 m is reported in the western Ventura basin below the Santa Clara River, but DeVecchio and others (2012b) report a thickness of only 40 to 60 m in the Camarillo area near the southwest margin of the basin. In the eastern Ventura basin, the base of the Saugus is estimated at about 2.3 Ma west of Valencia and in the Mission Hills (Levi and Yeats, 1993) to about 2.6 Ma near Gold Canyon in the northern San Fernando Valley (Beyer and others, 2009). Unfossiliferous deltaic deposits mapped as Saugus in the Elsmere Canyon area by Dibblee (1991d, 1992c) and Squires (2012) may be significantly older based on their position below Sunshine Ranch strata and mapped interfingering relationships with older Pico and Towsley Formation strata. The top of the Saugus in the eastern Ventura basin is estimated at about 0.5 Ma by Levi and Yeats (1993) and is younger to the west. North of Ventura, Lajoie and others (1982) report an age of 0.2 Ma in marine sands underlying the Saugus and an age of 85 ka in overlying marine terrace deposits. In the Moorpark area, Wagner and others (2007) report an age of 780 to 850 ka at a Mammoth fossil site. In the Camarillo and Las Posas Hills area, DeVecchio and others (2012a, 2012b) report that Saugus strata overlie marine sands as young as about 125 ka and may be as young as 25 ka south of the Camarillo Hills based on OSL dating. Based on reported ages, Saugus strata west of Fillmore and west of the Tapo Canyon area are considered post-Pliocene in age and therefore mapped as Qs rather

than QTs. Clasts within the Saugus Formation are typically plutonic, metamorphic and volcanic rocks, derived primarily from the San Gabriel Mountains, and transported westward by the ancestral Santa Clara River; however, distinctive clast assemblages have locally been recognized and mapped as informal members or facies by various workers. These include upper Saugus (QTsu); volcanoclastic breccia-conglomerate (Qsv) and Camarillo member (Qsc); additional facies are defined by Weber (1982) in the Santa Clarita area based on the presence or absence of San Francisquito Formation sandstone, Pelona Schist, or anorthosite clasts. The Saugus Formation was initially defined by Hershey (1902b) as the “Saugus division” for continental strata exposed in railroad cuts east of Bouquet Junction near Saugus (type area). These deposits were subsequently lumped into the Fernando Formation by Eldridge and Arnold (1907). Kew (1923, 1924) formally adopted the term Saugus Formation for the upper section of the Fernando Group and extended usage into the western Ventura basin. Kew generally followed Hershey’s nonmarine definition except that he also included underlying coarse-grained shallow marine deposits within the Saugus Formation. The unit was redefined and remapped by Winterer and Durham (1962) in the eastern Ventura basin, who reassigned most of the shallow marine strata to the Pico Formation, conforming to Hershey’s nonmarine definition of the Saugus. This nonmarine definition has been adopted by most workers in the eastern Ventura basin (e.g. Saul, 1975, 1979; Weber, 1982; Yeats and others, 1985; Saul and Wootton, 1983; Treiman, 1986, 1987a; Dibblee Foundation maps; Squires and others, 2006; Squires, 2012). Maps covering areas south and west of the area mapped by Winterer and Durham commonly include marine deposits as part of the Saugus based on Kew’s definition (e.g. Weber and others, 1973; White, 1985; Squires and White, 1983; Groves, 1991). The restricted usage of Winterer and Durham (1962) in the type area is adopted herein and shallow marine strata formerly assigned to the Saugus Formation in the Santa Susana Mountains and Oak Ridge located east of, and down section of, the Grimes deltaic unit (QTpg) are reassigned as an upper informal member of the Pico Formation (QTpcu) (see Appendix A for details). Nonmarine strata of similar age are mapped as the La Habra Formation in the Los Angeles basin (Eckis, 1934), and as the Casitas Formation in the Santa Barbara basin (Upson, 1951). Mapped members include:

- QTsu Saugus Formation, upper member (middle Pleistocene)**—On the south flank of the Santa Susana Mountains this unit consists of nonmarine sandstone and conglomerate with clasts composed primarily of shale and sandstone derived from the Modelo and Towsley Formations (Oat Mountain 7.5’ quadrangle); the most representative section is at Horse Flats. This clast assemblage is interpreted to represent uplift, emergence and initial erosion of the Santa Susana Mountains, as described in Saul (1975), Shields (1977a), Saul (1979), and Levi and Yeats (1993); Qt of Bishop (1950) and Jennings (1957). Strata mapped as upper Saugus west of Valencia and southwest of Castaic Junction consist of moderately sorted, yellowish-gray to light yellowish-brown sandstone, conglomerate and silty sandstone, and poorly sorted sandy mudstone beds; the conglomerate beds also contain clasts derived from the Santa Susana Mountains; less lithified and sorted than underlying Saugus Formation strata. Most of this section was assigned to the Saugus Formation by Winterer and Durham (1962) and by Dibblee (1996d), but was assigned to the Pacoima Formation by Treiman (1986). This unit appears to be a transitional facies between the two formations, both structurally and lithologically; angular discordance with the underlying Saugus varies from locally distinct along the southeastern

portion of the contact, where it coincides with a monoclinical warp, to negligible to the northwest at the Santa Clara River. The contact with the overlying Pacoima Formation is a subtle angular unconformity or disconformity. This unit may correlate with the upper Saugus strata on the south flank of the Santa Susana Mountains based on the appearance of clasts derived from the newly emergent Santa Susana Mountains.

- Qsc Saugus Formation, Camarillo member (late Pleistocene)**—Thickly bedded, reddish, pebble-bearing siltstone; paleosols with carbonate-cemented rhizoliths common; clasts are dominantly composed of locally derived Miocene shale and volcanic clasts, with subordinate granitic and metamorphic clasts. Defined informally by DeVecchio and others (2012b) for their chronostratigraphic units Q_{s2} and Q_{s3} exposed in the Camarillo and Las Posas Hills area; locally derived clast assemblage distinguishes this member from older sections of the Saugus Formation to the north and is interpreted by DeVecchio and others (2012b) to indicate that uplift of South Mountain and Oak Ridge had diverted the ancestral Santa Clara River to the north, thereby preventing crystalline clasts derived from the San Gabriel Mountains from reaching this area; DeVecchio and others (2012b) report IRSL dates of 78 ± 6 ka to 125 ± 9 ka for this member; thickness 40 to 60 m.
- Qsv Saugus Formation, volcanoclastic breccia-conglomerate (Pleistocene)**—Massive to crudely bedded, breccia-conglomerate composed of angular to subrounded, pebble- to boulder-size, weathered and fresh clasts of Conejo Volcanics in a poorly consolidated matrix of caliche, clay, silt and sand. Amount of matrix material is variable; some exposures consist only of angular, monolithologic volcanic clasts coated with caliche and contain little or no other matrix material. Previously mapped as part of the Conejo Volcanics. May represent remnants of debris shed from Conejo Volcanics highland into local basin during deposition of Saugus Formation (T. F. Blake, pers. com., 1993). (Dibblee, 1992a and 1992b; Irvine, 1995).
- QTsg Saugus Formation, conglomerate (early Pleistocene)**—Conglomerate mapped at the base of the formation. Clasts are predominantly crystalline igneous and metamorphic rocks recognizable as presently exposed in the northwestern San Gabriel Mountains. (Saul and Wootton, 1983).
- QTsr Saugus Formation, Sunshine Ranch Member, undivided (early Pleistocene to late Pliocene)**—Sulfur-yellow to light-brown and light-gray sandstone, conglomerate and silty sandstone, greenish-gray sandy siltstone and mudstone, and local limestone beds; sandstone and conglomerate commonly cross bedded or channeled; considered primarily paralic nonmarine or transitional brackish lagoon or estuary deposits with local interfingering marine beds; the greenish-gray fine-grained interbeds are considered the most characteristic lithologic type of the member (exposed in the Oat Mountain, San Fernando, Newhall, and Mint Canyon 7.5' quadrangles). The thickness of the Sunshine Ranch Member is estimated to be about 3,000 ft. (915 m) in the type area. This member is primarily late Pliocene in age based on fossil horse teeth, but likely early Pleistocene in part based on revised time scale of Gibbard and others (2010). It was initially named informally by Hazzard (1940) in an unpublished report as the "Sunshine Ranch formation" for distinctive transitional strata at Sunshine Ranch in the Mission Hills area of the northern San Fernando Valley. Oakeshott (1950, 1958) published formal descriptions and mapping of this unit, which he assigned as an upper member of the Pico Formation; subsequently reassigned as a lower member of the Saugus Formation by Winterer

and Durham (1958, 1962) and this usage has been adopted by most subsequent workers in the area (e.g. Barrows and others, 1974; Saul, 1975; Treiman 1987b; Dibblee Foundation maps); Saul and Wootton (1983) excluded all fossiliferous marine beds and subdivided the Sunshine Ranch into an upper and lower facies. Diagnostic greenish-gray mudstone and peaty siltstone occur locally in the lower Saugus Formation south and east of Newhall, leading Treiman (1987b) and Dibblee (1991d, 1992c) to map these outcrops as the Sunshine Ranch Member. The diagnostic beds are uncommon and laterally discontinuous, however. Winterer and Durham (1962) concluded that it is not practical to delineate this member in this area. These possible areas of the Sunshine Ranch Member are shown as queried.

QTsru Saugus Formation, Sunshine Ranch Member, upper facies—Nonmarine, poorly consolidated grayish-green clayey sandy siltstone and mudstone, light-brown silty sandstone, light-gray to yellowish-gray pebbly arkosic sandstone and sandy conglomerate, and thin beds of white sandy and nodular limestone; thickness as much as 300 m. Saul and Wootton (1983) note that this facies best characterizes the member and is mapped by them north of the San Gabriel Fault (southwest part of Mint Canyon 7.5' quadrangle).

QTsrl Saugus Formation, Sunshine Ranch Member, lower facies—Nonmarine sulfur-yellow, brown or gray arkosic sandstone, silty sandstone, pebbly sandstone, and conglomerate (Saul and Wootton, 1983); thickness about 120 m; occurs on both sides of the San Gabriel Fault (southwest part of Mint Canyon 7.5' quadrangle).

QTse Saugus Formation, Elsmere Canyon delta plain facies (Pliocene)—Sandstone and conglomerate with subordinate siltstone and sandy siltstone interbeds; typically weathers light gray and gray to light greenish gray but is locally brown on fresh surfaces due to oil impregnation; light-brown to brown iron-oxide staining locally common; clasts pebble to local boulder size, subrounded to rounded, and composed primarily of crystalline rock derived from the adjacent San Gabriel Mountains; small-scale, low-angle to larger-scale trough cross bedding and channels with erosive bases common (Squires, 2012); foreset beds locally apparent; commonly forms resistant exposures and cliffs in the Elsmere Canyon area; over 450 m thick. Squires (2012) interprets this unit as a braid delta where a braided river flowing from the ancestral San Gabriel Mountains entered the ocean; strata in the Elsmere Canyon area are interpreted as braided river deposits on the delta plain that interfinger to the southwest with delta front and offshore marine deposits of the Pico and Towsley Formations west and south of the Antelope Valley (14) Freeway. This facies may interfinger with Sunshine Ranch-like mudstone beds northeast of Whitney Canyon and is overlain to the northwest by possible Sunshine Ranch member strata per Treiman (1987b). Squires (2012) notes a possible marine transgression at the top of this unit. This section previously mapped as Pico Formation by Winterer and Durham (1962) and Treiman (1987b), but assigned to the Saugus Formation by Dibblee (1991d, 1992c) and by Squires (2012) based primarily on the lack of marine fossils. This unit is assigned here to the Saugus Formation following the definitions of Winterer and Durham (1962) based on the lack of marine fossils and interpreted nonmarine depositional environment (Squires, 2012); however, differentiation of the lateral transition from marine to nonmarine aspects of the delta is problematic in this area and some unfossiliferous marine delta front deposits may be included west of Highway 14. This facies is mapped because of the unique combination of its nonmarine character and stratigraphic position below Sunshine

Ranch member strata; based on this position and interfingering relationships with the Pico and possibly even the Towsley Formations, this unit is likely entirely Pliocene in age.

Qlp Las Posas Formation (middle to late early Pleistocene)—Shallow marine, light-gray to light yellowish-gray, fine- to locally coarse-grained sandstone, silty sandstone and pebbly sandstone with greenish-gray mudstone and subordinate conglomerate interbeds in the type area; invertebrate fossils and bivalve-dominated hash beds locally common; sands commonly quartz rich; pebbles composed of well-rounded plutonic, metamorphic and volcanic clasts derived primarily from the San Gabriel Mountains; moderately well sorted; medium bedded to locally laminated; poorly cemented. The Las Posas Formation crops out on either side of the Las Posas Valley in the Las Posas Hills and on the south side of South Mountain/Oak Ridge west of Long Canyon, and west of Fillmore on the north side of the Santa Clara River (western Ventura basin). A prominent basal conglomerate is commonly present in the South Mountain area (Lung, 1958) and northwest of the Santa Clara River at Adams Canyon (basal Saugus of Driver, 1928; Irvine, unpublished mapping 1991). It overlies or interfingers with the Mudpit shale north of the Santa Clara River. In the South Mountain area, it conformably overlies or locally interfingers with upper Pico Formation siltstone and is distinguished from older shallow marine strata of the upper Pico Formation (QTpcu) to the east by its stratigraphic position above the Grimes Canyon deltaic unit (QTpg), whereas QTpcu is generally below QTpg; to the south, it unconformably overlies the Sespe Formation and Conejo Volcanics in the Las Posas Hills. The Las Posas Formation is up to 300 m thick below Las Posas Valley (Dibblee, 1992g). Its age is estimated at 450 ka to 750 ka based on amino acid racemization (Wehmiller, 2010 in DeVecchio and others, 2012b), but DeVecchio and others (2012b) report an OSL date of 141 ± 10 ka near the base of the section in the Las Posas Hills. Sarna-Wojcicki and others (1984) estimate the base of the shallow marine sands (their “San Pedro”) is at about 1.0 Ma in the South Mountain area, but also report an age of about 0.4 Ma in the Ventura area. This unit was originally mapped as Fernando Formation by McLaughlin and Waring (1914) after the definition of Eldridge and Arnold (1907) and subsequently assigned to the Saugus Formation by Kew (1924). The Las Posas “formation” was coined by Pressler (1929) for sands in the Las Posas Hills type area, and nearby South Mountain, Oak Ridge and Camarillo Hills that are stratigraphically above the “Santa Barbara horizon” and contain warm water “Saugus” fauna of Kew (1924) and Waterfall (1929). Pressler subdivided this unit into a lower Kalorama member (which Bailey, 1935 subsequently included in his Santa Barbara Formation) and an upper Long Canyon member. Subsequent workers referred to this section either as a marine member of the Saugus following Kew, 1924 (e.g. Pasta, 1958; Lung, 1958; Jakes, 1979), as the San Pedro Formation (e.g. Grant and Gale, 1931; Bailey, 1943, 1951; State Water Resources Board, 1953; Weber and others, 1973), or as the Las Posas Sand or Formation (e.g. Dibblee Foundation Maps; DeVecchio and others, 2012a and b); the term Las Posas Formation is adopted because the term San Pedro is restricted to the Los Angeles basin and the term Saugus Formation is restricted to nonmarine deposits following the original definitions of Hershey (1902b) and Winterer and Durham (1962).

Los Angeles Basin

- Qsp San Pedro Formation (middle Pleistocene)**—Unconsolidated sand with local gravelly sand, silty sand and silt interbeds; shallow marine invertebrate fossils common. Woodring and others (1946) report a maximum stratigraphic thickness of about 300 ft. (90 m). The San Pedro Formation has an estimated age range of 200 to 500 ka, as summarized in Jacobs, (2007). The San Pedro Formation was defined at San Pedro Hill (Palos Verdes Peninsula) and extended to other portions of the Los Angeles basin. Fossils were noted at San Pedro Hill by early workers (e.g. Trask, 1855b; Lawson, 1893) but Dall (1898) is credited as the first to use the term “San Pedro beds” (Wilmarth, 1938). Arnold and Arnold (1902) and Arnold (1903) distinguished a “lower” and “upper” San Pedro series and the “lower series” was subsequently assigned the name San Pedro “formation” by Kew *in* Tiejie (1926). Terminology for the San Pedro Formation was formalized by Woodring and others (1946) and their usage is adopted herein. This term was extended into the subsurface by Poland and others (1956, 1959) and additional background is summarized by Powell and Ponti (2007). The term San Pedro has also been extended by some workers in the past to granular Pleistocene strata in the western Ventura basin based on molluscan fauna (e.g. Grant and Gale, 1931; Bailey, 1935); however, this extended usage is not used here, as suggested by Ponti (pers. comm., 2012), based on the presence of an intervening depositional basin boundary.
- Qi Inglewood Formation (early Pleistocene)**—Shallow marine, well-consolidated clay-siltstone and interbedded very fine-grained sandstone, commonly with calcareous, limonitic concretions; relatively dense and moderately expansive where weathered. This unit is now recognized as one from which most of the landslides in the Baldwin Hills are derived (Hsu and others, 1982).
- QTms Sedimentary rocks of the Pacific Palisades area (early Pleistocene to late Pliocene)**—A few small exposures of marine siltstone and very fine-grained silty sandstone; very soft and slightly indurated, locally very fossiliferous, fossils referred to the late Pliocene or early Pleistocene; maximum thickness about 120 m (Hoots, 1931; McGill, 1989).

Soledad Basin and San Andreas Fault Zone

- QTjh Juniper Hills Formation (early Pleistocene to late Pliocene) undifferentiated**—Pink, buff, light-brown, or red, pebbly to cobbly, coarse, arkosic sandstone, silty sandstone, lesser conglomerate, and thin-bedded shale. Mapped by Barrows and others (1985) in the San Andreas Fault zone. Sandstone and conglomerate represent fluvial and other continental deposits. Sandstone is poorly to moderately indurated, typically well bedded and poorly sorted. Clasts are sub-angular to well-rounded and include abundant yellow-brown sandstone and a variety of very well-rounded, tough metavolcanic cobbles recycled from the San Francisquito Fm.; abundant volcanic rocks probably recycled from the Punchbowl fm.; leucocratic granitic rocks; silver, gray and spotted Pelona Schist; ferruginous syenite; and medium- to coarse-grained blue-Quartz granite and leucogneiss. This unit is typically folded and internally deformed.
- QTjhc Juniper Hills Formation (early Pleistocene to late Pliocene) Clay shale member**—Greenish-gray, light brown, and black silty clay shale with very thin maroon sandstone layers. Mapped by Barrows and others (1985) in San Andreas Fault zone. Shale is thin-bedded,

gypsiferous, with local iron oxide stained bedding. Also contains minor beds of finely laminated gray- to light grayish-brown silty sandstone, white arkose, and white chalky calcareous beds. Clay shale member probably represents lake deposits that are interbedded with other continental deposits. This unit is typically folded and internally deformed. Clay rich units are locally expansive with typical “popcorn” weathering.

QTjhr **Juniper Hills Formation (early Pleistocene to late Pliocene) Red arkose member**—Red to dark-red pebbly arkose and minor white and gray silty sandstone. Localized along Northern Nadeau Fault and is stained, deformed, crushed, and contains fractured clasts. Clasts are predominantly subrounded, light-colored granitic rocks and lesser varicolored volcanic rocks. Strongly resembles Punchbowl Fm. and may have been derived exclusively from a Punchbowl terrane.

QTjhm **Juniper Hills Formation (early Pleistocene to late Pliocene) Mixed clast member**—White to buff, coarse, poorly sorted and locally chaotic, pebbly, arkosic sandstone and angular cobble to boulder conglomerate with abundant, rounded, leucocratic granitic-rock cobbles; subangular to subrounded clasts of gray mica schist, thinly laminated quartzite, and white quartz from Pelona Schist; yellowish rusty-brown, rounded sandstone cobbles and recycled, tough, metavolcanic clasts from San Francisquito Fm.; and scarce, maroon, fine-grained sandstone pebbles from Vasquez Fm. (?). Volcanic clasts (other than recycled San Francisquito Fm. cobbles) not seen. The presence of abundant (locally 80-90%) large clasts of Pelona Schist is distinctive.

Ventura Basin, including San Fernando Basin

QTp **Pico Formation (middle Pleistocene to Pliocene)**—Thick marine sequence composed of siltstone, sandstone and subordinate conglomerate deposited in the Ventura basin; coarser-grained sediments deposited primarily by turbidity currents and are commonly the dominant lithology along the axis of the basin, in feeder channels on the adjacent basin slopes (Yeats, 1979a; Sylvester and Brown, 1988), and at the eastern margin of the basin south of Newhall (Winterer and Durham, 1962); hemipelagic clayey siltstone is interbedded or interfingering with the turbidity deposits and is locally the dominant lithology; deposited primarily at bathyal depths exceeding 4,500 ft. (1400 m) at the base of the section (Natland, 1967), but grades or interfingers up section into upper bathyal to neritic mudstone (see Mudpit shale - QTpms) and shallow water shelf and delta sandstone, conglomerate, and siltstone, with locally prominent fossil hash beds (see QTpcu and QTpg). The siltstone is typically bluish gray where fresh and olive gray with limonite stains or nodules where weathered; coarse-grained units range from light olive gray to light gray and light brown; compact but typically not well cemented. Siltstone beds typically contain abundant foraminifers and local invertebrate fossils. The upper shallow water deposits also contain locally abundant molluscan fossils and ostracodes. The Pico Formation is widely exposed in the eastern Ventura basin; it is exposed in the central Ventura basin on either side of the Santa Clara River Valley, but is thickest below this valley along the Ventura basin axis, where it is largely concealed by alluvium and faulting. Winterer and Durham (1962) report a maximum thickness of about 5,000 to 6,000 ft. (1500 to 1800 m) in the eastern Ventura basin; however, Bailey (1952) reports a thickness of about 13,900 to 15,400 ft. (4200 to 4700 m) west of the map area in the Ventura area. The lower basinal section

pinches out to the south and Pico deposits along the northern margin of the Ventura basin are missing in the upper reaches of the mountains on the north due to uplift and erosion. The basal portion of the formation was reportedly deposited during the Repettian stage in both the western and eastern Ventura basin (e.g. Dibblee, 1988; Beyer and others, 2009), and overlies the Modelo Formation to the west and overlies or interfingers with the Towsley Formation to the east in the type area. The top of the formation is time transgressive and is progressively younger to the west. Near the type section west of Valencia, the Pico Formation is reportedly older than about 2.5 Ma, the age of the base of the Saugus Formation estimated by Levi and others (1986). However, Winterer and Durham (1962) report the presence of the benthic foraminifera *Uvigerina peregrina* and *Bulimina subacuminata* within Pico siltstone, which characterize the early Pleistocene Wheelerian and Venturian stages respectively (Natland, 1952; Squires and others, 2006). McDougall and others (2012) report that these species also occur in the upper Repettian stage. In the western Ventura basin the upper Pico Formation includes early to middle Pleistocene ash beds, and alternatively underlies or includes the 0.6 Ma Lava Creek ash (see QTpms). This section was initially assigned to the Fernando Formation as defined by Eldridge and Arnold (1907) and as mapped by McLaughlin and Waring (1914). Kew (1924) subsequently assigned the lower, marine strata of the Fernando to the Pico Formation (except for coarse-grained shallow marine deposits), with the type section at Pico Canyon. Winterer and Durham (1962) remapped and redefined the formation in the type area and assigned the coarse-grained shallow marine units to the Pico Formation. This usage has been adopted by most workers in the eastern Ventura basin and is adopted here and extended to the Santa Susana Mountains and Oak Ridge. Strata in the Ventura basin containing Repettian-age fauna that are lithologically similar to the type Pico section are included within the Pico Formation. The term Repetto is abandoned entirely as a lithologic formation per the recommendation of Durham and Yerkes (1964). The term Pico is abandoned as a lithologic formation in the Los Angeles basin following the recommendation of Durham and Yerkes (1959, 1964). The term Fernando Formation is not used in the Ventura basin based on differences in lithologic facies reported between the type Pico section and Pliocene strata in the Los Angeles basin (Durham and Yerkes, 1959, 1964) (see Appendix A for details). Lithologic facies have been mapped locally, including:

QTpg Pico Formation, Grimes Canyon deltaic facies—Medium- to coarse-grained sandstone, pebbly sandstone, and pebble conglomerate; cross bedding common to pervasive and foreset beds locally apparent; channeling common as well; weakly cemented to uncemented, clasts typically crystalline and derived from the San Gabriel Mountains, and rounded to well-rounded and smooth; moderately to well sorted; conglomerate locally clast supported; typically light gray; light-brown iron-oxide staining varies from local to prominent; generally unfossiliferous; uncommon greenish-gray sandy siltstone to rare thin claystone interbeds with local invertebrate fossils. This unit is well exposed along Grimes Canyon road and at quarries to the east and west of the road (Moorpark and Simi Valley West quadrangles). It is equivalent to a unit interpreted by Dibblee (1992b) as a delta deposit from west-flowing streams and expanded eastward into Happy Camp Canyon on this map based on additional field mapping. It interfingers with and is underlain by Pico siltstone to the west; underlain by and likely grades into or interfingers with fossiliferous shallow marine sands to the east that are assigned here to the upper coarse-grained marine member of the Pico Formation (QTpcu). Overlain by Las Posas Formation or

undifferentiated Saugus Formation. Maximum thickness is about 315 m per Dibblee (1992b) cross section. This section historically assigned either to the Saugus or San Pedro Formations; designated herein as an informal member of the Pico Formation based on the definition of Winterer and Durham (1962) and the interpretation that most of this unit is marine; This interpretation is based on mapped interfingering relationships with offshore marine siltstone of the Pico Formation to the west, the presence of uncommon fossiliferous interbeds, the presence of marine sands up section of this unit near Grimes Canyon Road, the prevalence of well-rounded and nearly polished clasts indicative of extensive abrasion in a littoral environment, and foreset bedding suggestive of a delta front environment; however, differentiation of unfossiliferous marine sands from nonmarine sands is problematic in some areas and some nonmarine paralic strata are likely included in the unit as currently mapped. This unit stratigraphically separates and distinguishes older, shallow marine sands to the east, assigned herein as an informal upper facies of the Pico Formation (QTpcu), from younger, shallow marine sands to the west assigned herein to the Las Posas Formation.

QTpcu Pico Formation, coarse-grained upper facies—Sandstone, conglomerate and locally prominent fossil hash/coquina beds overlying Pico offshore deposits; locally cross bedded and channeled; gradational with or underlying the Grimes deltaic unit (QTpg); onlaps older formations to the south; overlain conformably or unconformably by nonmarine Saugus or transitional Sunshine Ranch Member strata in most areas; invertebrate fossils locally common. This facies is interpreted as shallow marine shelf, delta or embayment deposits (White, 1983, 1985; Groves, 1991). This section was initially mapped as the lower portion of the Saugus Formation by Kew (1924), but was reassigned to the upper Pico Formation in the eastern Ventura basin by Winterer and Durham (1962). Shallow marine strata previously assigned to the lower marine Saugus Formation in the Santa Susana Mountains are reassigned here to this facies following the usage of Winterer and Durham and subsequent workers in the type localities of the Saugus and Pico Formations (see Appendix A for details).

QTpms Pico Formation, Mudpit shale member (middle to early Pleistocene)—Marine mudstone and siltstone with locally common sandstone interbeds and conglomerate lenses and rare, thin ash beds; conglomerate beds with hard siliceous clasts common at base; foraminifers common; local invertebrate fossils; typically bluish gray when fresh, weathering to olive gray; poorly bedded to locally laminated; 3,500 ft. (1067 m) thick north of Ventura (Natland, 1967). This member was deposited in the western Ventura basin (Fillmore quadrangle) at bathyal to neritic depths (Natland, 1967). Lower contact is conformable with the underlying Pico Formation. Correlative strata in the South Mountain/Balcom Canyon/Oak Ridge area are not lithologically distinctive relative to typical Pico Formation strata (Lung, 1958) and therefore the Mudpit shale member is not distinguished in this area. The upper contact is reportedly time transgressive and interfingers with shallow marine (Las Posas) sands to the east of Ventura (Bailey 1935; Hopps, 1995). Natland (1967) reports this unit contains lower Hallian and upper Wheelerian benthic foraminifers. Contains the 0.73 to 0.78 Ma Bishop ash and 0.8 to 1.1 Ma Glass Mountain ashes and spans the 0.78 Ma transition from reverse (Matuyama) to normal (Brunhes) polarity. The base occurs in proximity to the 1.2 Ma Bailey ash and the top is alternatively shown either above or below the 0.6 Ma Lava Creek ash (Wehmiller and others, 1978, Lajoie and others, 1982; Sarna-Wojcicki and others, 1984). Mudpit shale strata were originally assigned to the

Fernando Formation of Eldridge and Arnold (1907), as mapped by McLaughlin and Waring (1914). These strata were subsequently included in the Pico Formation by Kew (1924) and described as upper Pico Formation by Cartwright (1928) and Driver (1928). Waterfall (1929) noted the similarity of molluscan fauna in this section with the fauna at Bath House beach in Santa Barbara and many subsequent workers assigned this section to the Santa Barbara Formation based on this faunal criteria (e.g. Bailey, 1935, 1951; usage adopted by Weber and others, 1973). Early workers in the Ventura Avenue/Rincon/San Miguelito oil fields referred to this section more informally as the Mudpit shale and Dibblee (1990) assigned it to the informal Mudpit shale member of the Pico Formation. This usage is adopted here (see Appendix A for details).

QTpc Pico Formation, sandstone and conglomerate—Sandstone and conglomerate interbeds within typical Pico siltstone (Val Verde quadrangle and Moorpark 7.5' quadrangles).

Los Angeles Basin

Durham and Yerkes (1964) described two members, upper and lower, in the Puente Hills:

QTfu Fernando Formation, Upper Member (early Pleistocene to Pliocene)—In general, the Fernando Formation consists of massive light-gray siltstone, light yellowish-brown fine- to medium-grained sandstone, and light-brown to reddish-brown pebbly conglomerate in the Los Angeles basin; primarily marine but nonmarine conglomerate beds are reportedly included in the upper part of the section (Lamar, 1970); exposed primarily in the Los Angeles and El Monte quadrangles. Name introduced by Eldridge and Arnold (1907) based on unpublished mapping of Homer Hamlin in the San Fernando Valley and initially extended to Pliocene strata from southern Los Angeles County to Santa Maria. The term Fernando was elevated to group status by Kew (1923, 1924), but was subsequently reclassified back to formational rank to name Pliocene strata of the Los Angeles basin by Durham and Yerkes (1964). See Appendix A for nomenclature details. Locally contains Repettian-Wheelerian (early Pleistocene to early Pliocene per McDougall and others, 2012) foraminiferal zone boundary (Lamar, 1970).

The upper member on this map includes Fernando Formation members 2 and 3 of Lamar (1970): **QTfuc**—pebbly sandstone and conglomerate; **QTfuf**—fossiliferous.

QTfl Fernando Formation, Lower Member (Pliocene)—Interbedded silty sandstone and massive pebble conglomerate of the Los Angeles basin. Includes Fernando Formation member 1 of Lamar (1970). See QTfu above and Appendix A for discussion of nomenclature **QTflc**—conglomerate.

Ventura Basin

Tw Towsley Formation, undivided (early Pliocene to late Miocene)—Interbedded sandstone, conglomerate, and sandy siltstone and mudstone; the coarse-grained facies is light-colored and commonly lenticular, and is interpreted as turbidity current deposits in a submarine fan; the fine-grained facies is characteristically brown weathering and represents deposition between the fan lobes (Fritsche, pers. comm. 2011). Winterer and Durham (1962) report the presence of numerous transported fossil invertebrates that suggest a depositional water depth in excess of 600 ft. (180 m), and possible depths of 3,000 ft. (900 m) or more based on foram assemblages

Strata, up to 4,000 ft. (1200 m) thick, form widespread exposures in eastern Ventura County; overlies Modelo Formation strata in the Topatopa Mountains. The Towsley Formation overlies and interfingers with the Modelo Formation in the Santa Susana Mountains and overlaps Modelo strata to rest directly on basement rocks near and east of San Fernando Pass. Its base is distinguished from the Modelo Formation at the first thick bedded pebbly sandstone. The generally conformable, locally interfingering upper contact with the Pico Formation is chosen at the transition from diagnostic brown-weathering siltstone of the Towsley to olive-gray siltstone with common limonite nodules typical of the Pico. The Towsley Formation is early Pliocene to late Miocene (Winterer and Durham, 1962; Squires and others 2006, fig. 2). This section was initially included in the Modelo Formation by Kew (1924); the section in the Elsmere Canyon area was assigned to the “Repetto formation” by Oakeshott (1950); a new, unnamed formation was proposed by Winterer and Durham (1951), was subsequently named the Towsley Formation in Winterer and Durham (1954), and was formally described and mapped by Winterer and Durham (1962) based on the type section at Towsley Canyon, southwest of Valencia. In the northern San Fernando Valley, east of Pacoima Canyon, a band of strata was shown as Pico Formation by Yerkes and Campbell (2005); Hill (1930) also mapped this section as Pico, but Oakeshott (1958) mapped it as “Repetto formation” and several early Caltech theses note the presence of brown weathering siltstone, which is typical of the Towsley Formation of Winterer and Durham (1962); Barrows and others (1974) mapped it as undifferentiated Towsley/Pico Formation; Dibblee (1991e) maps it as Towsley Formation. This unit is mapped here as Towsley Formation based on Dibblee and the noted lithology, but is queried due to the possible inclusion of undifferentiated Pico Formation strata. Mapped subunits and members include:

- Tws **Towsley Formation, siltstone**—Brown mudstone and siltstone, locally carries foraminifera referred to the Mohnian Stage (late Miocene) of Kleinpell (1938).
- Twc **Towsley Formation, conglomerate**—Pale pebble conglomerate and sandstone in lenticular beds.
- Twhc **Towsley Formation, Hasley Conglomerate Member**—Basal conglomerate member.

Los Angeles Basin

- Tpn **Puente Formation, undivided (early Pliocene and late Miocene)**—Marine siltstone, sandstone, and shale; mostly a Los Angeles basin temporal equivalent of the Modelo Formation, but partly younger; named by Eldridge (*in* Eldridge and Arnold, 1907) from exposures in the Puente Hills; strata are associated with the Los Angeles basin (El Monte, Los Angeles and Hollywood 7.5’ quadrangles) as contrasted with Modelo strata, which are associated with the eastern Ventura basin. In the Los Angeles and Hollywood 7.5’ quadrangles Lamar (1970) mapped four non-sequential, interbedded, informal lithologic subunits, which have not been specifically correlated with the formal members recognized by Shoellhamer and others (1954).
- Tpsl **Puente Formation, siltstone (early Pliocene)**—Well-bedded, light gray siltstone; thickest beds at top of section, also interbeds lower in section (Lamar, 1970, fig. 14).

- Tpsh** **Puente Formation, siliceous shale (early Pliocene)**—Well-bedded, light gray, siliceous shale and siltstone; regularly interbedded with thin, fine- to coarse-grained sandstone beds; most common in a few discontinuous zones, chiefly in upper-central part of formation (Lamar, 1970, fig. 14).
- Tpds** **Puente Formation, diatomaceous shale (early Pliocene)**—Well-bedded, dull white diatomaceous shale; a discontinuous single zone in central part of formation (Lamar, 1970, fig. 14).
- Tpss** **Puente Formation, sandstone (late Miocene)**—Well-bedded, very fine- to very coarse-grained sandstone; medium to light brown and light gray; mostly well cemented but less so in uppermost parts; local discoidal concretions; most abundant in lower part of formation (Lamar, 1970, fig. 14).
- Tpnsc** **Puente Formation, Sycamore Canyon Member (late Miocene)**—Predominantly sandstone and pebble conglomerate, laterally variable; sandstone is thick-bedded to massive, medium- to coarse-grained, friable; siltstone is massive- to thin-bedded, siliceous; conglomerate is massive, contains pale to brownish-gray pebbles and cobbles; siltstone locally contains bathyl-depth foraminiferal faunas; **Tpnsc** - conglomerate bed. Member named by Schoellhamer and others (1954).
- Tpny** **Puente Formation, Yorba Member (late Miocene)**—Predominantly siltstone, with sandstone interbeds; named for Yorba Bridge over the Santa Ana River, east of Atwood; white to gray, thin-bedded, micaceous and siliceous siltstone; upper part contains large boulders “floating” in much fine-grained material – interpreted to be a turbidity current deposit. Named by Schoellhamer and others (1954).
- Tpnsq** **Puente Formation, Soquel Member (late Miocene)**—Predominantly sandstone, minor interbedded siltstone; sandstone is gray to yellowish-gray, massive- to well-bedded, medium- to coarse-grained, poorly sorted; interbedded pebbly sandstone; many such beds are graded, locally pebbly to cobbly conglomeratic; lower part of unit contains ellipsoidal, calcite-cemented boulders as large as 1.5 m. Named by Schoellhamer and others (1954).

Eastern Ventura Basin

- Tcs** **Castaic Formation, undivided (late Miocene)**—Marine tuffaceous or diatomaceous shale, interbedded pebbly sandstone, sparse limestone concretions with well-preserved foraminifera. Named by Winterer and Durham (1954) for marine sandstone strata of late Miocene age (equivalent in age to the Modelo Formation), north of the San Gabriel Fault and east of Newhall; name extended to north for late Miocene shale with interbedded sandstone and minor pebble conglomerate in Soledad-Ridge basin area by Crowell (1954).
- Tm** **Modelo Formation, undivided (late and middle Miocene)**—Predominantly gray to brown thin-bedded mudstone, diatomaceous clay shale, or siltstone, with interbeds of very fine-grained to coarse-grained sandstone; proportion and thickness of sandstone interbeds allows lithofacies to be mapped in some areas; generally unconformable on older rocks around northern, eastern and southern margins of the Ventura basin. The base of the Modelo is generally unconformable on middle Miocene and older rocks. The name, Modelo, was

introduced by Eldridge and Arnold (1907) for strata exposed in the Topatopa Mountains, north of Piru and further described in the Santa Susana Mountains and San Fernando Pass areas by Winterer and Durham (1962); extended to the eastern Santa Monica Mountains and described in detail by Hoots (1931) where further noted for turbidite features indicating submarine fan deposition (Sullwold, 1960); Along the north flank of the Santa Monica Mountains the unconformity mapped by Hoots (1931) in the eastern part of the range, where Modelo locally overlies Santa Monica Slate, has been mapped continuously westward (Yerkes and Campbell, 1980; Weber, 1984; and unpublished 1:12,000-scale mapping by Yerkes and Campbell, 1965-1974, in the Canoga Park and Calabasas 7.5' quadrangles) as far as the north side of the Ventura Freeway (U.S. 101) at the west side of Las Virgenes Creek, to the west of which it becomes accordant with (and apparently conformable on) subjacent strata of the Calabasas Formation (Weber, 1984); further west, the Modelo and subjacent parts of the Calabasas appear to grade progressively westward into more diatomaceous, clayey, Monterey-like lithofacies. Many of the sandstone and shale beds below (south of) the unconformity (and its westward conformable extension) and above (north) of the Conejo Volcanics are lithologically similar to the Modelo but more intensely folded and faulted; these have been assigned to the Calabasas Formation by Yerkes and Campbell (1979). Fellbaum and Fritsche (1993) include them in the Modelo Formation; however, their stratigraphic position below the unconformity mapped by Hoots (1931) as the base of the Modelo, and the predominance of middle Miocene foraminifera (Luisian or Relizian?) in the Calabasas, suggests their correlation with Modelo strata is questionable. In the eastern Santa Monica Mountains the Modelo was mapped and described in detail by Hoots (1931), and Kleinpell (1938) used the unconformity at the base, well exposed near Mohn Springs in Topanga Canyon, where it is underlain by predominantly middle Miocene Topanga strata, as the base for his type Mohnian (foraminiferal) Stage (late Miocene). Widespread in eastern Ventura basin; locally extended to include some strata along the south flank of the Santa Monica Mountains in the Pacific Palisades-Westwood area. Five members were described by Cemen (1977) in the Topatopa Mountains and four of them have been mapped as far south as the north flanks of Oak Ridge and the Santa Susana Mountains. Age-correlative strata in the Los Angeles basin are generally referred to the Puente Formation or, west of the Newport-Inglewood zone, to the Monterey Shale. Mapped facies of the Modelo Formation include:

Tmsu **Modelo Formation, upper sandstone unit at Laskey Mesa**— *Light-gray to light-brown-weathering fine-to coarse-grained sandstone and silty sandstone with very light-gray siliceous siltstone interbeds.* Weber (1984) assigned strata at Laskey Mesa to the Towsley Formation, as shown by Yerkes and Campbell (2005); Truex and Hall (1969) previously assigned most of this section to the Modelo Formation and the uppermost portion to the Santa Margarita Formation, and Brown (1957) mapped it as Modelo Formation; Dibblee (1992b) mapped this section as Tertiary unnamed shale and sandstone; Yeats (1979) reported that Towsley Formation does not occur south of the Santa Susana Fault. Field review of this area did not reveal any brown mudstone or coarse-grained turbidite beds typical of the Towsley Formation and this unit has been reassigned to the upper Modelo Formation herein based on lithologic similarity to Modelo strata to the west and previous usage.

- Tm₅ **Modelo Formation, member 5**—Upper shale and siltstone unit; dark brown to gray, moderately to well compacted, thin-bedded to laminated silty shale and siltstone, locally siliceous near base; contains foraminifera assigned to the upper Mohnian and lower Delmontian Stages of Kleinpell (1938); thickness locally exceeds 458 m. (Cemen, 1977) Includes units mapped as Sisquoc Formation by Dibblee (1991).
- Tm₄ **Modelo Formation, member 4**—Upper sandstone unit; white to gray, fine to coarse-grained arkosic sandstone, with subordinate thin partings and lenticular interbeds of silty clay shale, locally siliceous; thickness variable, locally as much as 825 m. (Cemen, 1977).
- Tm₃ **Modelo Formation, member 3**—Middle shale unit; porcelaneous and calcareous shale and porcelaneous mudstone, brown to buff, thin-bedded to laminated, moderately to well indurated, with thick lenses of gray calcareous sandstone locally; thickness variable but may exceed 763 m.; foraminifera referred to lower part of the Mohnian Stage of Kleinpell (1938) (Cemen, 1977).
- Tm₂ **Modelo Formation, member 2**—Lower sandstone unit; grayish white to dark brown, fine to medium-grained sandstone, locally interbedded with dark brown siltstone and claystone; locally as much as 915 m. thick, thins westward and pinches out between the middle and lower shale units (Cemen, 1977).
- Tm₁ **Modelo Formation, member 1**—Lower shale unit; cherty to porcelaneous shale and mudstone, locally calcareous, locally diatomaceous, moderately to well indurated, thin-bedded to laminated, generally dark gray to brown; contains foraminifera referred to the Relizian and Luisian Stages of Kleinpell (1938), indicating the unit is age-correlative with the Calabasas Formation and, possibly the upper part of the Topanga Canyon Formation in the Santa Monica Mountains; thickness 214-794 m. (Cemen, 1977).
- Tmd **Modelo Formation, diatomaceous shale**—Diatomaceous shale; includes outcrops on the south side of the San Fernando Valley at Pierce College shown as Pico Formation by Yerkes and Campbell (2005), based on the presence of Repettian stage benthic foraminifers (Ingle, 1967; Yerkes and Campbell, 1993); previously assigned to the Modelo Formation by Hoots (1931). Review of these exposures indicates that much of this unit is lithologically more consistent with the Modelo Formation than the Pico Formation. This section is assigned here to the Modelo Formation based on the noted lithology and presence of Modelo Formation mapped on strike to the east and west, but is queried based on the reported presence of Repettian stage fauna.
- Tms **Modelo Formation, sandstone**—Sandstone and conglomerate.
- Tmb **Modelo Formation, “burnt shale”**—Unusual slag and scoriaceous- to obsidian-like material found within the upper part of the Modelo Formation in the Grimes Canyon area, Big Mountain/Happy Camp Canyon, and upper Las Virgenes Canyon area. It is composed of red, yellowish-orange, purple, brown, and black mudstone, siltstone, and diatomite that has been altered by in-situ combustion of natural gas in layers containing abundant organic material, as described and mapped by Irvine (1995), Brown (1957), and Jestes (1958).

Soledad Basin and San Andreas Fault Zone

- Tpbc **Punch Bowl Formation, clay shale member (late Miocene)**—Gray, poorly indurated clayey shale with local gypsum. (Dibblee, 2001).
- Tpbv **Punch Bowl Formation, volcanic clast member (late Miocene)**—White to pink, coarse, pebbly to cobbly, arkosic sandstone, thin-bedded silty sandstone, and minor thin-bedded, white, nodular limestone. Silty layers range from yellowish tan through greenish brown to red. Sandstone is well-indurated, well-stratified and was probably deposited in alluvial fan and floodplain environments. Clasts are predominately light-colored granitic rock pebbles and cobbles with lesser (up to 40%) tuffaceous and porphyritic volcanic rocks ranging in composition from rhyolite to andesite. (Barrows and others, 1985).
- Tmc **Mint Canyon Formation, undivided (late and middle Miocene)**—First described by Hershey (1902b), named by Kew (1924), mapped in detail by Saul and Wootton (1983) and Saul (1985), who recognized three intertonguing lithofacies. Includes a variety of semi-consolidated nonmarine sediments deposited in fluvial and lacustrine environments. Jahns and Muehlberger (1954) describe two informal members: a lower member including reddish-brown basement rock breccia, conglomerate, sandstone, siltstone and mudstone (thickness ~ 335 m); and an upper member consisting of thin-bedded brownish or greenish siltstone and interbedded tuff (thickness ~ 790 m).
- Tmcd **Mint Canyon Formation, Lacustrine deltaic (foreset) facies**—Predominantly fine- to coarse-grained, sparsely-concretionary, cross-bedded, arkosic sandstone, interbedded with conglomeratic sandstone, gray to brown sandy siltstone and claystone; tuff and tuffaceous sedimentary beds; marly and nodular carbonate. Sparsely fossiliferous: small clam and snail shells, vertebrate bones and teeth. (Saul and Wootton, 1983).
- Tmcl **Mint Canyon Formation, Lacustrine bottomset facies**—Interbedded sandstone, silty sandstone, siltstone, claystone and thin beds and lenses of limestone; a few lenses of turbidite sandstone and coarse conglomerate; tuffaceous beds; ostracod shells; bedding planes commonly darkened by finely divided lignite; graded beds common. (Saul and Wootton, 1983).
- Tmcm **Mint Canyon Formation, Lacustrine and lake-marginal fluvial facies**—Deposits of arkosic sandstone and conglomeratic sandstone, with interbedded siltstone and mudstone; some nodular carbonate in siltstone; thin beds of limestone common in mudstone. (Saul and Wootton, 1983).
- Ttk **Tick Canyon Formation, undivided (middle to early Miocene)**—Reddish, fluvial and lacustrine sandstone, siltstone and claystone, and gray, tan, and reddish, well-cemented and well-bedded conglomerates (Mint Canyon, Agua Dulce and San Fernando 7.5' quadrangles; Oakeshott, 1958). Named by Jahns (1940), and separated from the overlying lower part of the Mint Canyon Formation on the basis of a distinctively older vertebrate fauna. Includes area east of Tick Canyon and in upper Agua Dulce Canyon mapped by Oakeshott (1958) as Mint Canyon Formation but shown by Jahns and Muehlberger (1954) and Dibblee (1996b,c) as Tick Canyon Fm. Ehlert (2003) found no lithologic differences or unconformity between Tick Canyon and overlying Mint Canyon Formations and suggests that units mapped as Tick Canyon Formation should be considered basal sediments of the Mint Canyon Formation. Original usage retained, but question regarding validity of Tick Canyon Formation noted.

Ttkc **Tick Canyon Formation, conglomerate (middle to early Miocene)**—Dark gray, coarse, poorly-bedded conglomerate, Oakeshott, 1958), Dibblee (1996b,c).

Los Angeles Basin and Continental Borderland

Tmt **Monterey Shale, undivided (late, middle, and early Miocene)**—Marine clay shale, thin interbedded siltstone, minor sandstone and pebble conglomerate, and glassy tuff; siltstone is commonly diatomaceous, locally bituminous, siliceous, or dolomitic; sandstone is commonly quartz arenite; some conglomerates contain clasts of glaucophane schist. Shale is gray to dark brownish gray where fresh, weathers quickly to chalky white; contains foramifera referred to the Relizian, Luisian, or Mohnian Stages (early middle, late middle, or early late Miocene respectively) of Kleinpell (1938). Monterey strata are exposed only south of the Malibu Coast Fault and west of the Newport-Inglewood zone of faulting and folding; rocks of equivalent age north of the Malibu Coast Fault are referred to the Topanga Group and the Modelo Formation; east of the Newport Inglewood zone, strata of equivalent age are referred to the Puente Formation and the Topanga Group. The Monterey is generally considered a distal, deep-basin facies of the more-proximal Modelo, Puente and other formations of the equivalent age range. Name extended into southern California from type area in Monterey County, central California (Woodring and others, 1936). The upper part of the unit in some areas (chiefly along the Pacific Coast Highway west of Point Dume) is late Mohnian in age and locally overlies the early Miocene Trancas Formation unconformably; its relation to middle Miocene Monterey strata on Point Dume is obscured, but could be an intraformational unconformity. The (mostly middle Miocene) section exposed on Point Dume is about 1000 m thick. The Monterey Shale in the northern Los Angeles basin is unconformably overlain by unconsolidated Pliocene, Pleistocene and Holocene deposits; *includes*:

Tmtd **Monterey Shale, deformed (middle and early Miocene)**—Intensely deformed shale, siltstone, and sandstone, commonly dolomitic, locally siliceous, locally very cherty; contains foraminifera referred to the Relizian or Luisian (middle Miocene) Stages of Kleinpell (1938). In upper plate of Escondido thrust fault beds are tightly folded, with vertical limbs and gently east-plunging axes; thickness across folded beds is at least 650 m.

Ventura Basin and Los Angeles Basin

Tt **Topanga Group, undivided (middle and early Miocene)**—First called the Topanga Formation by Kew (1923) for exposures in the central Santa Monica Mountains that include the type locality for the “Topanga Canyon fauna” (about 50 molluscan species) of Arnold (1907a). Durrell (1954) recognized that the three subdivisions identified by Kew (1923) are contiguous westward with extensive units of formation rank, labeling them the Lower Topanga, Middle Topanga and Upper Topanga Formations. Subsequent publication of the North American Stratigraphic Code led Yerkes and Campbell (1979) to change the names to conform, and designated the set of three formations as the Topanga Group, consisting of the Calabasas Formation, the Conejo Volcanics, and the Topanga Canyon Formation, each with two or more members. Elsewhere, middle Miocene strata with similar lithologic and biologic facies have been informally divided: in the eastern Ventura basin and the northern Los Angeles basin beds

containing Luisian BFZ foraminifera (late middle Miocene), that are labeled **Tt** are chiefly age-equivalent to the Calabasas Formation; beds containing a “Temblor” or “Topanga” molluscan fauna have also been labeled **Tt**. Middle Miocene volcanic rocks that may be related to the Conejo Volcanics, but are spatially separated, are labeled **Ttb**. The distribution and nomenclature history of the Topanga Group has been reviewed by Campbell and others (2007).

In the Santa Susana Mountains, informal subunits include:

- Tt₄** **Topanga Group, Oat Mountain unit 4**—Upper sandstone with interbedded siltstone and local pebble conglomerate; sandstone, medium- to coarse-grained arkose, locally contains *Amusium lompocensis*; thickness about 140 m; (Saul, 1979).
- Tt₃** **Topanga Group, Oat Mountain unit 3**—Shale, foram-bearing siltstone, and mudstone, about 122 m thick (Saul, 1979).
- Tt₂** **Topanga Group, Oat Mountain unit 2**—Sandstone, fine- to coarse-grained, arkosic, well indurated, massive, about 244 m thick (Saul, 1979).
- Tt₁** **Topanga Group, Oat Mountain unit 1**—Shaly siltstone, massive- to well-bedded, minor lenses of conglomeratic sandstone; siltstone locally contains microfauna assigned to the Luisian Stage of Kleinpell (1938) suggesting it is an age-correlative of the Calabasas Formation (Saul, 1979).

In the eastern Santa Monica Mountains informal subunits include:

- Ttss** **Topanga Group, sandstone**—Sandstone, medium- to coarse-grained, well-bedded, light brown and gray (Lamar, 1970).
- Ttsl** **Topanga Group, siltstone**—Siltstone, well bedded, medium to dark brown, with interbedded sandstone, shale and chert (Lamar, 1970).
- Ttcg** **Topanga Group, conglomerate**—Conglomerate, massive- to well-bedded, light brown; includes basal breccia locally (Lamar, 1970).
- Ttb** **Intrusive and extrusive volcanic rocks**—Chiefly basaltic, interlayered with sandstone and shale assigned to the Topanga Group. In part, may be correlative with Conejo Volcanics of central and western Santa Monica Mountains and adjacent areas to the northwest; but includes rocks that are dated as older than the oldest contiguous Conejo (McCulloh and others, 2002). (eastern Santa Monica Mountains, Hoots, 1931; Santa Susana Mountains, Evans and Miller, 1978; northeastern Verdugo Mountains, Oakeshott, 1958).

In the central and western Santa Monica Mountains divisions include:

- Tcb** **Calabasas Formation, undivided (early late Miocene and late middle Miocene)**—Interbedded impure, clayey to silty sandstone and silty shale, with local beds of sedimentary breccia; sandstone is thin-, medium- and thick-bedded, mostly medium to coarse grained, poorly sorted, commonly with wacke texture, commonly shows graded bedding; shale, locally diatomaceous; may have small phosphatic pellets, locally abundant fish scales, sparse Foraminifera and rust-colored plant casts, some thicker beds contain zones of large ovoid dolomitic concretions; sedimentary breccia, olistostromes incorporating cobble- to large

boulder-size clasts of recognizable older Tertiary strata, some as fossil-bearing clasts of Paleocene, Eocene, early Miocene, and middle Miocene strata. Many of the sandstones are lithologically similar to those in the overlying, less-deformed Modelo Formation. Total thickness is about 1,200 m in the type area. The Modelo is unconformable on the Calabasas in the name area, however, west of Malibu Junction and north of the Ventura Freeway the two formations are accordant, the Calabasas is greatly thinned, and grades westward into finer-grained clayey siltstone and shale much like that of the Modelo in the area, and the two formations are distinguished only by differences in foraminiferal fauna. (The Calabasas there contains foraminifera referred to the Luisian Stage of Kleinpell, 1938; the Modelo contains foraminifera referred to the Mohnian Stage of Kleinpell, 1938). The contact relationships with the underlying Conejo Volcanics are marked by extreme variability, ranging from unconformable to accordant and intertonguing, apparently reflecting marine sedimentation, at least partly contemporaneous with the development of a submarine volcanic edifice and associated tectonic disturbance. Intraformational deformation west of Liberty Canyon, the angular unconformity east of Medea Creek, and the abruptly thinner Calabasas section near and west of Agoura reflect local tectonic activity during deposition; and the volcanic conglomerate is probably significantly younger than most of the Calabasas section to the east. In the west-central Santa Monica Mountains the Calabasas Formation and older strata are involved in major pre-Modelo deformation that includes detachment faulting. Well-defined upper-plate ramps in Trancas and Topanga Canyons show offsets exceeding many hundreds of feet on faults that bend to follow bedding planes, along which intervening beds are missing or thinned, and establish a style of younger-over-older faulting as a significant structural feature. Outcrops where contact relations can be observed in macroscopic detail, and confirm depositional or shear-surface relations, are extremely rare, but where found indicate little discordance at stratigraphic hiatus or local unconformity contacts between pre-Conejo Tertiary Formations. The Paleogene sequence is similar to that in the adjacent Simi Hills and the more distant Santa Ana Mountains, where variations in depositional environments appear to represent epeiric transgressions and regressions. Therefore, we conclude that contacts lacking local exposures of diagnostic depositional character, where significant parts of the section are missing or dramatically thinned, are one or more of a set of detachment faults. The alternative is to infer Paleogene orogenic deformation on a scale not recognized elsewhere in southern California.

Tcbvc Calabasas Formation, Volcanic conglomerate (late middle Miocene)—Volcanic conglomerate, mapped by Weber (1984) as basal Topanga Formation where it rests unconformably on the Chatsworth Formation (Cretaceous) along the south flank of the Simi Hills, and extends northwestward across the Cretaceous-Paleogene sequence at the west end of the Simi Hills. This conglomerate is probably correlative with volcanic conglomerates that locally forms the base of the Calabasas Formation sandstone and shale exposed along and north of the Ventura Freeway in the Agoura area (Blackerby, 1965), and overlying volcanic strata in the Thousand Oaks area (Weber, 1984). In addition to the informal volcanic conglomerate member, five members were named by Yerkes and Campbell (1979).

Tcbs Calabasas Formation, Stokes Canyon Breccia Member (late middle Miocene)—Sedimentary breccia consisting of angular boulders and cobbles of redeposited well-cemented

sandstone with molluscan faunas diagnostic of the "Martinez" (Paleocene) and "Domengine" (middle Eocene) Stages; the breccia bed is locally as thick as 60 m; underlain and overlain conformably by Calabasas sandstone and siltstone; locally overlain unconformably by basal conglomerate of the Modelo Formation. Thinner, less continuous breccia beds are present at two other horizons nearby. (Stokes Canyon area, northern Malibu Beach and southern Calabasas 7.5' quadrangles; Yerkes and Campbell, 1979, p. E22; Yerkes and Campbell, 1980).

Calabasas subunits in the upper plate of Malibu Bowl Detachment Fault include:

- Tcbmp Calabasas Formation, Mesa Peak Breccia Member**—Sedimentary breccia consisting of angular boulders and cobbles of volcanic rock in a very coarse-grained sandstone matrix; maximum thickness approximately 288 m. Overlies the Newell Sandstone Member of the Calabasas Formation in the upper plate of the Malibu Bowl Detachment Fault, west central Malibu Beach 7.5' quadrangle (Yerkes and Campbell, 1979, p. E23; Yerkes and Campbell, 1980).
- Tcbn Calabasas Formation, Newell Sandstone Member**—Poorly sorted turbidite sandstone and interbedded shaly siltstone with large dolomitic concretions; overlies and wedges out westward into Malibu Bowl Tongue of the Conejo Volcanics; maximum thickness approximately 244 m. (Yerkes and Campbell, 1979, p. E23; Yerkes and Campbell 1980).
- Tcbd Calabasas Formation, Dry Canyon Sandstone Member**—Sandstone (proximal turbidites) and subordinate interbedded siltstone, many thin turbidites, locally prominent dolomitic concretions in siltstone; overlies and tongues eastward into Solstice Canyon Tongue of the Conejo Volcanics; underlies and intertongues westward into Escondido Canyon Shale Member of the Calabasas Formation; overlain by, and locally intertongues with, the Malibu Bowl Tongue of the Conejo Volcanics, and locally overlain by the Newell Sandstone member of the Calabasas Formation; locally overlain by Latigo Canyon Breccia Member of the Calabasas Formation; underlain by Ramera Canyon Tongue of Conejo Volcanics; approximate maximum thickness 686 m (Campbell and others, 1996; Yerkes and Campbell, 1979, p. E24; Yerkes and Campbell, 1980).
- Tcbl Calabasas Formation, Latigo Canyon Breccia Member**—Sedimentary breccia, large angular boulders of Sespe Sandstone and fossiliferous Vaqueros sandstone in sandy, tuffaceous or volcanic breccia; intertongues with epiclastic volcanic breccia; approximate maximum thickness 91 m; underlies the Solstice Canyon Tongue of the Conejo Volcanics and overlies the Escondido Canyon shale member of the Calabasas formation (Yerkes and Campbell, 1979, p. E23; Campbell and others, 1996).
- Tcbe Calabasas Formation, Escondido Canyon Shale Member**—Siltstone, mudstone, shale and minor interbedded thin sandstone turbidites; locally prominent dolomitic concretions; tongues eastward into Dry Canyon Sandstone Member of the Calabasas Formation; westward laps onto and intertongues with Ramera Canyon Tongue of the Conejo Volcanics; approximate maximum thickness 276 m; (Yerkes and Campbell, 1979, p. E24; Campbell and others, 1996).
- Tco Conejo Volcanics, undivided (middle Miocene)**—Basalt, andesitic basalt, basaltic andesite, andesite, and dacite in a thick sequence of extrusive volcanic flows, flow-breccias, agglomerates, and epiclastic volcanic breccias, volcanic sandstones and siltstones; thickest

(probably in excess of 3 km) where it underlies the north flank of the western Santa Monica Mountains, and thinning eastward to as little as 200 m of interbedded flows and volcanoclastic sedimentary rocks on the nose of the Topanga Anticline; further east the volcanic rocks are thin and discontinuous, and the name has not been extended eastward for more than a mile east of Topanga Canyon Road. The thick sequence shows a crude compositional layering: pillow basalts, pillow breccias, aquagene tuffs, black volcanic sandstones and interbedded black siltstones are common in the basal part of the Conejo, associated with basalt, andesitic basalt, and basaltic andesite flows, breccias, and agglomerates; andesite and basaltic andesite predominate in the central part of the sequence with interlayered andesitic basalt; and an upper zone, dominated by andesitic and basaltic andesite but including dacite flows in some areas as well as epiclastic volcanic conglomerates containing andesite and dacite clasts. The map by Durrell (1954) called the volcanics that intervene between lower Miocene and upper-middle Miocene sedimentary strata the "Middle Topanga Formation"; but his students Sonneman (1956) and Blackerby (1965) adopted the name "Conejo Formation" and "Conejo Volcanics", following the usage of Taliaferro (1924) for rocks in the Conejo Mountain area. This usage was formalized by Yerkes and Campbell (1979). In the vicinity of boundary between the Triunfo Pass and Point Dume quadrangles the contact with the upper part of the underlying Topanga Canyon and Vaqueros Formations is a buttress unconformity against a degraded half graben or caldera wall that laps eastward conformably onto shelf sediments at a higher stratigraphic level. Weigand and Savage (1993) have summarized the geochemistry of the Conejo Volcanics, comparing them with other southern California Miocene volcanic suites. The range in initial $^{87}\text{Sr}/^{86}\text{Sr}$ is reported as 0.60294-0.70320, indicating parent magmas derived from the upper mantle without important crustal rock contamination (Weigand and Savage, 1993, p. 105,106). K-Ar ages on plagioclases from basalt and andesite, reported by Turner and Campbell (1979), range from 15.5 ± 0.8 m.y. near the base of the Conejo to 13.9 ± 0.4 m.y. near the top. McCulloh and others (2002, p. 3) have recalculated the older date using updated decay constants to yield a 15.9 ± 0.8 m.y. age.

Along the north flank of the Santa Monica Mountains, lithologic subunits include:

- Tcode** **Conejo Volcanics, dacite-bearing epiclastic lenses**—Epiclastic volcanic rocks, but including basalt, andesite and dacite pyroclastic flows and flow breccia; forms relatively thin layers and lenses interbedded in lower part of Calabasas Formation, which locally includes volcanic sandstone and volcanic conglomerate (north of Ventura Freeway, Thousand Oaks 7.5' quadrangle; after Blackerby, 1965).
- Tcod** **Conejo Volcanics, dacite-bearing upper zone**—Interlayered dacite (including trachytic dacite), andesite and basalt flows and pyroclastics; minor volcanic sandstone. Malibu Junction Member of Conejo Volcanics of Blackerby (1965) (south of Ventura Freeway, Thousand Oaks 7.5' quadrangle).
- Tcoa** **Conejo Volcanics, andesitic central zone**—Interlayered porphyritic and microporphyritic andesite, andesitic basalt, and basaltic andesite flows, agglomerates and flow breccias; includes some crystal tuff, vesicular andesite, pyroclastics and volcanic sandstone; includes Ladyface Member and Medea Member of Blackerby (1965), as well as Potrero and Triunfo Members of Sonneman (1956) and Guynes (1959). (Blackerby, 1965 and unpublished mapping 1965-1973;

Campbell and others, 1996, and unpublished mapping 1962-1976; Sonneman, 1956; Guynes, 1959; and Weber, 1984). Lithologically recognized subunits, which occur at various stratigraphic levels, and do not form a consistent stratigraphic sequence, include:

- Tcoaf Conejo Volcanics, andesitic central zone, andesitic flows**—Andesite flows, mapped as Potrero Member of the Conejo Formation by Sonneman (1956) and Guynes (1959).
- Tcoaa Conejo Volcanics, andesitic central zone, andesitic agglomerate**—Andesite agglomerate and tuff, mapped as part of Potrero Member of the Conejo Formation by Guynes (1959).
- Tcoab Conejo volcanics, andesitic central zone, andesite breccia**—Andesitic and basaltic breccia and some agglomerate; mostly equivalent to rocks mapped as the Triunfo Member by Sonneman (1956) and Guynes (1959), and includes rocks mapped as Medea Member by Blackerby (1965). (Yerkes and Campbell, 1980; Campbell and others, 1970; Sonneman, 1956; Guynes, 1959; Weber, 1984; and unpublished 1:12,000-scale mapping by R. H. Campbell and B. A. Blackerby, 1967-1972).
- Tcob Conejo Volcanics, basaltic lower zone, basalt and andesitic basalt**—Chiefly basalt, olivine basalt, basaltic andesite, and andesitic basalt; ranges from trachytic olivine basalt to porphyritic quartz andesite; as flows, breccias, agglomerates, pillow basalts, pillow breccias, and basaltic sand and silt; includes Olivine Basalt and Seminole Members of Blackerby (1965); (Malibu Beach, Point Dume, Triunfo Pass, and Thousand Oaks 7.5' quadrangles; Yerkes and Campbell, 1980; Campbell and others, 1996; Blackerby, 1965; Sonneman, 1956; Guynes, 1959; Weber, 1984; and unpublished 1:12,000-scale mapping by R. H. Campbell and B. A. Blackerby, 1962-1976). Lithologically recognized subunits (flows and breccias) are interlayered at various stratigraphic levels in the upper part of the zone, and do not form a consistent stratigraphic sequence; however pillow basalt, pillow breccia, and volcanic sand predominate in the lower part of the zone. Subunits include:
- Tcobf Conejo Volcanics, basaltic lower zone, basalt and andesitic basalt, basalt flows**—Basalt, andesitic basalt and basaltic andesite flows (Blackerby, 1965; Yerkes and Campbell, 1979, 1980; Campbell and others, 1996; Weber, 1984).
- Tcobb Conejo Volcanics, basaltic lower zone, basalt and andesitic basalt, basaltic breccia**—Basalt, andesitic basalt and basaltic andesite breccias; can include some pillow breccia; in part, mapped as Serrano member of Conejo Volcanics by Sonneman (1956) and Guynes (1959). (Sonneman, 1956; Guynes, 1959; Blackerby, 1965; Yerkes and Campbell, 1980; Weber, 1984; Campbell and others, 1996).
- Tcop Conejo Volcanics, basaltic lower zone, pillow basalt**—Basalt pillow lavas, pillow breccias and probable aquagene tuffs; included in Seminole Member mapped by Blackerby, 1965, and Serrano Member mapped by Sonneman, 1956, and by Guynes, 1959. (Sonneman, 1956; Guynes, 1959; Blackerby, 1965; Yerkes and Campbell, 1980; Campbell and others, 1996).
- Tcobz Conejo Volcanics, basaltic lower zone, basaltic sand**—Black basaltic sand and siltstone; included in Seminole Member of Blackerby, 1965. (Blackerby, 1965; Yerkes and Campbell, 1980; Campbell and others, 1996).

In the upper plate of Malibu Bowl Detachment Fault, three stratigraphically distinct tongues of volcanic rocks are interbedded with members of the Calabasas Formation:

- Tcom Conejo Volcanics, Malibu Bowl Tongue**—Andesitic and basaltic flows and flow breccias; underlies and tongues eastward into the Newell Sandstone Member of the Calabasas Formation and overlies the Dry Canyon Sandstone Member of the Calabasas Formation; as much as 143 m thick (Yerkes and Campbell, 1979; Yerkes and Campbell, 1980).
- Tcos Conejo Volcanics, Solstice Canyon Tongue**—Basaltic and andesitic flows, breccias, and tuffs; local water-laid volcanic sandstone; underlies and intertongues eastward into the upper part of the Dry Canyon Sandstone Member of the Calabasas Formation, overlies Latigo Canyon Breccia Member of the Calabasas Formation; as much as 143 m thick (Campbell and others, 1970; Yerkes and Campbell, 1979; Yerkes and Campbell, 1980; Campbell and others, 1996).
- Tcor Conejo Volcanics, Ramera Canyon Tongue**—Basaltic and andesitic breccias, tuff-breccias, and flows(?); minor volcanic sandstone; underlies, and upper part intertongues with lower part of Escondido Canyon Shale Member of the Calabasas Formation; underlain in some areas by shallow marine strata of the Topanga Canyon Formation which is cut out locally by the Malibu Bowl Detachment Fault; as much as 518 m thick. (Campbell and others, 1970; Yerkes and Campbell, 1979; Yerkes and Campbell, 1980; Campbell and others, 1996).
- Ti Intrusive rocks, undivided (middle Miocene)**—Dikes, sills and irregularly shaped intrusive bodies of diabase, basalt, and andesite; commonly pervasively altered and easily eroded, undercutting slopes and, therefore, commonly spatially associated with toes of landslides; sills are larger and more abundant in the Topanga Canyon Formation at shallow stratigraphic depths below the base of the Conejo Volcanics; intrusive along the Malibu Bowl Detachment Fault only where Topanga Canyon Formation and younger strata are carried in the upper plate; (widespread in central and western Santa Monica Mountains; Yerkes and Campbell, 1980; Campbell and others, 1996; Yerkes and Campbell, 1994. In the central and western Santa Monica Mountains these are related to the Conejo Volcanics; however, in the eastern Santa Monica Mountains and elsewhere they may be related to other volcanic centers of roughly the same age (for example, small dikes mapped by Saul (1976) in the Mount Wilson 7.5' quadrangle).
- Tid Intrusive rocks, dacite (middle Miocene)**—Dacite dikes, irregular intrusive bodies in older Conejo rocks, and a plug intrusive into Topanga Canyon Formation; (Dibblee and Ehrenspeck, 1993, p. 89).
- Tia Intrusive rocks, andesitic (middle Miocene)**—Andesitic dikes, sills and irregular intrusive bodies, chiefly sills in Topanga Canyon and Vaqueros Formations, and dikes in older rocks.
- Tib Intrusive rocks, basaltic (middle Miocene)**—Basaltic, diabasic, and gabbroic dikes, sills and irregular intrusive bodies, chiefly sills in Topanga Canyon Formation and following detachment faults, and dikes in older rocks.
- Tim Mixed rocks (middle Miocene and early or early middle Miocene)**—Very fine- to fine-grained basalt, pervasively intrusive into black siltstone and very fine-grained sandstone of the Topanga Canyon Formation on a spacing too intimate to map separately at 1:12,000-scale; (Campbell, unpublished mapping, 1967-1976).

- Ttc Topanga Canyon Formation (middle and early Miocene)**—Marine sandstone, commonly arkosic, with interbedded siltstone, pebbly sandstone and pebble-cobble conglomerate; generally well indurated; recognized only in the central and western Santa Monica Mountains, where it is overlain unconformably by the Conejo Volcanics, and conformably overlies lithologically similar older Miocene and Oligocene strata of the Vaqueros Formation; elsewhere, correlative strata are included in the undivided Topanga Group, **Tt**. Yerkes and Campbell (1979) formalized the name “Topanga Canyon Formation” and described as members lithologic facies that indicate an eastward shoaling of depositional environments from deeper shelf on the west to shoreface, estuarine, and fluvial deposits, wedging out just east of Santa Ynez Canyon. (Note that the deposition precedes post-volcanic tectonic rotation, so in early middle Miocene time the direction of shoaling was nearly north). North of Castro Peak, where the formation is undivided (**Ttc**), it is as much as 1,070 m thick. West of Santa Ynez Canyon to Malibu Canyon three members are recognized: the Cold Creek (**Ttcc**), Fernwood (**Ttcf**), and Saddle Peak (**Ttcs**) Members (Yerkes and Campbell, 1960). The Fernwood Member represents an estuarine and fluvial depositional environment, and separates shelf marine strata of the underlying Saddle Peak and overlying Cold Creek Members, both of which pinch out west of Topanga Canyon. The Fernwood Member wedges out westward and the two nearshore marine members coalesce just east of Malibu Canyon; therefore, the Formation is undivided from Malibu Canyon west to Zuma Canyon. Interbeds of siltstone and mudstone, suggestive of deepening offshore shelf depositional environments, become progressively thicker westward, and siltstone strata of the Encinal Canyon Member (**Ttce**) predominate west of Zuma Canyon. In and west of Arroyo Sequit some thick sandstone beds become prominent in the upper part of the Topanga Canyon Formation, and are here called the Big Sycamore Member (**Ttcb**).
- Ttcc Topanga Canyon Formation, Cold Creek Member**—Marine sandstone, siltstone, and minor pebbly sandstone; sandstone commonly medium grained, moderately to well sorted arkosic arenite, in laminated and graded beds as much as two meters thick, and locally biotitic. About 707 m thick in the northeast corner of the Malibu Beach 7.5' quadrangle. Locally abundant molluscan fauna referred to "Temblor Stage" of Weaver and others (1944), including the locality for the “Topanga Canyon fauna” (about 50 molluscan species) of Arnold (1907a); named as a member of the Topanga Canyon Formation by Yerkes and Campbell (1979). Conformably overlies the Fernwood member of the Topanga Canyon formation; overlain, in most places conformably, by Conejo Volcanics. In a few localities in upper Topanga Canyon the Conejo is missing and the Cold Creek Member is accordantly overlain by the Calabasas Formation. Foraminifera from siltstone in upper part assigned to Relizian BFZ. (Yerkes and Campbell, 1980; Campbell, unpublished 1:12,000-scale mapping, 1965-1972).
- Ttcf Topanga Canyon Formation, Fernwood Member**—Paralic, fluvial, estuarine, and marine sandstone, pebbly sandstone, and mudstone, with minor tuff and limestone; interbedded with grayish-red or olive-gray mudstone and, locally, minor vitric rhyolite tuff and algal(?) limestone; fluvial sandstone forms thick lenticular ledge-forming beds and is complexly channeled and crossbedded; locally abundant closely spaced borings normal to sandstone bedding (ophiomorpha?), and rare fragments of bone occur; the shallow-water gastropod *Melongena*, known only from the provincial middle Miocene, occurs in sandstone on a ridge west of Topanga Canyon (in the Fernwood area) (Yerkes and Campbell, 1979; Yerkes and

Campbell, 1980). The Fernwood is overlain conformably by and intertongues into the Cold Creek Member of the Topanga Canyon Formation. The Fernwood overlies the Saddle Peak Member conformably and may intertongue with it. In several parts of the Topanga Canyon drainage area Fernwood strata are cut off down dip by Sespe Formation redbeds along the Malibu Bowl Detachment Fault or by basalt and diabase intrusive into the fault. Fritsche (1993) and Flack (1993) propose that the Fernwood member should be assigned to the Sespe Formation. However, the Fernwood has nowhere been observed to be in direct depositional contact with Sespe strata (even though short segments of approximately located contact are shown on the map, there is no outcrop exposure of unfaulted contact relationships). Nor does the Fernwood contain any red sandstone, which is characteristic of (though not always present in) the Sespe Formation. Therefore, the usage of the source maps is retained. (Yerkes and Campbell, 1979; Yerkes and Campbell, 1980; Yerkes and Campbell, 1994).

Ttcs Topanga Canyon Formation, Saddle Peak Member—Thick-bedded to massive, medium-to coarse grained marine sandstone, pebbly sandstone, and hackly fracturing sandy siltstone, over a 1/2-m-thick basal pebble conglomerate; conformably overlain by the Fernwood Member of the Topanga Canyon Formation; conformably overlies the Piuma Member of the Sespe Formation or its' marine correlative Vaqueros Formation; in places faulted against Sespe and older rocks, or strata of the Calabasas Formation, chiefly along the Malibu Bowl Detachment Fault. A resistant sandstone near the base of the Saddle Peak Member contains an abundant "Temblor" megafauna that includes the gastropod *Antillophos dumbleanus* (Anderson), that is apparently restricted to the middle Miocene; immediately above this bed is a 10-cm thick layer of well-preserved, in part articulated valves of the giant pectinid *Vertipecten nevadanus* (Conrad) (also called *V. bowersi*); the entire fauna is referred to the middle Miocene "Temblor" provincial Stage. Fritsche (1993) has proposed that the Saddle Peak Member be included with the Vaqueros Formation because some elements of the fauna are long ranging and are also found in the Vaqueros, and because closely similar lithofacies are found in both units. However, detailed mapping can carry continuous and overlapping stratigraphic horizons in most areas where the Saddle Peak Member is in contact with underlying Vaqueros, and the two units are mappable separately. Therefore, the usage of the source maps is retained. The unit is about 220 m thick along Piuma Road on the west shoulder of Saddle Peak. (Yerkes and Campbell, 1979; Yerkes and Campbell, 1980).

Ttcb Topanga Canyon Formation, Big Sycamore Member—Alternating gray sandstone and dark gray siltstone or silty mudstone, commonly platy to shaly; chiefly mudstone with interbedded thin- to thick-bedded lenticular sandstone in sets that locally coalesce to massive beds; sandstone grain size variable, with local rip-up clasts of shale, and pebbly sandstone with polished, rounded chert pebbles; mudstone interbeds commonly thin-bedded to shaly. A rare occurrence of detrital glaucophane in sandstone is the earliest known north of the Malibu Coast Fault. Sonneman (1954) estimated a total thickness of 2,400 ft. (732 m) to 3,500 ft. (1,066 m). Mapped as the "Upper Member of the Sycamore Formation" by Sonneman (1956); mapped as individual sandstone beds in the "Undivided Topanga Canyon Formation" by Dibblee and Ehrenspeck (1990); here called "Big Sycamore Member of the Topanga Canyon Formation" to follow rules of the North American Code. Fossils include: locally common *Vertipectin*

Nevandus at Point Mugu; rare *Turritella Temblorensis* (Sonneman, 1954); and Relizian foraminifera (Sonneman, 1954).

Ttce **Topanga Canyon Formation, Encinal Member**—Chiefly dark gray siltstone or silty mudstone, commonly platy to shaly, but at many localities bedding fissility is obscured by a dominant conchoidal fracture, possibly indicating bioturbation; lenticular dolomitic concretions locally abundant, particularly along locally restricted stratigraphic zones as thick as 60 cm; rare medium- and fine-grained sandstone beds in the Encinal Canyon area (western Point Dume 7.5' quadrangle) increase in abundance somewhat westward in the Triunfo Pass 7.5' quadrangle. The siltstone rests conformably on sandstone of the underlying San Nicholas Member of the Vaqueros Formation, but there is apparent discordance in some places where lack of exposure prevents clear discrimination. The Encinal Canyon Member intertongues with and is overlapped conformably by the Big Sycamore Member of the Topanga Canyon Formation, and unconformably overlain by Conejo Volcanics (see discussion of base of Conejo, above). Poorly preserved foraminifera in two collections from the Encinal Canyon Road exposures reported by Yerkes and Campbell (1979) are assigned to the Relizian(?) stage and Saucesian or Relizian stages of Kleinpell (1938), respectively. Further west, in the Triunfo Pass and Point Mugu quadrangles Sonneman (1956) reports that the “Lower Member of the Sycamore Formation”, which is contiguous with the Encinal Canyon Member of the Topanga Canyon Formation (Yerkes and Campbell, 1980), also contained foraminifera assignable to the Relizian Stage. A subsequent collection reported by Flack (1993) is also assigned a late Saucesian to early Relizian age. Flack (1993, p. 46) considers the Encinal Member, as well as the entire Topanga Canyon Formation, to be late early Miocene rather than early middle Miocene. (Campbell and others, 1996; Campbell, unpublished 1:12,000-scale mapping, 1965-1975; Sonneman, 1956; Dibblee and Ehrenspeck, 1990).

Western Los Angeles Basin-Continental Borderland

Tr **Trancas Formation, undivided (middle and early Miocene)**—Marine mudstone, silty shale, claystone, sandstone, and locally prominent sedimentary breccia on Lechusa Point and Point Dume; the breccias are distinctive for their abundant detritus of the Mesozoic Catalina Schist, including glaucophane schist (San Onofre breccia of Woodford and Bailey, 1928). The Trancas has been much deformed in the zone south of the Malibu Coast Fault, and no complete section is known. The Sovereign Oil Company Malibu 1 exploratory well on Point Dume drilled through 290 m of marine sandstone, mudstone, claystone, and sedimentary breccia (San Onofre Breccia) between the base of the Monterey Shale and the underlying Zuma Volcanics, assigned to the Trancas formation by Yerkes and Campbell (1979); (Point Dume and Triunfo Pass 7.5' quadrangles; Campbell and others, 1996; Campbell, 1965-1975, unpublished 1:12,000-scale mapping). The siltstones locally contain abundant foraminiferal assemblages assigned to the Saucesian (lower Miocene) and Relizian or Luisian (middle Miocene) stages of Kleinpell (1938). **Tra**—quartz-bearing calcarenites in the western part of the Point Dume 7.5' quadrangle and eastern part of the Triunfo Pass 7.5' quadrangle are distinctive for the pervasive intergranular disruption that causes original bedding to be completely masked; further west, at Sequit Point, the sandstones are seen to be coarse-grained, cross-laminated calcarenites, composed chiefly of barnacle plates and oyster fragments, with significant areas intruded by sandstone of similar composition but in which the original fabric is no longer visible (inferred

to be a result of liquefaction). An exposure of San Onofre Breccia overlying Zuma Volcanics on the tip of Point Dume, south of the Point fault, is assumed to represent the base of the Monterey Shale in that area. The Trancas may intertongue with both the Zuma Volcanics and the lower part of the Monterey Shale, but is locally unconformably overlain by upper (late Miocene) beds of the Monterey Shale.

- Tz** **Zuma Volcanics (middle and early Miocene)**—Basaltic, andesitic and dacitic flows, flow breccias, pillow lavas, aquagene tuffs, mudflow breccias, volcanic sand and interbedded mudstone, siltstone, sandstone, minor breccia-conglomerate; all probably deposited in a marine environment; no igneous rocks south of the Malibu Coast Fault are recognizably intrusive into the associated sedimentary rocks; sedimentary interbeds carry foraminifera referred to the Relizian or Luisian Stages (middle Miocene) of Kleinpell (1938). Weigand and Savage (1993), from a study of major element analyses, showed that most of the analyzed samples of Zuma Volcanics fall in the dacite field of the classification of LeBas and others (1986). Plagioclase phenocrysts from basalt near the tip of Point Dume have been dated at 14.6 ± 1 my (Berry and others, 1976). Base not exposed, but an equivalent section in the exploratory well, Sovereign Malibu 1 on Point Dume, is about 430 m (stratigraphic) thick above probable metamorphic basement (Catalina Schist). Although the Zuma and Conejo Volcanics fall within the same range of ages, the overlying and underlying sedimentary strata, and the basement rocks, are significantly different, suggesting that they could be related to different extrusive centers. (Campbell and others, 1970, 1996; Yerkes and Campbell, 1980; and Campbell, unpublished 1:12,000-scale mapping, 1967-1971).

Soledad Basin and San Andreas Fault Zone

- Tvz** **Vasquez Formation, undivided (early Miocene to Oligocene?)**—Yellowish and reddish sandstone, conglomerate, and interbedded andesite-basalt, lying on pre-Tertiary crystalline basement rocks and unconformably below strata of Tick Canyon Formation; total thickness as much as 3,810 m (Jahns and Muehlberger, 1954). Includes numerous beds and lenses of megabreccia, many monolithologic. Named by Sharp (1936); further described by Jahns (1939). (Dibblee, 1996a,b).
- Tvza** **Vasquez Formation, andesitic volcanic rocks (early Miocene? to late Oligocene)**—Dark-gray to dark reddish-brown andesite and basaltic andesite, hard, very fine-grained matrix with fine- to medium euhedral phenocrysts of plagioclase feldspar. Occasional flow banding, conglomeratic layering, and some silica-filled amygdules. Outcrops locally exhibit sub-parallel sheet jointing.
- Tvzb** **Vasquez Formation, basaltic volcanic rocks (early Miocene? to late Oligocene)**—Dark-gray, basaltic to andesitic volcanic rocks. Unit contains small phenocrysts of augite and olivine. Outcrop exposures are highly jointed and resistant, with weathered surfaces dark-gray to dark-brown.
- Tvzc** **Vasquez Formation, non-marine conglomerate (early Miocene? to late Oligocene)**—Pebble- to cobble fluvial conglomerate and red clayey siltstone. Unit consists of sub-rounded to rounded clasts of gray, tan, pink, and lavender volcanic rocks. Also contains quartz monzonitic to granodioritic clasts.

Tvzs **Vasquez Formation, sedimentary rocks (early Miocene? to late Oligocene)**—Pebble- to cobble fluvial conglomerate and red clayey siltstone. Unit consists of sub-rounded to rounded clasts of gray, tan, pink, and lavender volcanic rocks. Also contains quartz monzonitic to granodioritic clasts.

Topatopa Mountains and eastern Santa Ynez Range

Trn **Rincon Formation (early Miocene and late Oligocene)**—Marine shale and mudstone with dolomitic and limonitic concretions as much as 0.65 m in diameter (Fillmore 7.5' quadrangle); foraminiferal faunas referred to the Zemorrian and Saucesian Stages (early Miocene) of Kleinpell (1938); thickness about 275 m. Overlain, apparently accordantly, by shale and mudstone assigned to the lower part of the Modelo formation (which, in this area, is designated middle and upper Miocene), and conformably overlies Vaqueros Formation strata. The type section for the Rincon Formation is approximately 30 mi. to the west in the vicinity of Rincon Point where the name, Rincon Shale, was suggested by Kerr (1931) (south flank of Santa Ynez Mountains, Fillmore and Piru 7.5' quadrangles; Eschner, 1969). Fritsche (1993) proposed that similar rocks within a similar age-range in the western Santa Monica Mountains (the Encinal Member of the Topanga Canyon Formation and the Danielson Member of the Vaqueros Formation) should be termed "tongues" of the Rincon Formation; however, we have retained the nomenclature of the source maps

Western Santa Monica Mountains, Oak Ridge and eastern Ventura Basin

Tv **Vaqueros Formation, undivided (early Miocene and Oligocene)**—A heterogeneous sequence of thick- and medium-bedded sandstone and interbedded siltstone and mudstone; sandstone ranges from coarse- to very fine-grained, chiefly biotitic arkosic arenites and wackes; siltstone and mudstone interbeds commonly dark gray, but can be greenish or reddish in color; commonly carries *Turritella inezana* and other elements of the "Vaqueros fauna". Although the name was first used in central California (Hamlin, 1904) and subsequently extended on the basis of faunal elements, it has long been used in coastal Southern California, and is used consistently throughout intervening areas, to refer to a well-recognized and widespread, predominantly marine sequence that contains a distinctive molluscan fauna (Loel and Corey, 1932). Since Addicott (1972) noted that the range of the Temblor fauna included the range of the Vaqueros fauna in the Temblor Range type area, some authors (Fritsche, 1993; Dibblee, 1989a) have proposed abandoning the name, Vaqueros, and combining the pre-Conejo post-Sespe strata into a single unit. However, in nearly all the problematical areas there are sufficient continuous or overlapping beds, as well as differences in fauna, to provide a realistic basis for mapping separate formations. In the Santa Monica Mountains a complete section in the vicinity of Castro Peak, where the Vaqueros accordantly overlies the nonmarine Sespe formation, is as much as 760 m thick; east of Malibu Canyon however, shoreface facies intertongue with nonmarine strata of the Sespe Formation, and Vaqueros strata are not present in and east of Topanga Canyon. Along the north side of Simi Valley, Vaqueros strata about 600 m thick lie accordantly above Sespe redbeds and are overlain by Conejo Volcanics; the Vaqueros wedges out to the east in the Simi Valley West 7.5' quadrangle. In the Simi Valley area, Squires and Filewicz (1983, Fig. 2) show the Vaqueros as approximately 310 m in thickness, intertonguing with and overlying the Sespe Formation; it pinches out eastward beneath the unconformably

overlying Conejo Volcanics. North of Fillmore, the easternmost Vaqueros is about 183 m thick. (Cemen, 1977; Eschner, 1969; Bailey, 1951). Osborne (1993) has described the several interbedded lithofacies that are present to the west of Topanga Canyon and interprets them to represent deposition during a rapid marine transgression from west to east over nonmarine strata of the Sespe. This compilation retains the usage and nomenclature of Yerkes and Campbell, 2005. (western Santa Monica Mountains, western Topatopa Mountains, and north side of Simi Valley; Yerkes and Campbell, 1979; Yerkes and Campbell, 1980; Campbell and others, 1996; Eschner, 1969; Bailey, 1951; Cemen, 1977; Squires, 1983a; Sonneman, 1956; Durrell, 1954). Includes:

- Tvn Vaqueros Formation, San Nicholas Member**—Very thick bedded to massive cliff- and ledge-forming marine sandstone, generally very light gray to pale bluish gray; rare interbeds and partings of siltstone and shale, commonly dark gray. Sandstone, very fine- to very coarse-grained arenite, locally pebbly; thick beds show internal cross lamination, parallel, lamination, and disturbed (burrowed?), laminations; local common barnacle detritus. Generally conformably underlain by the Danielson Member of the Vaqueros Formation; however, locally thinned where it rests on older rocks beneath the Zuma Detachment Fault, as in Encinal Canyon. Conformably overlain by the Encinal Member of the Topanga Canyon Formation. Mapped as “Nicholas Formation” by Sonneman (1956), named for exposures in the vicinity of San Nicholas Canyon (Triunfo Pass 7.5’ quadrangle); formalized as a member of the Vaqueros Formation by Yerkes and Campbell (1979). (Campbell and others, 1996; Campbell, unpublished 1:12,000-scale mapping, 1967-1975).
- Tvd Vaqueros Formation, Danielson Member**—Grayish black, very fine-grained, marine sandy siltstone or mudstone, in medium and thin beds, generally with indistinct parallel lamination; fractures commonly conchoidal or irregularly subparallel to bedding, but locally platy or shaly. In San Nicholas Canyon, several prominent interbeds, 1/3 to 1 m thick, of calcareous very fine-grained sandstone and sandy mudstone contain fossil remains of *Turritella inezana* Conrad in such numbers as to locally form biostromes (Yerkes and Campbell, 1979, p. E12). Mapped as “Danielson Formation” by Sonneman (1956), named for exposures on the Danielson Ranch in Big Sycamore Canyon (Triunfo Pass 7.5’ quadrangle); formalized as a member of the Vaqueros Formation by Yerkes and Campbell (1979). (Sonneman, 1956; Campbell and others, 1996; Campbell, unpublished 1:12,000-scale mapping, 1967-1975).

Western Santa Monica Mountains, Oak Ridge and eastern Ventura Basin

- Ts Sespe Formation, undivided (early Miocene, Oligocene, and late Eocene)**—A nonmarine “redbed” sequence of sandstone, pebbly sandstone, varicolored mudstone, and pebble-cobble conglomerate; sandstone beds commonly very thick to massive, with strong internal cross lamination; and rare thin interbeds varicolored reddish, greenish and grayish mudstone. The sandstone beds are characteristically red in color, chiefly as a result of intergranular hematized biotite; several sections include beds that lack the characteristic red color. The only complete section of the Sespe exposed in the Santa Monica Mountains is in the Solstice Canyon-Castro Peak area, where about 1000 m of the nonmarine strata are in depositional contact on (and accordant with) the underlying marine Llajas Formation, and accordantly beneath the overlying marine Vaqueros Formation. Elsewhere in the Santa Monica Mountains, both to the east and to

the west, the Sespe is in fault contact with underlying older strata, chiefly along the Zuma Detachment Fault. At the west end of the Simi Hills about 1365 m of Sespe strata lie accordantly above the marine Lajas and unconformably below Conejo Volcanics. Along the north side of Simi Valley, Sespe exposures total as much as 1656 m in thickness in the west (Simi Valley West 7.5' quadrangle), but wedges out to the east, north of Santa Susana Pass (Simi Valley East 7.5' quadrangle). Along the north flank of Oak Ridge the Sespe can be as much as 2135 m thick, based in part on drill-hole data. In the western Topatopa Mountains, north of Fillmore, the Sespe is about 430 m thick between the underlying marine Coldwater Formation and overlying marine strata assigned to the Vaqueros Formation (Fillmore 7.5' quadrangle). The name, Sespe Formation, was introduced by Watts (1897) and further described by Bailey (1947) for exposures in the vicinity of Sespe Creek, north of Fillmore, and has been extended over large parts of coastal southern California by various workers. Generally, it has been applied to a thick nonmarine sandstone, conglomeratic sandstone and siltstone sequence that is underlain by marine Eocene strata and overlain by marine Miocene beds.

- Tsp** **Sespe Formation, Piuma Member (early Miocene)**—In contrast to the thicker bedded, more coarsely grained sandstone and conglomerate of the undivided Sespe Formation below, the Piuma Member is distinguished by thinner individual beds, sandstone of generally finer grain size, absence of pebble and cobble conglomerate, and greater abundance of interbedded lacustrine or lagoonal siltstone. The member name was formalized by Yerkes and Campbell (1979) for the upper of two tongues of the Sespe that can be easily distinguished where strata of the marine Vaqueros Formation separate them; the Vaqueros wedges out eastward, but the contact between the Piuma Member and the undivided Sespe below can be carried some distance eastward beyond the Vaqueros wedge-out. (Yerkes and Campbell, 1980).

Topatopa Mountains and eastern Santa Ynez Range

- Tcw** **Coldwater Formation (late Eocene)**—Marine arkosic sandstone and shale, with lenses of pebble conglomerate and oyster reefs; thickness about 390 m. Earliest use of “Coldwater Sandstone Member” by Kew (1924); referred to “Coldwater Formation” by Bailey (1947). (Eschner, 1969).
- Tcz** **Cozy Dell Formation (late to middle Eocene)**—Well-bedded brown clay shale and mudstone; thickness as much as 600 m. Earliest use of “Cozy Dell Shale ” member of the Tejon Formation by Kerr and Schenk (1928); described as “Cozy Dell Shale” by Dibblee (1950). (Eschner, 1969).
- Tma** **Matilija Formation, undivided (middle to early Eocene)**—Marine sandstone, arkosic, very well indurated, and interbedded mudstone and siltstone. Conformable beneath Cozy Dell Formation; base not exposed in the map area; total thickness exceeds 1 km. Molluscan fossils are of the Tejon Stage (late Eocene); however, interbedded shale contains foraminifera referred to the Ulatisian and Narizian (early to middle Eocene) Stages of Mallory (1959). “Matilija sandstone” member of the Tejon Formation defined by Kerr and Schenk (1928), described as Matilija Sandstone by Dibblee (1950). (Eschner, 1969). Includes:

Tmasl **Matilija Formation, siltstone and shale**—Micaceous shale with thin sandstone interbeds; Foraminifera referred to the Ulatisian and Narizian (middle to early Eocene) Stages of Mallory (1959). (Eschner, 1969).

Santa Susana Mountains, Simi Hills and Santa Monica Mountains

Tl **Llajas Formation (middle to early Eocene)**—Shallow marine, light-gray to yellowish-gray, very fine- to medium-grained sandstone, laminated siltstone and local mollusk coquina beds; interfingers with alluvial conglomerate (Tlc) at the base; sandstone is laminated to bioturbated; moderately indurated (Irvine, 1990, 1991; Squires, 1983b); section is about 1,800 ft. (550 m) thick. Locally contains fossil mollusks assigned to the “Domengine Stage” (Weaver and others, 1944); Figure 3 of Squires (1983b) suggests the basal portion corresponds to the upper “Capay Stage”. As summarized by Squires (1983b), the Llajas section in the Simi Valley area was originally assigned to the “Tejon” or “Meganos” Formations (e.g. Kew, 1919, 1924); subsequently assigned informally to the Llajas Formation by Schenck (1931) and McMasters (1933); more formally named by Cushman and McMasters (1936) for surface outcrops at the type section on the northwest side of the north branch of Llajas Canyon (now known as Chivo Canyon and formerly known as “Oil Canyon”), and from corehole data obtained from the nearby Tapo No. 42 oil well, all located on the northeast side of Simi Valley) (Simi Valley East, Oat Mountain, Thousand Oaks 7.5’ quadrangles, and correlative strata in the Point Dume, Malibu Beach, and Topanga 7.5’ quadrangles). Includes:

Tlc **Llajas Formation, basal conglomerate**—Alluvial to shallow marine, light-brown to reddish-brown conglomerate interbedded with subordinate, poorly sorted, generally massive sandstone (Irvine, 1990); conglomerate is typically unstratified, ungraded, clast supported, and poorly sorted; clasts are typically well rounded, cobble size, and composed dominantly of quartzite with lesser amounts of granitic, volcanic and metamorphic rocks (Squires, 1983b). Squires (1983b) interprets this facies as a coastal alluvial fan or fan delta deposit. This unit defines the base of Llajas strata relative to the underlying Santa Susana Formation in the area northeast of Simi Valley (Evans and Miller, 1978).

San Gabriel Mountains

Tj **Juncal Formation (late early Eocene)**—Marine, brown amalgamated sandstone beds with interbedded conglomeratic sandstone, conglomerate and siltstone exposed in Elsmere Canyon (San Fernando 7.5’ quadrangle); moderately to well cemented; clasts include exotic purple volcanic porphyry and local large siltstone rip-up clasts, and range up to boulder size. The coarse-grained units are interpreted as turbidity current deposits in a middle- to upper-fan submarine fan depositional environment (Squires, 2008). The Elsmere Canyon section has a measured thickness of about 520 m (Squires, 2008) and it locally contains fossil mollusks originally assigned to the “Domengine Stage” of late early to early middle Eocene age (Weaver and others, 1944); however, detailed studies by Squires (2008) suggest the section at Elsmere Canyon represents the transition from the “Domengine Stage” to the underlying “Capay” Stage, at an age of about 50.5 Ma. The Eocene strata at Elsmere Canyon were first assigned to the “Domengine formation” by Brown and Kew (1932) and this usage was followed by early workers in the area (e.g. Oakeshott, 1950, 1958), and this usage was followed on Version 1.0 of

the Los Angeles 30'x60' geologic map (Yerkes and Campbell, 1995). The Elsmere section was left unnamed by Winterer and Durham (1962), Kern (1973), and Dibblee (1991). Some subsequent workers assigned the name "Llajas Formation" to this section (e.g. Seedorf, 1983 and Yeats and others, 1994). Squires (2008) re-evaluated the past nomenclature and conducted additional field studies, and concluded the Elsmere Eocene section is more consistent lithologically with exposures of Juncal Formation mapped to the northwest in the Piru Creek area (Squires, 1987) rather than the type Llajas section, and the Piru and Elsmere sections may have originally been contiguous (Yeats and others, 1994).

The term "Martinez Formation" was previously retained on Version 1.0 of the Los Angeles 30x60' sheet for coarse-grained marine greenish-black to light olive-gray sandstone, with thin interbeds of black shale, and lenticular beds of well-cemented conglomerate of Eocene or Paleocene age mapped as fault-bounded slivers along the San Gabriel Fault between Bear Divide and Tujunga Canyon on the Sunland and San Fernando 7.5' quadrangles (Oakeshott, 1958; Yerkes and Campbell, 2005); clasts reportedly include exotic volcanic porphyry. The term "Martinez Formation" was imported from a type locality in the San Francisco Bay area; the term "Martinez" now generally refers to a Paleocene molluscan stage. Assignment of this section to the "Martinez Formation" was reportedly based on lithologic similarity with "Martinez" strata mapped in the Tejon quadrangle (Oakeshott, 1958) and on the discovery of the age-diagnostic fossil *Turritella pachecoënsis* (Clements and Oakeshott, 1935); however, use of the term "Martinez" has generally been abandoned as a lithologic formation name in southern California. Squires (pers. comm. 2014) notes that the reported specimens of fossil *Turritella* cannot be located for review and additional specimens could not be found during recent field studies; based on field observations of the stratigraphy and presence of exotic volcanic porphyry clasts, Squires suggests that the fault-bounded slivers may actually be part of the Juncal Formation; the fault-bounded slivers are therefore queried as Juncal Formation herein.

Santa Susana Mountains, Simi Hills and Santa Monica Mountains

Tss **Santa Susana Formation (early Eocene to late Paleocene)**—Marine clay shale and conchoidally fractured mudstone and siltstone with interbeds of fine- to medium-grained sandstone and lenses of pebble-cobble conglomerate; gray limestone concretions common in shale; locally contains foraminifera; locally abundant mollusks diagnostic of the "Meganos" and "Martinez" Stages (Saul, 1983); thickness as much as 1,000 m in the Simi Hills; unit thickness varies laterally and rapid lateral facies changes are common across map area. Named by Nelson (1925) for exposures in the Simi Hills near the town of Santa Susana. As summarized by Parker (1983, 1985), lower Tertiary strata in the Simi Hills were originally correlated and assigned to the "Martinez and/or Meganos Formations" by early workers, including Waring (1914, 1917), Kew (1919, 1924), and Clark (1921). Nelson (1925) raised the "Martinez Formation" to group status and subdivided it into the Simi Conglomerate, Las Virgenes Sandstone, and the Martinez marine member, overlain by the Santa Susana Formation. Most literature published to date follows some form of Nelson's terminology, but the placement of contacts varies considerably among different authors. Parker (1983, 1985) modified Nelson's Santa Susana Formation to include the underlying Martinez marine member, thereby encompassing all strata above the Simi Conglomerate and Las Virgenes Sandstone and

below the Llajas Formation in the Simi Hills and northeastern Simi Valley. Parker and other authors abandoned “Martinez Group” and “Martinez marine member” because “Martinez” is a molluscan Stage name, imported from a central California type locality, and no longer considered appropriate to use as a formation name for this interval. Colburn and others (1988) and Colburn and Novak (1989) extended Parker’s nomenclature to correlative rocks in the Santa Monica Mountains and included beds mapped as Coal Canyon Formation by Yerkes and Campbell (1979, 2005) in the Santa Susana Formation. Distribution of lower Tertiary strata in the Simi Valley area on this map is based on Squires (1983a), which includes Parker’s nomenclature and contacts. Parker described the lower Tertiary units in terms of western and eastern facies based on the location of the stratigraphic sections relative to the “Runkle Canyon fault” (Squires, 1983a). The western facies of the Santa Susana Formation in the Simi Valley area (Simi Valley East, Calabasas and Thousand Oaks 7.5’ quadrangles) overlies the Las Virgenes Sandstone with a gradational to sharp contact and is disconformably overlain by the Llajas Formation. It generally consists of a lower unit of densely bioturbated, fossiliferous, fine- to medium-grained sandstone and an upper unit dominated by poorly fossiliferous fractured mudstone and siltstone interbedded with subordinate sandstone and minor conglomerate. The lower unit represents transition zone and offshore to shelf deposits and the upper unit represents deposition within a slope environment. The eastern facies overlies the Simi Conglomerate with a gradational or sharp contact and is overlain disconformably by the Llajas Formation. The eastern facies is more variable, but generally consists of fractured mudstone and siltstone similar to the western facies with discontinuous interbeds of sandstone and conglomerate. East of Meier Canyon, mudstone and siltstone are present in the lower half and sandstone and conglomerate present in the upper half. Sandstone occurs as discontinuous lenses in conglomerate and in beds up to 20 meters thick. Near Runkle Canyon, sandstone occurs as thin interbeds within the mudstone and siltstone and in tongues up to 150 m with locally abundant megafossils occurring in layers within concretionary beds. Northeast of Simi Valley in Poison Oak Canyon, beds are dominantly mudstone interbedded with minor sandstone above two tongues of Simi Conglomerate. These beds represent inner fan deposits. Interbedded sandstone and conglomerate near Meier Canyon represent the coarse portion of an inner fan and slope deposits. The uppermost portion of the Santa Susana Formation in both the western and eastern facies consists of sandstone with megafossils and microfauna indicative of a shelf environment and may record a basin filling and shoaling event prior to the deposition of the nonmarine basal Llajas conglomerate. In the Santa Monica Mountains, Santa Susana strata include marine sandstone, pebble conglomerate, siltstone and algal limestone. Sandstone is very fine to medium grained, poorly to well sorted, consisting of subrounded quartz and feldspar grains in a sparse clay matrix, locally biotitic; locally contains abundant mollusks; beds commonly are thick and locally have graded upper parts and sharp upper contacts. Siltstone and silty claystone are present locally in the upper part of the formation; closely jointed, conchoidal fracture, and containing abundant biotite; local partings of fine-grained silty biotitic sandstone, and calcareous beds or concretions as thick as 15 cm and as long as 1 m. Pebble-cobble conglomerate forms resistant steep slopes in Carbon and Topanga Canyons; in beds as much as 7 m thick with scattered pebbles, boulders, slabs, and interbeds of mudstone and medium-to coarse-grained sandstone. The Yerkes and Campbell (2005) map shows the Coal Canyon Formation to be about 335 m thick in Solstice Canyon, the only complete section exposed in

the Santa Monica Mountains. The thickness summed from incomplete sections in the Carbon Canyon-Topanga Canyon area is as much as 450 m. Commonly carries a molluscan fauna that includes the Martinez-Stage gastropods *Turitella pachecoensis* and *Mesalia martinicensis* (Gabb, 1869). Colburn and others (1988) and Colburn and Novak (1989) prepared five stratigraphic columns and detailed geologic maps of the section localities along the axis of the Santa Monica Mountains from Solstice Canyon in the west to Runyon Canyon near Hollywood and correlated Simi Conglomerate, Las Virgenes Sandstone, and Santa Susana Formation strata. The Las Virgenes Sandstone and Simi Conglomerate are not separately delineated on the current version of the Los Angeles compilation map in the central and eastern Santa Monica Mountains (Malibu Beach, Topanga, Beverly Hills, and Hollywood 7.5' quadrangles) and Simi Conglomerate and Las Virgenes Sandstone strata mapped by Colburn and Novak (1989) are included in Santa Susana Formation in these areas. Yerkes and Campbell (1979) mapped the Simi Conglomerate in Solstice Canyon (Point Dume 7.5' quadrangle), but did not recognize the Las Virgenes Sandstone in the Solstice Canyon section, and included most of that interval in the Simi Conglomerate. In the Santa Monica Mountains, the Santa Susana Formation overlies and interfingers with the nonmarine Las Virgenes Sandstone (included in Simi Conglomerate on this map) or overlies the late Cretaceous Tuna Canyon Formation; the relations are generally accordant but locally unconformable. In Solstice Canyon, the Santa Susana Formation is overlain disconformably(?) by marine strata of Eocene age. (Squires, 1983a; Yerkes and Campbell, 1980; Campbell and others, 1996). Includes:

- Tssl** **Santa Susana Formation, limestone**—Algal limestone occurs as scattered lenses and pods in siltstone sequences east of Topanga Canyon, most prominently in the eastern wall of Santa Ynez Canyon.

Santa Susana Mountains, Simi Hills and Santa Monica Mountains

- Tlv** **Las Virgenes Sandstone (early(?) Paleocene)**—Nonmarine to marine light-gray to yellowish orange, predominantly medium- to coarse-grained weakly to moderately indurated sandstone with green interbedded mudstone and red-bed mudstone, and minor pebble conglomerate; megafossils and burrows are present in the upper part of the section at Bus Canyon; thin sequence, locally as thick as 195 m near Bus Canyon in the Simi Hills, but thins westward to zero; originated as sandy, braided alluvial and meandering stream deposits on a coastal plain; upper part represents nearshore marine deposits (Parker, 1983); conformably overlies Simi Conglomerate and is overlain by and interfingers with the Santa Susana Formation. Named by Nelson (1925) for exposures near Las Virgenes Canyon in the Simi Hills. Colburn and others (1988) and Colburn and Novak (1989) correlated Las Virgenes Sandstone from the Simi Hills to five localities in the Santa Monica Mountains. These strata are included in the Santa Susana Formation on the current Los Angeles compilation map in the central and eastern Santa Monica Mountains (Malibu Beach, Topanga, Beverly Hills, and Hollywood 7.5' quadrangles). Yerkes and Campbell (1979, 2005) did not recognize the Las Virgenes Sandstone in the Solstice Canyon section (Point Dume 7.5' quadrangle), and included most of that interval in the Simi Conglomerate, including distinctive pisolite-bearing beds that Colburn assigned to the Las Virgenes Sandstone. Pisolite-bearing red beds are also mapped in the Bus Canyon section in the Simi Hills by Parker (1985), but he included the beds in the Simi Conglomerate. (Squires, 1983a).

- Tsi** **Simi Conglomerate, undivided (Paleocene)**—Thin, predominantly nonmarine cobble-boulder conglomerate mapped at the base of the Tertiary sequence in the Simi Hills, the Santa Monica Mountains, and northeast of Simi Valley. The conglomerate is poorly bedded, weakly to moderately indurated and contains abundant well-rounded, polished cobbles and boulders of quartzite, granitic, rhyolitic, and gneissic rocks in conglomeratic, coarse-grained sandstone. Distribution of lower Tertiary strata in the Simi Valley area shown on this map is based on Squires (1983a), which includes Parker’s (1983, 1985) nomenclature and contacts. Parker described the lower Tertiary units in terms of western and eastern facies based on the location of the stratigraphic sections relative to the “Runkle Canyon fault” (Squires, 1983a). According to Parker, Simi Conglomerate west of the Runkle Canyon fault (Squires, 1983a) represents alluvial fan and braided river deposits and Simi Conglomerate east of the Runkle Canyon fault in Runkle and Meier Canyons and northeast of the Simi Valley represents channel and inner fan facies of a deep-sea fan, based on observed sedimentary structures and microfaunal studies summarized by Parker (1983, 1985). The marine conglomerate included by Parker in the Simi Conglomerate is considered by other authors to be part of the Santa Susana Formation or an unnamed Paleocene marine unit (Hanson, 1981). Yerkes and Campbell (1979) tentatively correlated beds described in the Simi Hills by Nelson (1925) as the Simi Conglomerate with lithologically similar beds in the Solstice Canyon area of the Santa Monica Mountains, and the correlation is supported in subsequent detailed petrographic work by Colburn and Novak (1989). In Solstice Canyon (eastern Point Dume 7.5’ quadrangle) the conglomerate includes a 1-m-thick bed of brick-red pisolitic clayey sandstone, which Colburn and Novak (1989) include in the Las Virgenes Sandstone. Simi Conglomerate beds mapped by Colburn and Novak (1989) in the central and eastern Santa Monica Mountains (Malibu Beach, Topanga, Beverly Hills, and Hollywood 7.5’ quadrangles) are included in the Santa Susana Formation on the current Los Angeles compilation map. Correlative strata in the Santa Susana Mountains, mapped as “Martinez Formation” by Evans and Miller (1978), are here included with the Simi Conglomerate. Evans and Miller (1978) recognized three local lithologic members.
- Tsic** **Simi Conglomerate, conglomeratic member**—Massive, yellowish brown pebble to cobble conglomerate with numerous brownish sandstone lenses as much as 1 m thick and continuous for a few tens of meters along strike. Locally contains molluscan fauna referred to the Martinez Stage (Paleocene) (Evans and Miller, 1978).
- Tsis** **Simi Conglomerate, shale member**—Light olive gray micaceous siltstone, silty shale, and shale with local thin interbeds of brown, medium- to coarse-grained sandstone. Dark gray limestone occurs in the shale as thin, discontinuous beds as well as small pods and lenses (Evans and Miller, 1978).
- Tsia** **Simi Conglomerate, sandstone member**—Massive, gray to brownish, coarse- to very coarse-grained sandstone, cemented by silica and hydrous iron oxides, with thin interbeds of micaceous siltstone and lenses of boulder, cobble and pebble conglomerate; locally strongly cemented by calcite (Evans and Miller, 1978).

Santa Susana Mountains, Simi Hills and central and western Santa Monica Mountains

- Kc** **Chatsworth Formation (late Cretaceous)**—Dominantly turbidite sandstone, massive, thick-bedded, medium- to coarse-grained, well-cemented; conglomeratic sandstone with rounded,

polished clasts of quartzite, porphyry and granitic rocks; with minor siltstone and conglomerate. Molluscan faunas include the ammonite *Metaplacenticeras californicum* and the gastropod *Tuttitella pescaderosensis*, referred to the Campanian or Maestrician (late Cretaceous) Stages (Popenoe, 1973; Saul and Alderson, 1981); benthic foraminifera from mudstones in the lower-middle part of the sequence are referred to the late Campanian. Exposed thickness exceeds 1830 m; base not exposed nor drilled; overlain with slight unconformity by Paleocene strata along north side of the Simi Hills, elsewhere, as along the south flank of the Simi Hills, unconformably overlain by Miocene beds. The name, Chatsworth Formation was introduced and defined by Colburn and others (1981) for rocks in the eastern Simi Hills near Chatsworth, that were previously mapped as “Chico Formation” or as unnamed “Upper Cretaceous Rocks” (“Chico” is a molluscan Stage name imported from central California). (Weber, 1984).

Central and western Santa Monica Mountains

- Kt Tuna Canyon Formation, undivided (late Cretaceous)**—Marine sandstone, siltstone and conglomerate. Sandstone, thick-bedded to very thick-bedded, laminated and graded arkosic wacke (turbidite); locally containing abundant fragments of black slate(?); convolute lamination in some beds, load casts, low-angle cross-lamination, or concentrations of carbonized plant fragments or mica. Fossiliferous sandstone and siltstone are present locally as interbeds or thick lenses; in Las Flores Canyon, contains several beds of olive-gray siltstone that locally contain foraminifera. The Tuna Canyon Formation is nowhere completely exposed in the Santa Monica Mountains; the maximum exposed thickness, in the Pena Canyon-Tuna Canyon area, is nearly 800 m. East of Santa Ynez Canyon rests on nonmarine red conglomerate (Trabuco Formation, late Cretaceous) and the Santa Monica Slate (late Jurassic). The formation is overlain disconformably (?) by the Simi Conglomerate in Solstice Canyon, and elsewhere by a basal conglomerate of the Coal Canyon Formation (Paleocene). In several places it contains the Campanian ammonite *Metaplacenticeras sp.*; foraminifera faunas are referred to zones D-2, E, and F-1 (Maestrician or Campanian - late Cretaceous) of Goukoff (1945). Named by Yerkes and Campbell (1979) to replace the name “Chico”, which was imported from central California and used on earlier maps in the Santa Monica Mountains. (central and eastern Santa Monica Mountains; Campbell and others, 1996; Yerkes and Campbell, 1980; Alderson, 1988; Hoots, 1931). East of Santa Ynez Canyon the formation was subdivided by Alderson (1988) into four informal members:
- Kte Tuna Canyon Formation, informal member 'e'**—Greenish-gray shale with interbedded coarse-grained sandstone in the upper part.
- Ktd Tuna Canyon Formation, informal member 'd'**—Fine-grained, thick-bedded, fossiliferous sandstone.
- Ktc Tuna Canyon Formation, informal member 'c'**—Pebble-cobble conglomerate and minor sandstone.
- Ktb Tuna Canyon Formation, informal member 'b'**—sandstone with minor conglomerate and black shale, carrying Turonian and Coniacian ammonites.
- Ktr Trabuco Formation (late Cretaceous)**—Conglomerate with well-rounded, polished pebbles, cobbles and boulders of varicolored quartzite, porphyry, granite, basalt, and with angular chips

of black slate in a matrix of soft, clayey, coarse-grained to pebbly grit. Thickness estimated at 225 m; unconformably overlies Santa Monica Slate. Name applied by Durrell (1954) for rocks of similar composition and stratigraphic position in the type area in the Santa Ana Mountains, where it was named by Packard (1916); correlation reiterated by Colburn (1973). (Yerkes and Campbell, 1980; Hoots, 1931).

Kgr **Granitic rocks (late Cretaceous)**—Includes a variety of plutonic igneous rocks ranging from quartz monzonite and granodiorite to tonalite, quartz diorite, and diorite; chiefly quartz diorite; intrudes Santa Monica Slate in the eastern Santa Monica Mountains (Durrell, 1954).

San Gabriel and Verdugo Mountains

Kgl **Granitic rocks, leucocratic granodiorite (late Cretaceous)**—Light gray to buff, fine- to medium- grained granodiorite; intrudes all other crystalline rocks in area south of south branch of the San Gabriel Fault (Smith, 1982).

Kgd **Granodiorite (Cretaceous)**—Light-gray to dark-gray, medium-grained granodiorite. Unit includes well-foliated, gneissic mafic enclaves. In thin section, samples have some hornblende, apatite, euhedral zircons, and biotite although much is altered to chlorite. Some myrmekitic texture observed in plagioclase feldspars. Exposed in northeast Pacifico Mountain quadrangle. Mapped as qd by Barrows and others (1985) and Dibblee (1997); described by Olson and Hernandez (2013) on map of adjacent Palmdale quadrangle.

Kto **Tonalite (late Cretaceous)**—Mapped by Jahns and Muehlberger (1954) as “granite and other quartz-bearing plutonic rocks”; these rocks are compositionally tonalite (D. M. Morton, oral communication, 2003) in the IUGA classification (Streckheisen, 1973).

Ktoqd **Tonalite and quartz diorite (late Cretaceous)**—Mapped by Morton (1973) as predominantly quartz diorite, grading to granodiorite, quartz monzonite and diorite; compositionally mostly tonalite (D. M. Morton, oral communication, 2003) in the IUGA classification (Streckheisen, 1973).

Ktowd **Tonalite (Wilson Diorite of Miller, 1934) (late Cretaceous)**—Designated granodiorite and quartz diorite on source maps; identified as mostly tonalite (D. M. Morton, oral communication, 2003) in the IUGA classification (Streckheisen, 1973).

Kgrd **Granodiorite**—Gray medium to coarse grained granodiorite with quartz diorite and granite. Described as Granodiorite by Oakeshott (1958). Includes rocks mapped as the Mt Josephine Granodiorite by Carter (1980). Mostly massive, but commonly gneissoid near contacts with older rocks; locally carries large inclusions and pendants of gneiss and Placerita metasediments. (Oakeshott, 1958, Carter, 1980).

Kp **Pelona Schist (Late Cretaceous to Paleocene?)**—Greenish-gray chlorite-albite, actinolite-albite, quartz-albite, and albite-talc schists, locally interbedded with metavolcanics and brown to black quartzites; a thick, isoclinally(?) folded sequence. The protolith of the Pelona and its correlative Orocopia Schist was presumably deposited during the mid-Mesozoic, recrystallized during burial to depths of 25-35 km, and later thrust beneath western North America at rates > 4 mm/y on the Vincent thrust. Named by Hershey (1902a) for outcrops on the Sierra Pelona

ridge. (Ehlig, 1981, p. 266; Jacobson, 1990; northern Mint Canyon 7.5' quadrangle, map after Jahns and Muehlberger, 1954).

Jeg **Echo granite (Jurassic)**—Coarse-grained, pinkish-orange granite and monzogranite; medium-grained, xenomorphic, inequigranular, and showing protoclastic granulation in thin section (Miller, 1946). Determined to be Jurassic in age by Barth (2008). Named by Miller (1934). (Smith, 1986).

Eastern Santa Monica Mountains

Jsm **Santa Monica Slate, undivided (late Jurassic)**—Black slate, sheared metasilstone, and fine-grained metagraywacke; intensely jointed, isoclinally(?) folded; intruded by Cretaceous granitic pluton forming contact aureole zones of phyllite and spotted cordierite slate; rare pelecypod fragments indicate a late Jurassic age in part (Imlay, 1963). Named by Hoots (1931, p. 88) (Hoots, 1931). Includes:

Jsms **Santa Monica Slate, spotted slate**—Spotted with large crystals of cordierite; outer zone of contact aureole with nearby granitic intrusive rocks; grades to unspotted slate through a zone in which individual spots become progressively smaller outward (Hoots, 1931).

Jsmg **Santa Monica Slate, phyllite**—Chiefly mica schist and dark gray phyllite; forms inner zone of contact aureole with adjacent granitic intrusive (Hoots, 1931).

San Gabriel and Verdugo Mountains

Mzdbh **Biotite-hornblende diorite (Mesozoic?)**—Medium- to dark-gray, medium-grained biotite-hornblende monzodiorite; includes scattered small bodies of older brownish-gray coarse-grained weakly gneissic biotite quartz monzonite; intruded by leucocratic granodiorite (Smith, 1986).

Mzdhb **Hornblende-biotite diorite (Mesozoic?)**—Medium-gray, medium-grained hornblende-biotite diorite; intruded by coarse-grained hornblende diorite and younger leucocratic granodiorite (Smith, 1986).

Mzqdb **Biotite-quartz diorite (Mesozoic?)**—Medium- to dark gray, medium grained quartz diorite; slightly gneissic. Locally contains inclusions of coarse-grained quartz diorite a few m across, and small elongate bodies of marble, quartzite, and schist of Paleozoic (?) age (Smith, 1986).

Mzmg **Biotite Monzogranite (Mesozoic)**—Light gray fine to coarse grained generally non-porphyritic monzogranite. Locally includes granodiorite. Foliated to locally gneissic. Mapped by Smith (1986) as leucogranitic and metamorphic complex. (Smith, 1986; Powell and others 1983).

Mzmgp **Porphyritic Biotite Monzogranite (Mesozoic)**—Light gray fine to coarse grained generally non-porphyritic Monzogranite. Locally includes granodiorite. Foliated to locally gneissic. Mapped by Smith (1986) as leucogranitic and metamorphic complex. (Smith, 1986; Powell and others 1983).

- Mzd** **Biotite-Hornblende Quartz Diorite, Diorite, and Gabbro (Mesozoic)**—Dark gray fine to coarse grained diorite. Locally includes tonalite and granodiorite. Foliated. Mapped by Saul (1976) as diorite. (Saul, 1986; Powell and others 1983).
- Mzhd** **Hornblende Diorite (Mesozoic)**—Gray, medium- to coarse-grained hypidiomorphic granular diorite. (Smith, 1986).
- Mza** **Alaskite (Mesozoic?)**—Salmon-pinkish-gray, medium-grained, mildly gneissic syenogranite. Forms long thin klippe over a much larger mass of granitic rock (Smith, 1986).
- Mzh** **Hornblendite (Mesozoic)**—Melanocratic coarse-grained hornblendite (Powell and others, 1983).
- Mzm** **Mylonite (Mesozoic)**—Gray fine-grained to microcrystalline mylonite. Mapped by Smith (1986) as siliceous metasedimentary rock. (Powell and others, 1983; Smith 1986).
- Mzdg** **Diorite gneiss (early to middle Mesozoic)**—Dark-colored gneisses including metadiorites, massive hornblende diorite, and amphibolite and biotite schists (60-80% plagioclase, 5-15% quartz, 5% or less potassium feldspar, locally as much as 30% biotite and locally as much as 10% brown hornblende); intrudes the Placerita Formation and intruded by Cretaceous granitic rocks; (Oakeshott, 1958).
- Ŧlgd** **Mount Lowe intrusive suite, undivided (Triassic)**—A compositionally layered pluton exposed over a large area in the western San Gabriel Mountains and northeastern Soledad basin (studied and described by Ehlig, 1981); varies from hornblende diorite and quartz diorite near the base to albite-rich granite and syenite in the upper part; large phenocrysts of hornblende, orthoclase and garnet contribute to distinctive appearance (pebbles and cobbles are readily recognizable as clasts in younger gravel deposits); metamorphosed to lower amphibolite facies and upper amphibolite facies (grade apparently varies with proximity to Cretaceous intrusive rocks); average composition 60-90% feldspar, of which plagioclase (oligoclase to albite) is most abundant and orthoclase occurs chiefly as phenocrysts, quartz ranges from a trace to as much as 25 %, averages about 10% (Ehlig, 1981). Initially named Mount Lowe Granodiorite by Miller (1926 abstract), subsequently termed Lowe Granodiorite by Miller (1934, 1946); renamed Mount Lowe intrusion by Barth and Ehlig (1988). The common usage of most source maps has been retained in this map compilation. A U-Pb age on zircon is reported as 220 ± 10 my (Silver, 1971), and a Rb-Sr whole rock age of 208 ± 14 my reported by Joseph and others (1982). Joseph and others (1982) also report a high (800-1,100 ppm) Sr content, a low initial $^{87}\text{Sr}/^{86}\text{Sr}$ ratio of 0.70456 ± 0.00003 , and a high alkali content ($\text{Na}_2\text{O} = \text{K}_2\text{O} \sim 10$ wt.%). More recently, Barth and others (1990) report a U-Pb zircon age of 218 my. Subunits include:
- Ŧlgb** **Mount Lowe intrusive suite, biotite-orthoclase facies**—As much as 10 percent biotite in a nearly white granular plagioclase and subordinate (less than 25 percent) quartz matrix. Has orthoclase phenocrysts; hornblende phenocrysts prominent in other subunits are absent, although a few hornblende-bearing layers occur in the lower part of this subunit (Dibblee 1996, 2001; Ehlig, 1981 and unpublished).
- Ŧlgdp** **Mount Lowe intrusive suite, Porphyritic facies**—Orthoclase phenocrysts in granular matrix of plagioclase and subordinate quartz; garnet also occurs as small crystals concentrated in veinlets (Dibblee 1996, 2001; Ehlig, 1981 and unpublished).

- Trlghd** **Mount Lowe intrusive suite, orthoclase-hornblende facies**—Light gray hornblende diorite (Dibblee 1996, 2001; Ehlig, 1981 and unpublished).
- Trlgm** **Metamorphosed Mount Lowe intrusive suite (Cretaceous and Triassic)**—Relatively uniform light-colored orthogneiss containing porphyroblasts (relict phenocrysts) of hornblende and, less commonly, potassium feldspar in a plagioclase and quartz matrix. Parent plutonic rock is (Triassic) Lowe Granodiorite and was metamorphosed during a Cretaceous orogenic event (Morton, 1973a, p. 9; and D. M. Morton, oral communication, 2003).
- Trhdg** **Hornblende diorite gabbro**—dark to very dark gray, medium-grained hornblende diorite gabbro. Massive to locally foliated. (Dibblee 1996, 2001; Ehlig, 1981 and unpublished).
- MzPzsp** **Serpentinite (Mesozoic or Paleozoic)**—Light to dark green, well foliated, sheared and slickensided serpentinite, altered peridotite (chiefly augite and olivine); slickensided fragments up to boulder size; boundaries intensely sheared and relations to adjacent rocks obscure (Barrows and others, 1975).
- Pzgn** **Gneiss complex (Paleozoic?)**—Feldspathic gneisses, including granitic to granodioritic augen gneisses, gneissic intrusive rocks of granitic to dioritic composition, amphibole-rich gneiss, and local interlayered schist, quartzite, amphibolite, and marble; according to Jahns and Muehlberger (1954), many of the gneisses are of hybrid origin, and some may be parts of the Placerita Formation that have been intimately injected by younger igneous material.
- Pzp** **Placerita Formation (Paleozoic)**—Metamorphosed sedimentary rocks, including marble, dolomite, feldspathic gneisses, graphitic marble, quartzite, calcic pyroxene hornfels and a variety of schists including feldspar-tremolite, graphite-tremolite, graphite-biotite-feldspar, and tremolite-talc; the various schists and gneisses occur as septa and pendants of all sizes in a granodioritic host rock, along with diorite gneisses and migmatites. The best-preserved section may be as much as 600 m thick. Named by Miller (1934), for exposures in Placerita Canyon, the type locality. The age indicated by Oakeshott (1958) is pre-Cretaceous; however, Morton (oral communication, 2003) indicates the age is Paleozoic. (Central Sunland 7.5' quadrangle, Oakeshott, 1958; southern Mint Canyon 7.5' quadrangle, Saul and Wooton, 1983).
- Egn** **Gneiss (Proterozoic?)**—Alternating discontinuous dark brown biotite-rich and light-colored quartz-feldspar-rich layers and lenses; layers generally about an inch thick; sheared, as expressed by an intricate structure of gneiss lenses with common local small microscopic tight flow-type folds. Described by Morton (1973) and by Crook and others (1987) as Cretaceous or older, but recently described by Morton (oral communication, 2003) as Precambrian. (Morton, 1973; Crook and others, 1987).

Anorthosite-gabbro complex of Oakeshott (1958) probably a result of differentiation of a single parent magma. Anorthosite and gabbro are pervasively shattered, sheared and brecciated. Barth and others (1995) indicate a general age of 1,200 Ma on the basis of dated zircons and thermobarometry, substantially older than 930 ± 90 Ma and 810 ± 80 Ma lead-alpha zircon ages determined by Neuerburg and Gottfried (1954). Unit is composed of sub-units mapped and described by Carter (1980) including:

- Pan** **Anorthosite-gabbro complex, anorthosite (Proterozoic)**—Composed of medium- to very coarse-grained plagioclase; light gray and white; contains more than 90 percent plagioclase

(andesine) and less than 10 percent mafic minerals (mostly hypersthene); grain size ranges from less than 1 mm to more than 30 cm.

- Pagb Anorthosite-gabbro complex, anorthosite with gabbro (Proterozoic)**—Composed of anorthosite as above with layers or zones of gabbro or diorite. 10 to 50% mafic minerals, mostly hornblende, white to gray, medium to coarse grained (Carter, 1980, 1982).
- Esy Anorthosite-gabbro complex, syenite (Proterozoic)**—Composed of plagioclase feldspar (andesine) with lesser potassium feldspar (Microcline-perthite). Has minute black specks of magnetite which may be altered from augite. Rock is generally tan, stained rusty tan to brown by limonite where weathered. (Jahns and Muehlberger, 1954; Oakeshott, 1958; Carter, 1980, 1982).
- Pfjb Anorthosite-gabbro complex, ferro-gabbro (Proterozoic)**—Composed mostly of ferro-magnesian minerals with lesser feldspars dark greenish brown. Contains sub-metallic molecules of iron ilmenite (magnetite-titanite). Intrusive into Pan and Psy. (Carter, 1980, 1982).
- Plgb Anorthosite-gabbro complex, leucogabbro (Proterozoic)**—Light gray compositionally layered gabbro, leucogabbro and anorthosite (Carter, 1980, 1982).
- Pjgb Anorthosite-gabbro complex, jotunitic gabbro (Proterozoic)**—Light gray compositionally layered gabbro with antiperthitic andesine. (Carter, 1980, 1982).
- Pjgba Anorthosite-gabbro complex, jotunitic-norite-gabbro-diorite (Proterozoic)**—Composed of hornblende, chlorite, biotite, and actinolite (altered from pyroxene) and limonite-magnetite, dark greenish brown, locally compositionally layered, contains inclusions of anorthosite (Carter, 1980, 1982).
- Eggn Anorthosite-gabbro complex, gabbroic to anorthositic gneiss (Proterozoic)**—Rocks of the anorthosite-syenite complex that were strongly deformed and in part recrystallized during emplacement of the Triassic Mt Lowe Intrusive suite (Carter, 1980, 1982).
- Egb Anorthosite-gabbro complex, gabbro (Proterozoic)**—Gray, mottled with greenish or brownish black, and solid dark greenish and brownish black; mafic mineral content ranges from 35 percent to 65 percent of rock; compositionally ranging from gabbroic anorthosite to norite, diorite, pegmatitic hornblende gabbro, and olivine gabbro. Chiefly xenomorphic granular texture; alternating felsic and mafic bands, from a few inches to several feet in thickness are common, but generally discontinuous. Feldspar is mostly calcic andesine (labradorite in more mafic rocks), in many places partly altered to albite or albite-oligoclase. Pyroxenes (and subordinate amphiboles) commonly altered to chlorite, antigorite and biotite (Oakeshott, 1958). (Carter, 1980, 1982, Oakeshott, 1958).
- Phgb Anorthosite-gabbro complex, hornblende bytownite gabbro (Proterozoic)**—Fine to medium grained foliated, layered, hornblende-chlorite gabbro with labradorite to bytownite plagioclase. Some layers of anorthosite (Carter, 1980, 1982).
- Egbla Anorthosite-gabbro complex, anorthosite inclusion-rich gabbro (Proterozoic)**—Strongly layered gabbro with numerous inclusions of anorthosite, some of which are up to 50 feet in length (Carter, 1980, 1982).

Emgn Mendenhall Gneiss (Proterozoic)—Layered migmatitic felsic gneiss and mafic granulite, having rare interlayered augen gneiss and aluminous gneiss. Gneiss is characterized by large-scale foliation, fracturing, jointing, and blocky shattering. Dikes of anorthosite and associated rocks cut gneiss, and centimeter- to meter-scale fragments of gneiss are scattered through the anorthosite. Most distinctive rock is dark gneiss with tint imparted by blue quartz (Oakeshott, 1958). Named by Oakeshott (1958, p. 21), who designated type locality on Mendenhall Peak. Age of Mendenhall Gneiss is greater than 1,200 Ma age of anorthosite sequence (Silver and others, 1963; Barth and others, 1995).

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APPENDIX A

SUMMARY OF PLIO-PLEISTOCENE NOMENCLATURE IN THE VENTURA BASIN

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Introduction

Plio-Pleistocene sedimentary rocks in the onshore Ventura basin have a complex history of formation designations extending back into the early 1900's and confusion in the correlation and nomenclature of these formations was noted as far back as 1919 (Smith, 1919). Some formations were initially defined lithologically, but many early workers defined formations in a faunal sense based on observed extinction rates of fossils or index fossils interpreted to have a limited age distribution, or based on inferred climatic conditions associated with certain fossil assemblages. Recognition of these biostratigraphic criteria in the field, however, is commonly impractical owing to the sporadic occurrence of diagnostic macrofossil assemblages, environmental control on the distribution of index fossils, and the inability of field geologists to identify microfossil assemblages without a microscope. Per the current North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005), formations and members (lithostratigraphic units) should be defined based on lithic characteristics rather than biologic criteria (biostratigraphic units) or inferred ages (geologic-time units), and this criterion is followed herein.

A series of factors have led to a pantheon of Plio-Pleistocene formation names in the Ventura depositional basin, which include: 1) Early use of faunal criteria rather than lithology and depositional continuity to define unit boundaries and as a basis for tenuous correlation of units across geographically widely spaced exposures and basin boundaries; 2) the presence of time-transgressive lithologic unit boundaries due to westward migration of the paleoshoreline and shelf as basin filling began to outpace basin subsidence during later Pliocene and Pleistocene times; 3) lateral variations in lithology and unit thickness from the axis of the basin, centered near the Santa Clara River, to basin margin areas and paleogeographic highs associated with pre-Pliocene extensional/rotational tectonic movement; 4) development of coeval and post-depositional structural complexities due to Pleistocene to recent, north-south-oriented compression associated with the "big bend" in the San Andreas Fault, which resulted in localized uplift and associated unconformities due to non-deposition or erosion of strata in elevated areas, and in concealment of units below thrust faults and young eroded sediments; 5) variations in criteria used to define unit boundaries based on subsurface exploration techniques versus surface mapping, and; 6) unit designations based on benthic faunal assemblages that are associated with specific depositional environments and are therefore sometimes time transgressive due to migration of these environments over time within the basin.

The purpose of the following discussion is to provide a historical perspective on the development of the Plio-Pleistocene formation nomenclature in the Ventura basin, summarize current discrepancies in this nomenclature, and to describe the basis for the formation designations adopted on the current Los Angeles 30 x 60' geologic map.

Summary of Depositional Sequence

The Plio-Pleistocene stratigraphic sequence in the onshore Ventura basin generally reflects a marine regression from deep basinal deposits to shallow marine shelf and littoral deposits, and transitional delta and lagoonal conditions, which are capped by nonmarine fluvial and alluvial fan deposits. Formation names adopted herein are typically distinguished by lithologic characteristics that are controlled by depositional environment. The deep, bathyal basinal deposits consist primarily of siltstone and mudstone with interbedded sandstone and local conglomerate beds that were generally deposited by turbidity currents and submarine landslides or slumps. Slope and outer shelf deposits typically consist of hemipelagic siltstone and claystone with local channels and lenses of sandstone and conglomerate that acted as feeders to the bathyal submarine fans. Inner shelf, littoral and delta deposits are dominantly granular with locally prominent coquina beds. These shallow marine deposits commonly interfinger with nonmarine sandstone and conglomerate or interfinger with braid-delta or lagoonal deposits consisting of sandstone and conglomerate interbedded with mudstone and local freshwater limestone in the eastern Ventura basin. Deposition was nearly continuous for much of this time interval near the basin axis in the western and central portions of the basin (e.g. Nagle and Parker, 1971) and marine deposition persisted much later, and is much thicker, in this area than in the eastern Ventura basin, where thick, coeval, Pleistocene nonmarine deposits accumulated. This geometry reflects the time transgressive nature of basin infilling from east to west during late Pliocene and Pleistocene times, as graphically illustrated in the idealized longitudinal cross section of the Ventura basin provided in Figure A1. Basinal deposits thin toward the southern and eastern margins of the basin where they are overlapped by shallow marine and

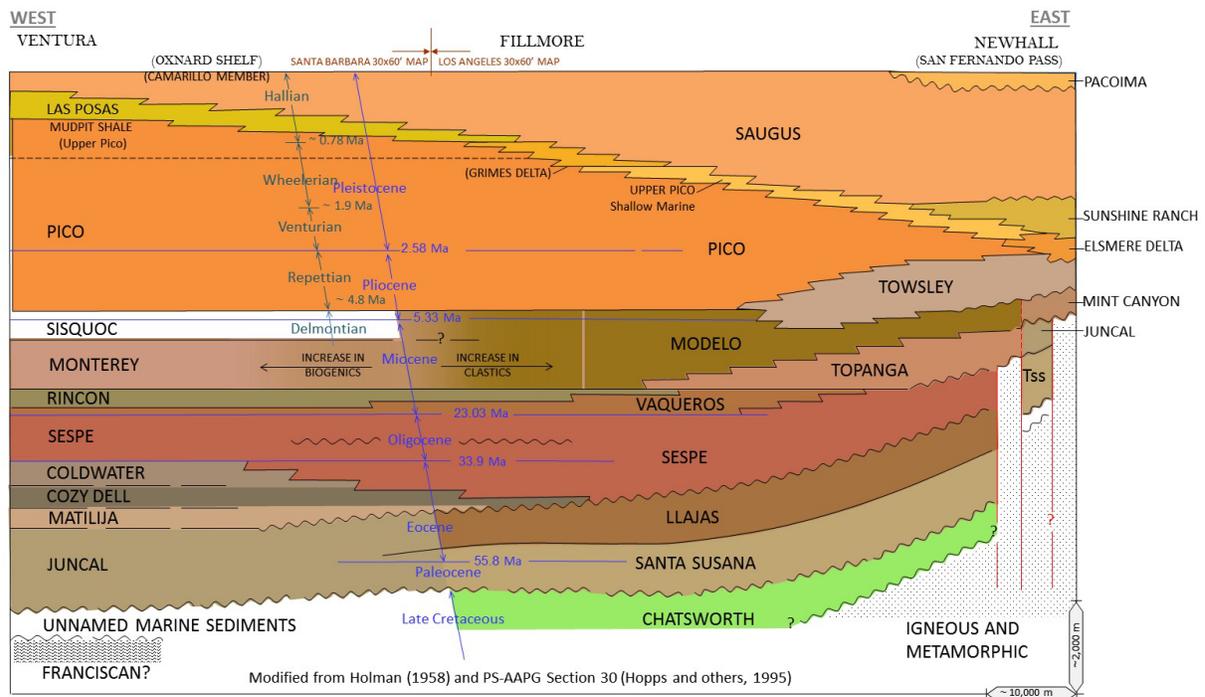


Figure A1. Diagrammatic longitudinal cross-section of the Ventura basin showing general relations of stratigraphic units.

nonmarine deposits, resulting in disconformities and local angular unconformities within the basin margin sequences. Plio-Pleistocene deposits on the northern margin of the central and western portions of the basin have largely been lost due to late Quaternary tectonic uplift and erosion. A grid work of geologic cross sections across the Ventura basin was prepared by the Ventura Basin Study Group (Hopps and others, 1992), which help to illustrate the complex subsurface relationships of the Plio-Pleistocene strata.

Paleogeographic Summary

Geologists began to realize in the early 1930's that Pliocene and Pleistocene deposits in the Ventura basin were paleogeographically isolated from similar age deposits of the Los Angeles basin (e.g. Edwards, 1932, 1934) as a result of uplift of the ancestral Santa Monica Mountains, and this conclusion is still generally accepted (e.g. Dibblee, 1995). The Sylmar sub-basin and San Fernando Valley basin/embayment are historically considered to be associated with the southeastern margin of the Ventura basin (Nagle and Parker, 1971; Dibblee, 1995), but subsequently became isolated due to tectonic movement and emergence of the Santa Susana Mountains (Treiman and Saul, 1986; Levi and Yeats, 1993; Langenheim and others, 2011). The Ventura basin overlaps older Miocene deposits on the southwestern margin of Soledad basin and the southern margin of Ridge basin. There does not appear to be a clear paleogeographic distinction between Pliocene basin deposits of the western onshore Ventura basin and the offshore Santa Barbara basin to the west (e.g. Vedder and others, 1969; Fisher, 1976; Galloway, 1998). However, Jackson (1981) and Jackson and Yeats (1982) report that a boundary developed during Pleistocene time between shallow marine deposition in the western Ventura basin and the Carpinteria basin as a result of uplift along the Red Mountain Fault. The paleogeographic relationships between Pleistocene strata exposed near Ventura and coeval strata in the Ojai Valley to the north were not evaluated.

Chronologic Development of Nomenclature in the Ventura Basin

Early History and Development of the Fernando, Pico and Saugus Formations – Through 1924

Late Tertiary strata in the Ventura basin were initially described during early government surveys, such as explorations by the United States for a railroad route to the Pacific Ocean (Antisell, 1856; Blake, 1857), geologic surveys by the State of California (Trask, 1855a; Whitney, 1865; Peckham, 1866), and Wheeler's explorations west of the hundredth meridian (Marcou, 1875). Geologic descriptions provided in these reports consist of basic lithologic and paleontologic characteristics encountered en-route and were typically written in a journalistic, sometimes rambling style; geographic locations of the outcrops and fossil sites are commonly vague. Lithologic descriptions focusing on locally significant petroliferous areas and fossil localities in the basin were also published near the turn of the century (e.g. Goodyear, 1887; Bowers, 1888, 1890; Ashley, 1895; Watts, 1897, 1901). No formation names were applied to Plio-Pleistocene units in the Ventura basin in these early publications.

The first published attempt at defining a Plio-Pleistocene formation in the Ventura basin was by Hershey (1902b), who assigned the youngest section of folded rocks in lower Soledad Canyon to the "Saugus division". Hershey described this section as southwest-dipping sand, gravel and clay "splendidly" exposed near Saugus in railway cuts along the Southern Pacific line, which is the type locality for this unit. Hershey interpreted these deposits to represent "an alluvial deposit, a river delta, progressively sinking and receiving fresh layers of gravel, overlaid by silt, the surface of which latter was

weathered into soil” of late Pliocene age (i.e. deposited prior to the Pleistocene “great orographic disturbance”). However, this term apparently did not initially gain much notoriety and was little used in the literature prior to 1921. Arnold and Arnold (1902) and Arnold (1903) suggested that fossiliferous sands north of Ventura were equivalent primarily to their “upper San Pedro series”, but did not provide a geologic map of their distribution; Kew *in* Tiejie (1926) later assigned Arnold’s “upper San Pedro series” to the Palos Verdes Formation. Eldridge (1903) subsequently suggested that conglomerate, sandstone and claystone beds overlying Monterey-type shales in the Santa Clara Valley (and elsewhere in southern California) are equivalent to the “San Pablo horizon” based on fossils and a distinctive dusty weathering characteristic similar to exposures at the type locality in San Pablo Bay. Per the 1938 USGS Lexicon (Wilmarth, 1938), however, the San Pablo Formation is late Miocene in age and characteristically contains ash beds, and this suggested usage was short lived in the Ventura basin.

Following the death of Eldridge in 1905, Arnold compiled Eldridge’s work and prepared the first geologic map of the Santa Clara River area, between Santa Paula and Newhall, along with geologic maps of the Los Angeles and Puente Hills areas (Eldridge and Arnold, 1907). These authors assigned the term Fernando Formation to an “enormous succession of conglomerates, sandstones and arenaceous clays, largely of Pliocene age” that they mapped in the Santa Clara River Valley, and they assigned this term to similar deposits mapped in the Los Angeles and Puente Hills areas. The authors stated that the term Fernando was derived from unpublished maps by Homer Hamlin, who applied it to “the beds above siliceous shale skirting the sides of the San Fernando Valley”, which Eldridge and Arnold considered “the general equivalent of all the post-Modelo, pre-Saugus beds in the Santa Clara province” (footnote on p. 22). However, with reference to the position of the Saugus beds, review of their map (which does not include Hershey’s type area) indicates that Saugus-equivalent strata on the south and west sides of the Santa Clarita Valley were included as part of their Fernando Formation and that the overlying Qp unit on their map corresponds to old river terrace deposits (Pacoima Formation) rather than the steeply dipping Saugus division of Hershey (1902b). Kew (1923) reported that the Saugus Formation of Hershey was always included in the Fernando Formation and Kew (1924) noted that the Saugus described by Eldridge and Arnold (1907) was applied to terrace deposits, not the Saugus division of Hershey (1902b). Eldridge and Arnold (1907) did not provide a geologic map of the San Fernando Valley or specifically define where the type section of the proposed Fernando Formation is located, and Hamlin never published his mapping or manuscript on the San Fernando Valley. The vague definition for the location of the type area of the Fernando Formation described by Eldridge and Arnold was never refined and a formal type section/locality was never defined in the San Fernando Valley. Eldridge and Arnold (1907) reported the Fernando is usually bounded by unconformities and ranges in age from late Miocene well up into the Pleistocene. They also recognized that it would be “possible to subdivide the formation locally on both lithologic and paleontological grounds, but taken over a considerable extent of territory these divisions merge into one another both stratigraphically and geographically by insensible gradations”.

Usage of the term Fernando Formation was initially extended to deposits primarily of Pliocene and early Pleistocene age in southern California from the southeastern Los Angeles basin to the Santa Maria district, including the Puente Hills, Los Angeles, Ventura, Summerland, and Santa Barbara areas (Arnold, 1907b; Arnold and Anderson, 1907a, 1907b; Willis, 1912; McLaughlin and Waring, 1914; Moody, 1916; Diller and others, 1916; Kew, 1919a). Smith (1912) noted that by 1912 the term Fernando had been used for faunas ranging from earliest Pliocene to middle Quaternary in age. McLaughlin and Waring (1914) compiled and published the first geologic map covering most of the onshore Ventura basin

(Plate III of their accompanying folio); their correlation chart of California formations of the Coast Ranges shows the Fernando Formation as unconformity bounded, lower Pliocene strata overlain by Pleistocene terrace deposits. Based on work in the Newhall area, English (1914) noted that the Fernando Formation “includes beds of diverse lithology and different ages, which probably belong to more than one formation, the recognition of which awaits more detailed mapping” and therefore informally referred to the Fernando as a group rather than a formation. With regards to the 1916 geologic map of California, Smith (1916) described the lower Pliocene of southern California as the Fernando Formation, which he noted as contemporaneous with the San Diego Formation of his standard marine section for all of California, apparently on the basis that they both contain warm water fossil fauna. Smith (1919) noted that there was already much confusion in the correlation and nomenclature of the Pliocene formations of the west coast, owing to the disconnected nature of the beds, their varying lithology, and the great variety of climatic conditions under which the beds were deposited. Kew (1919b) assigned Pliocene fossiliferous and overlying unfossiliferous granular strata in the Simi Valley area and in the far northwestern corner of the San Fernando Valley to the Fernando Formation.

By 1921 Kew was preparing to subdivide Fernando strata of the Ventura basin into two formations (Clark, 1921b; Vander Leck, 1921) and in 1923 Kew initially assigned the lower Pliocene marine, lower portion of the Fernando to the Pico Formation and the upper Pliocene and Pleistocene, shallow marine and nonmarine, dominantly granular upper portion of the Fernando to the Saugus Formation (Kew, 1923). In 1924, Kew thoroughly described the lithology and age of the Pico and Saugus Formations and published a geologic map showing the distribution of these formations in the Ventura basin south and east of Santa Paula (Kew, 1924). He formally elevated the term Fernando to group status. The type section of the Pico Formation was designated for gray siltstone with common limonite nodules and interbedded sandstone and local conglomerate exposed in Pico Canyon on the north side of the Santa Susana Mountains, southwest of Newhall. Kew interpreted the contact between the Pico Formation and overlying Saugus Formation as mostly unconformable. Kew’s description of the Saugus Formation largely followed the original description of Hershey (1902b) for exposures near the town of Saugus (north of Newhall) and Kew (1932) confirmed the Saugus is nonmarine at the type locality. However, Kew included shallow marine sandstone and conglomerate in the portions of the lower portion of the Saugus Formation, particularly west of Newhall and in the Santa Susana Mountains. For example, both the Pliocene marine and nonmarine strata previously mapped by Kew (1919b) as Fernando Formation on the north side of the Simi Valley were reassigned to the Saugus Formation by Kew (1924). The terms Saugus and Pico Formation were quickly adopted by many workers in the Ventura basin (e.g. Taliaferro and others, 1924; Wilmarth, 1927; Cartwright, 1928; Driver, 1928; Waterfall, 1929; Hill, 1930; Clark, 1930; Woodring, 1930) and usage of the term Pico Formation was also extended to Pliocene strata in the Los Angeles basin (as summarized in Wissler, 1943; Durham and Yerkes, 1959, 1964), and the Fernando was referred to as a group by English (1926) in the Puente Hills.

Development of San Pedro, Las Posas, and Santa Barbara and Formations – Beginning in 1928

Although usage of the terms Pico Formation and Saugus Formation was adopted by many workers in the Ventura basin, other suggested divisions were proposed by various early workers for local sections in the thick Plio-Pleistocene sequence of the western Ventura basin. For example, Carson (1925) designated the term “Ventura formation” in a faunal sense for upper Pliocene sands northeast of Ventura and in the South Mountain Las Posas Hills areas, and Eaton coined the terms “Santa Paula formation”

(Eaton, 1926) for lower Pliocene strata northwest of Santa Paula and “Hall Canyon formation” (Eaton, 1928) for Pleistocene strata in the Hall Canyon area. However, these names were found by later workers to be either untenable or unnecessary, and eventually fell into disuse (as noted by Waterfall, 1929; Grant and Gale, 1931; Bailey, 1935, 1943, and Keroher and others, 1966). However, four additional formation names were proposed by various workers between 1928 and 1932 for Pliocene and Pleistocene strata in the western Ventura basin that subsequently gained wide usage by geologists working in the Ventura basin. Of these four, the Las Posas Formation was defined within the Ventura basin and the other three formation names were extended to the Ventura basin based on interpreted similarities in fossil fauna with type sections located in adjacent basins: The San Pedro Formation and “Repetto Formation” were extended from the Los Angeles basin and the Santa Barbara Formation was extended from the onshore portion of the Santa Barbara basin.

Waterfall (1929) reported that Pico Formation beds near Ventura contain two invertebrate faunas, the younger of which occurs at the top of the formation. Waterfall considered this younger fauna equivalent to the Pleistocene, shallow marine Bath House Beach fauna of Santa Barbara, which he considered equivalent to (rather than younger than) the Packard’s Hill fauna. Smith (1912) had previously assigned the term “Santa Barbara” to these beds near Santa Barbara and is historically credited as the first worker to use this term (Wilmarth, 1938; Woodring and others, 1940), although Arnold and Arnold (1902) had previously referred to this section as the “Santa Barbara formation”. However, Arnold (1907b) subsequently assigned the Santa Barbara strata to the “Fernando formation”. Waterfall’s correlation was apparently the first published extension of the term “Santa Barbara” specifically to Ventura basin strata. Pressler (1929) continued Waterfall’s work and identified the upper Pico formation in the Las Posas and South Mountain areas as the “Santa Barbara horizon”. Clark (1930) noted that the Saugus fauna in Ventura County is referred to as the “Santa Barbara horizon” by Smith (1919). In their summary of the Ventura basin, Grant and Gale (1931) noted that upper Pliocene strata reportedly contains a cold water fauna and has been called by various names including middle or upper “Fernando”, “upper Pico”, “Santa Barbara horizon” and “Ventura horizon”. They reported that the earliest name applied to the cold water faunal zone is “Santa Barbara” and they adopted this name for this faunal horizon.

Bailey (1935, 1951) also adopted the term “Santa Barbara” for strata in the Ventura basin, which he described as composed mostly of mudstone north of Ventura, but with increasing sandstone and conglomerate in the upper portion of the section east of Sexton Canyon. Bailey (1935) noted that his “Santa Barbara” is synonymous with Pressler’s 1929 usage except that he also included Pressler’s Kalorama member because it contains a typical Santa Barbara fauna. He also noted that his “Santa Barbara” is the upper Pico of Cartwright (1928), Driver (1928) and Waterfall (1929). As stated in the 1938 USGS Lexicon (Wilmarth, 1938), Bailey (1935) reported that “at the type locality on the Santa Barbara “mesa,” at Rincon Point near the Santa Barbara-Ventura County line and at other localities near the edge of the basin, where it has a shallow-water facies, the Santa Barbara may be divided into two faunal zones on the basis of its mega-fauna”, an upper *Pecten caurinus* and a lower *Pecten bellus* zone [note that in the 1966 USGS Lexicon (Keroher and others, 1966) a comma is missing from the description after the word ‘mesa’, which gives an incorrect impression that the Santa Barbara ‘mesa’ type locality is at Rincon Point]. Bailey (1935) noted that the lower part of the “Santa Barbara Formation” near Ventura is deeper water than at the type area in Santa Barbara and rarely contains the age-defining megafossils typical of the shallow water facies. He concluded that the upper half of his “Santa Barbara Formation” is lower Pleistocene and the Plio-Pleistocene boundary is interpreted to occur near the middle of the

formation. Bailey noted the contact with the overlying “San Pedro Formation” is consistently marked by a sharp faunal break, which is used to check the contact location whereas the lithology is somewhat variable; however, he also recognized the existence of lateral changes in fauna and at the contact between the “Santa Barbara Formation” and “San Pedro Formation” east of Ventura and concluded that paleontological correlations alone are not reliable to distinguish these formations.

Woodring and others (1940) formalized the Santa Barbara Formation in the type area and a detailed stratigraphic description of the type section was first completed by Dibblee in 1941, which was initially published in Keen and Bentson (1944). The lithologic disparity between the dominantly granular beds composed primarily of biogenic carbonate grains at the type locality of the Santa Barbara Formation (Dibblee *in* Keen and Bentson, 1944; Dibblee, 1966; Bullivant, 1969), and the dominantly fine-grained section with subordinate terrigenous granular interbeds assigned to the Santa Barbara Formation in the Ventura basin (e.g. Bailey, 1935; Bailey *in* Redwine, 1952) was not discussed by early workers. However, usage of Santa Barbara Formation in the Ventura basin was adopted in many subsequent publications based on the interpreted faunal similarity with the type Santa Barbara section, including Grant and Hertlein (1943), Eaton (1943), the Ventura County Investigation (State Water Resources Board, 1953), and Weber and others (1973). The State Water Resources Board (1953) identified the informal Grimes Canyon member near the top of the Santa Barbara Formation as an aquifer in the Las Posas Valley area.

Pressler (1929) also coined the term “Las Posas formation” for shallow marine sands that contain a distinctive warm water “Saugus” molluscan fauna occurring stratigraphically above the “Santa Barbara horizon” in the Las Posas Hills area near Camarillo. As reported by Bailey (1935), this term became generally synonymous with “lower marine Saugus Formation” of Kew (1924) and “lower San Pedro Series” of Arnold (1903), which was renamed the San Pedro Formation per the restricted definition of Kew *in* Tiejie (1926). Eaton (1928) used the term “San Pedro formation” for lower Pleistocene (Pedroian) series in the hills north of Ventura, placing this section above the Saugus Formation and below his “Hall Canyon formation”. Grant and Gale (1931) strongly suggested that the term “Saugus” not be used for Pleistocene marine sands in the western Ventura basin and adopted “San Pedro Formation” in preference to “marine Saugus Formation”, “Ventura formation”, or Las Posas sand, which they show as underlying the nonmarine Saugus Formation in the western Ventura basin and interfingering with the Saugus to the east. This use was followed by many subsequent workers in the western Ventura basin (e.g. Bailey, 1935, 1951; Ingle, 1967; Sarna-Wojcicki and others, 1976; Yerkes and others, 1987), although Bailey (1935) recognized that the type San Pedro type section only comprises “a meager fraction” of the section exposed in the Ventura basin. The State Water Resources Board (1953) also adopted “San Pedro Formation”, typically including both marine and nonmarine strata, and in the Las Posas Valley area they identified the informal Epworth gravels and Fox Canyon member as aquifers within the upper and lower portions of the formation, respectively. Many workers continued to use the term “lower marine Saugus Formation” following Kew’s definition (e.g. Hetherington, 1957; Pasta 1958; Lung, 1958; Brown, 1959; Van Camp, 1959; Canter, 1974; Jakes, 1979; Hanson, 1981; Rockwell, 1983; White, 1983, 1985; Chen, 1988; Groves, 1991). The term Las Posas Formation was also adopted or noted for this section by other workers (e.g. Clark, 1930, 1943; Wilmarth, 1938; Merriam, 1941; Stewart, 1943; Natland, 1957; Holman, 1958; Hall, 1967; Natland, 1967; Hopps and others, 1995; DeVecchio, 2012a and 2012b). A few authors even referred to marine sands in the western Ventura basin as the “San Diego formation” on a faunal basis (e.g. Le Roy, 1943).

“Repetto Formation” – Beginning in 1930

In 1930, a committee of the Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM) was convened to address the Pliocene stratigraphic nomenclature issues that had developed at the time in the Los Angeles basin based on studies of benthic foraminifers, driven primarily by oil exploration. As first published by Reed (1932), this committee recommended that strata containing a foram assemblage diagnostic of the late (or middle and late) Pliocene be assigned to the Pico Formation and that strata containing the distinctive lower Pliocene assemblage be assigned to the “Repetto formation”. The usage recommended by the SEPM committee was adopted by many geologists working in the Ventura and Los Angeles basins (*see Commentary section at the end of this appendix for additional details regarding development and abandonment of the term “Repetto formation”*).

Mudpit shale member – Beginning by about 1933

Natland (1933) reported that a section of strata in Hall Canyon that contains the cool water species *Pecten caurinus*, and corresponds to his foraminiferal Zone III is commonly called “the mud pit shale”. Natland’s use of this term was the first that could be found in the published literature. Stewart (1943) informally referred to a section of Pleistocene marine mudstone in the western Ventura basin as the Mudpit shale, which had previously been assigned by many workers to the Santa Barbara Formation. The name reportedly refers to a quarry site on the eastern side of the Ventura River for the purpose of obtaining mud for use in oil drilling in the Ventura Avenue oil field, and for making bricks (Stewart, 1943). The quarry was subsequently mined to obtain expansible shale and was known as the Rocklite quarry (Rogers and Chesterman, 1957). *Additional details regarding the subsequent nomenclature and stratigraphy of the Mudpit shale section are provided under the commentary section at the end of this appendix.*

Sunshine Ranch Member – Beginning in 1940

Based on geologic studies for oil exploration in the northern San Fernando Valley area, Hazzard (1940) distinguished a stratigraphic sequence at the transition between the marine Pico Formation and nonmarine Saugus Formation in the eastern Ventura basin. Hazzard (1940) assigned this section to the “Sunshine Ranch formation” in a proprietary, unpublished report prepared for Standard Oil, and he selected outcrops north of Sunshine Ranch in the Mission Hills area of the northern San Fernando Valley, west of the San Fernando Reservoir between the axial region of the Reservoir anticline and Balboa Avenue, as the type section. A copy of Hazzard’s original report could not be located for review, but Oakeshott (1950) formally published a description of the Sunshine Ranch strata based on Hazzard’s work, and included excerpts of selected text from Hazzard’s report. As summarized in Oakeshott (1950), the Sunshine Ranch strata consist of sandstone, conglomerate, coquina beds in the lower portion of the section overlain by gray pebbly sandstone and gray to greenish-gray, very fine-grained sandstone, silty sandstone and sandy siltstone, which is noted as the most characteristic lithologic type of the unit. Oakeshott (1950) designated this section as a member of the upper Pico Formation rather than a separate formation. The excerpts from Hazzard’s report include descriptions of Ostracodes and other microfauna indicative of brackish-water, lagoonal and fresh-water depositional environments.

Oakeshott (1958) subsequently published a more comprehensive description of the Sunshine Ranch Member and its mapped distribution within the San Fernando 15’ quadrangle. Additional exposures were subsequently mapped in the Oat Mountain 7.5’ quadrangle on the south flank of the Santa

Susana Mountains by Saul (1979) and on the north side of the Santa Susana Mountains by Treiman (1987b). Barrows and others (1974) mapped exposures in the northern San Fernando Valley, south of San Fernando Pass following the 1971 San Fernando earthquake (Saul, 1975). Sunshine Ranch strata have been reported in the subsurface at the Placerita oil field by Willis (1952). Winterer (1954) reassigned the Sunshine Ranch Member to the lower Saugus Formation and this usage was followed by Jennings (1957); however, Merifield (1958) felt that formational status was appropriate. Winterer and Durham (1962) formalized placement of the Sunshine Ranch Member within the lower Saugus Formation, and Saul (1979) and Saul and Wootton (1983) subsequently limited this member to nonmarine strata during more detailed mapping of the southeastern portion of the Oat Mountain quadrangle and the southern Mint Canyon quadrangle, respectively.

Towsley Formation – Beginning in 1951

In 1951 Winterer and Durham recognized, but did not name, a lithologically distinctive stratigraphic section at the transition between the Pico and Modelo Formations on the northern flank of the Santa Susana Mountains. This section is composed of marine sandstone, conglomerate and brown-weathering sandy siltstone and mudstone deposited in a submarine fan environment, much of which had previously been included by Kew (1924) within the upper Modelo Formation. Winterer and Durham (1954) subsequently assigned the name Towsley Formation to this stratigraphic sequence, based on a type section in Towsley Canyon.

Pacoima Formation – Beginning in 1952

In 1952 Oakeshott proposed the name Pacoima Formation in an obscure journal for coarse-grained, poorly sorted, Pleistocene alluvial fan deposits in the northern San Fernando Valley, based on a type section on the east side of the mouth of Pacoima Canyon (Oakeshott, 1952). A copy of Oakeshott (1952) could not be located for review; however, Oakeshott (1958) published detailed descriptions and mapping of this formation in the San Fernando quadrangle. His mapping extended the formation into the Santa Clarita Valley, east of Newhall. Oakeshott's use of Pacoima Formation was not adopted in the Newhall area by Winterer and Durham (1962), who used the term Quaternary terrace deposits instead. However, Saul and Wootton (1983) mapped these alluvial deposits in more detail on the Mint Canyon quadrangle and followed Oakeshott's use of Pacoima Formation. Treiman (1986, 1987a, 1987b) also reassigned the older terrace deposits of Winterer and Durham (1962) to the Pacoima Formation on his geologic maps of the Oat Mountain and Newhall quadrangles.

Significant Refinements Affecting Ventura Basin Nomenclature – 1958 to 1964

Winterer and Durham (1958, 1962) provided updated mapping of the eastern Ventura basin and re-evaluated the Plio-Pleistocene nomenclature. They recommended several revisions that have generally been adopted by subsequent workers in the eastern Ventura basin: 1) They reverted to Hershey's 1902 nonmarine definition of the Saugus Formation and reassigned shallow marine sands that Kew (1924) had included in the lower portion of the Saugus Formation into the upper Pico Formation; 2) following the previous recommendation of Winterer (1954), they reassigned Sunshine Ranch Member strata that Oakeshott had included in the upper Pico Formation to the lower portion of the Saugus Formation and provided a diagram (Figure 54 on p. 309 of their 1962 report) that illustrates the facies relationships of the transitional Sunshine Ranch Member to the underlying marine Pico Formation and overlying nonmarine Saugus Formation; 3) following their previous work (Winterer and Durham, 1951, 1954), they formally

described the Towsley Formation and published detailed stratigraphic sections representative of the formation along strike from Tapo Canyon on the west to Rice Canyon on the east. They concluded that strata assigned by Oakeshott (1950, 1958) and Willis (1952) to the “Repetto formation” at Elsmere Canyon and the Placerita oil field is lithologically distinct, and was paleogeographically isolated, from “Repetto formation” strata in the Los Angeles basin, and reassigned this section to the Towsley Formation. The recommendations of Winterer and Durham (1958, 1962) have been adopted by most subsequent workers in the eastern Ventura basin (e.g. Saul, 1975, 1979; Weber, 1982; Saul and Wootton, 1983; Yeats and others, 1985; Barrows, 1986; Treiman, 1986, 1987a, 1987b; Dibblee Foundation maps of the eastern Ventura basin) and are generally followed herein.

Roughly concurrent with the work of Winterer and Durham in the eastern Ventura basin, Durham and Yerkes (1959, 1964) recommended similar far reaching revisions to the Pliocene stratigraphic nomenclature in the Los Angeles basin, and these revisions resulted in implications for the Ventura basin nomenclature as well: 1) Durham and Yerkes recognized that usage of the terms “Pico” and “Repetto” in the Los Angeles basin were based on fauna rather than lithology and that the type Pico section included early Pliocene strata and is a different facies than the Pliocene section mapped in the Los Angeles basin. They therefore formally abandoned use of the term “Repetto formation” and restricted use of the term Pico Formation to areas outside of the Los Angeles basin. They chose to lower the rank of the “Fernando” back to formational status in the Los Angeles basin and reassigned the “Pico” and “Repetto” strata to this formation. This usage was adopted by Jennings and Strand (1969) for the 1:250,000 scale geologic map of the Los Angeles sheet. *Additional details regarding the recommendations and implications of Durham and Yerkes (1959, 1964) are summarized in the following section of this appendix.*

Geologic Map of Ventura County - 1973

Weber and others (1973) compiled geologic mapping of Ventura County, based primarily on unpublished mapping by Bailey (1951), unpublished mapping by Ventura County geologist Blasé Cilweck, and on numerous master’s theses of the area completed primarily in the 1950’s (see Plate IV of Weber and others, 1973, for the areas covered in the source theses). Weber and others (1973) generally followed the usages described by the source authors, resulting in some inconsistent nomenclature across the Ventura basin. In general, they adopted the terms Towsley Formation, Pico Formation, Santa Barbara Formation, Saugus Formation, and San Pedro Formation for the Plio-Pleistocene sequence in the Ventura basin. The Saugus Formation and San Pedro Formation are noted as containing both marine and nonmarine strata and are noted as at least partially stratigraphically equivalent. They also mentioned the Mudpit shale, but incorrectly report on page 22 that it occurs in the lower portion of the Pico Formation, rather than addressing it as part of the upper portion of the Pico Formation or the Santa Barbara Formation. One of the referenced theses by Lung (1958) made the significant conclusion that the “Santa Barbara Formation” mapped by Bailey (1951) in the South Mountain area could not be differentiated from the underlying Pico Formation on a lithologic basis, and Lung’s mapping was adopted in this area. The geologic map compiled by Weber and others (1973) became a standard reference for the Ventura basin and strongly influenced subsequent formational nomenclature in Ventura County (e.g. Yeats and Grigsby, 1987; Yerkes and others, 1987). Cross sections prepared by the Ventura Basin Study Group (Hopps and others, 1992) are reportedly based largely on the nomenclature from Weber and others (1973) (Hopps pers. comm. 2014).

Resurgence of “Fernando Formation” in the Ventura Basin – Beginning in 1974

In his 1974 master’s thesis, Canter used the term “Fernando Formation” for Pliocene strata in the Big Mountain area near Moorpark (Canter, 1974), and Ricketts and Whaley (1975) also used the term “Fernando Formation” in their master’s thesis on the Oak Ridge-Santa Susana Fault intersection. However, Canter (1974) incorrectly reported that Kew (1924) named the Pico as the lower member of the “Fernando Formation” and Ricketts and Whaley (1975) incorrectly reported that Jennings and Strand (1969) redefined the Pico as the upper member of the “Fernando Formation”. Nevertheless, these two theses appear to represent the first usage of “Fernando” as a formational rank unit in the Ventura basin since Kew (1924) had elevated it to group status, and marked the revival of the term “Fernando Formation” in the Ventura basin (e.g. Yeats, 1976, 1979b; Rockwell, 1983; Liddicoat, 2001a and 2001b). Yeats and others (1994) reported that it was current USGS practice at the time to assign “all strata between the Towsley and Saugus Formations to the Fernando Formation”, citing Jennings and Strand, 1969 as the basis. However, Jennings and Strand (1969) actually continued to use the term Pico Formation for Pliocene strata in the Ventura basin and only used the term “Fernando Formation” for Pliocene strata in the Los Angeles basin, consistent with the nomenclature recommendations of Durham and Yerkes (1964) referenced therein. *Additional details regarding the recommendations of Durham and Yerkes (1964) are provided later in this appendix.*

Pleistocene, Shallow Marine Boundary between Ventura and Carpinteria Basins – 1981 to 1982

Jackson (1981) and Jackson and Yeats (1982) pointed out the discrepancy in lithology between the granular exposures of the Santa Barbara Formation in the type area of the formation and the fine-grained section previously correlated with this formation in the Ventura basin. They reported that correlation of the Ventura section and the section north of the Red Mountain fault (Rincon Point area) was originally based on megafossils rather than lithology. Based on structural relationships, Jackson and Yeats (1982) concluded that movement along the Red Mountain fault caused uplift of an elongate block near Rincon Point prior to deposition of the Santa Barbara Formation, forming a boundary for shallow marine sedimentation during Pleistocene times. They assigned Pleistocene strata northwest of the Red Mountain fault uplift to the Carpinteria basin, a Pleistocene, near-shore extension of the Santa Barbara basin. This basin boundary reportedly obscures shallow marine facies relations between the Pleistocene sections in the Ventura and Los Angeles basins.

Dibblee Foundation Mapping – 1988 to 1996

Between 1988 and 1996, the Dibblee Foundation published geologic maps of twenty 7.5’ quadrangles covering Plio-Pleistocene strata within the onshore Ventura basin south of Ojai, and several important standard criteria were consistently adopted for Plio-Pleistocene nomenclature across the basin on these maps: 1) The term Pico Formation was adopted in preference to the terms “Repetto formation” or “Fernando formation”; 2) shallow marine sands in the eastern Ventura basin and Santa Susana Mountains and Oak Ridge areas were assigned to the upper portion of the Pico Formation, following the suggested usage of Winterer and Durham (1962); 3) Shallow marine sands in the western Ventura basin were assigned to the Las Posas Sand, in preference to “lower marine Saugus Formation” or “San Pedro Formation”; 4) the Saugus Formation is consistently described as being nonmarine; 5) the term Towsley

Formation was adopted generally following the recommended usage of Winterer and Durham (1962). These criteria are generally followed herein as well.

Additional Facies of the Saugus Formation - 2012

DeVecchio (2012a and 2012b) recognized the occurrence of a transition in clast lithology within the Saugus Formation section in the Las Posas and Camarillo Hills areas; the older Saugus strata contain dominantly crystalline rock clasts transported from the San Gabriel Mountains by the ancestral Santa Clara River, whereas the younger Saugus strata are dominated by volcanic clasts derived from the nearby Santa Monica Mountains. DeVecchio informally assigned the younger strata containing the volcanic rock clasts to the Camarillo member of the Saugus Formation. Meanwhile, Squires (2012) concluded that Plio-Pleistocene strata in the Elsmere Canyon area represent deposition in a braid-delta depositional environment where a braided river sourced in the San Gabriel Mountains to the east reached the ocean. Squires interpreted the Elsmere Canyon section as a nonmarine delta plain deposit that interfingers westward with shallow marine littoral and delta deposits.

Additional Details and Commentary on Nomenclature adopted for the Ventura Basin

Pacoima Formation

The term Pacoima Formation is adopted herein for Pleistocene alluvial fan deposits following the definition of Oakeshott (1952, 1958), and as mapped and extended westward in the Santa Clarita Valley by Saul and Wootton (1983) and Treiman (1986, 1987a, 1987b). The contact with the underlying Saugus Formation is generally marked by an angular unconformity; however, west of Valencia the discordance is subtle. The contact between the Pacoima Formation and upper facies of the Saugus Formation has been shown at different locations by past workers; the contact shown in this area is based on detailed engineering geology studies conducted by Allan E. Seward Engineering Geology, Inc. (2008). The Pacoima Formation and underlying upper Saugus Formation in this area both contain sedimentary clasts suggestive of uplift of the Santa Susana Mountains to the south (Treiman, 1982). Clasts in the Pacoima Formation in the Santa Clarita Valley area are generally more rounded than reported at the type section in the northern San Fernando Valley, and clast lithology often reflects local source areas. Clasts in the eastern Santa Clarita Valley are dominantly composed of crystalline rocks derived from the San Gabriel Mountains and commonly range up to boulder size. However, overall clast size and abundance diminishes to the west consistent with greater distance from the San Gabriel Mountains source area. Treiman (pers. comm. 2014) notes that in addition to the dominant alluvial fan depositional environment, there are fluvial deposits associated with an ancestral channel of the Santa Clara River within the Pacoima Formation southeast of Bouquet Junction. The Pacoima Formation west of Bouquet Junction includes sedimentary clasts that suggest alluvial fan deposits derived from the Santa Susana Mountains to the south. (Treiman and Saul, 1986). The Pacoima Formation east of Bouquet Junction and north of the ancestral Santa Clara River contains abundant clasts of Pelona Schist, derived from the north (Treiman, personal communication). The Pacoima Formation is distinguished from younger fluvial terrace deposits based on the degree of soil development, degree of incision/modification, the presence of a gentle tectonic inclination overall and locally intense deformation and tilting adjacent to late Quaternary faults. The age of the Pacoima Formation is estimated between 300 ka and 400 ka (Treiman and Saul, 1986), and at minimum is greater than 49 ka based on radiocarbon dating.

Saugus Formation and Related Strata of the Upper Pico Formation

As originally defined by Hershey (1902b) and later adopted by Winterer and Durham (1962), the Saugus Formation is composed of nonmarine, dominantly granular, fluvial and alluvial strata occurring up section of the marine Pico Formation. Shallow marine sands previously assigned to the Saugus Formation by Kew 1924 in the eastern Ventura basin were reassigned to the Pico Formation by Winterer and Durham (1962) and this usage is followed herein. Shallow marine sands previously assigned to the “lower marine Saugus Formation” in the Santa Susana Mountains and Oak Ridge areas by Kew (1924) and subsequent workers are also reassigned herein as an upper facies of the Pico Formation. Mapping of the contact between the marine and nonmarine sands on the south flank of the Santa Susana Mountains is based on Saul (1975), Dibblee Foundation maps, and descriptions from Bishop (1950) and Groves (1991).

Grant and Gale (1931) recognized early on that the Saugus Formation is time transgressive, becoming progressively younger to the west. They published an idealized cross section along the axis of the Ventura basin illustrating the interpreted time transgressive, interfingering nature of the contact with the underlying Pico Formation. Holman (1958) published an updated version of this longitudinal cross section incorporating subsequent mapping and oil well data, and Hopps and others (1995) published a more refined version of Holman’s section as well. The interpreted time transgressive nature of the Saugus Formation and of the transition with underlying marine units has been substantiated by subsequent age dating: 1) The age of the Saugus Formation in the eastern Ventura basin has been estimated to range from about 2.5 Ma to 0.4 Ma (Levi and others, 1986) or 2.3 to 0.5 Ma (Levi and Yeats, 1993) based on the documented position of the Matuyama-Brunhes polarity reversal in the section, the presence of the 0.73 to 0.78 Ma Bishop ash (Sarna-Wojcicki and others, 1984; Izett and others, 1988; Izett and Obradovich, 1991), and interpreted depositional rates of the section exposed west of Valencia; 2) paleomagnetic dating in the Mission Hills area west of lower Van Norman reservoir indicates the Saugus Formation in this area ranges from 2.3 to 0.6-0.5 Ma (Levi and Yeats, 1993); 3) farther east in the Gold Canyon area, Beyer and others (2009) estimate an age of 2.6 Ma for the base of the Saugus based on paleomagnetic dating; 4) the overlying Pacoima Formation in the eastern Ventura basin has an estimated age range of 0.3 to 0.4 Ma (Treiman and Saul, 1986); 5) Wagner and others (2007) report the Saugus Formation near Moorpark is between 0.78 and 0.85 Ma based on the overlap of the Matuyama reversed polarity magnetochron and the age range of an Irvingtonian II North American Land Mammal Age fossil assemblage found in the area; 6) in the South Mountain area of the western Ventura basin, nonmarine strata of the Saugus Formation occur well up section of the Bailey ash bed at Balcom Canyon which has been dated based on fission-track dating of zircon at 1.2 ± 0.2 Ma (Izett and others, 1974) and 1.12 ± 0.36 Ma (Boellstorff and Steineck, 1975). The Bailey ash and the Bishop ash have also been recognized within the upper Pico Formation on the flanks of the Ventura Avenue anticline based on chemical similarity (Sarna-Wojcicki and others, 1984); 7) In the western Ventura basin, amino acid racemization dating of bivalve shells north of Ventura indicates an age of about 200 ka for marine sands occurring near the top of the underlying Las Posas Formation, providing a maximum age for nonmarine strata of the Saugus Formation (Lajoie and others, 1982), and a date of 85 to 105 ka in marine terrace deposits overlying the Saugus Formation with angular discordance, providing a minimum age constraint in this area (Lajoie and others, 1982); 8) DeVecchio (2012b) reported infrared stimulated luminescence age dates of 141 ± 10 ka for the Las Posas Formation in the Las Posas Hills and 78 ± 6 ka to 125 ± 9 ka for the Camarillo member of the Saugus Formation in the Camarillo and Las Posas Hills areas, suggesting that the Saugus Formation is younger in the Oxnard Shelf area than at Ventura. The time transgressive nature of the contact reflects a regressive

sequence overall resulting from basin filling from east to west as the sedimentation rate exceeded the rate of subsidence during later Pliocene and Pleistocene time (e.g. Jennings and Troxel, 1954; Natland, 1957; Rockwell, 1983). The idealized section of the Ventura basin presented in Figure A1 of this appendix is based on the earlier sections of Holman (1958) and Hopps and others (1995) and has been revised where needed to represent the nomenclature and stratigraphic relationships adopted herein.

The term Sunshine Ranch is adopted as a formal member of the lower Saugus Formation in the eastern Ventura basin, following the assignment of Winterer and Durham (1962). The original description of Sunshine Ranch strata by Hazzard (1940) and Oakeshott (1950, 1958) includes marine fossil hash beds in the lower portion of the section. However, during subsequent mapping in the type area (Saul, 1975), and north of the San Gabriel fault (Saul and Wootton, 1983), the Sunshine Ranch section was limited to nonmarine strata. Mapping compiled herein may locally include fossiliferous marine interbeds owing to different criteria used to define the member in the source reference maps and due to the interfingering nature of marine and nonmarine deposition observed in this transitional portion of the stratigraphic section. The Sunshine Ranch Member is best developed in the type area in the northern San Fernando Valley and on the north side of the San Gabriel Fault, where it is divisible into an upper and lower facies (Saul and Wootton, 1983). Between the San Gabriel Fault and San Fernando Pass, representative Sunshine Ranch lithologies, such as greenish-gray siltstone and mudstone, are less prominent in the lower Saugus Formation and Winterer and Durham (1962) questioned whether it was practical or misleading to map it in this area, and Squires (2012) did not distinguish this member near Elsmere Canyon. However, Treiman (1987a, 1987b) and Dibblee (1991d, 1992c) map the Sunshine Ranch Member south of Newhall and it is therefore shown as queried in this area. The subject strata may in part represent a lateral facies of the Elsmere delta unit of Squires (2012) and following this concept, the lower Sunshine Ranch facies queried by Saul and Wootton (1983) south of the Placerita fault is tentatively assigned herein as a northeastern extension of the Elsmere delta unit.

Clasts contained in the Saugus Formation were derived primarily from plutonic and metamorphic bedrock of the San Gabriel Mountains, including distinctive San Gabriel Anorthosite complex lithologies, Proterozoic gneiss, and Lowe Granodiorite, and to a lesser extent from other more local sources, such as the Pelona Schist from the Sierra Pelona, volcanic rocks from the Vasquez Formation and Conejo Volcanics, and from distinctive sedimentary formations such as the Modelo Formation. Strata assigned to the upper Saugus facies on the south flank of the Santa Susana Mountains (best expressed at Horse Flats) are distinguished by the presence of Modelo Formation shale clasts and sandstone clasts likely derived from the Towsley Formation (Bishop, 1950; Jennings, 1957; Saul, 1975); the presence of these clasts is interpreted to represent Pleistocene emergence of the adjacent Santa Susana Mountains (Shields, 1977a; Saul, 1979; Treiman and Saul, 1986). Treiman (1982) and Levi and Yeats (1993) interpreted that uplift of the Santa Susana Mountains initiated about 0.7-0.6 Ma. This facies is tentatively extended to the youngest portion of the Saugus Formation west of Valencia based on the occurrence of sedimentary clasts, similar stratigraphic position, and similar geomorphic expression. Weber (1982) subdivided the Saugus Formation in the Santa Clarita Valley area into facies based on assemblages of crystalline clasts with specific provenances in the San Gabriel Mountains and Sierra Pelona whereas Treiman (1986, 1987a, 1987b) differentiated facies based on lithologic and textural characteristics suggestive of various environments within the local Pleistocene basin. Dibblee (1992a, 1992b) and DeVecchio (2012b) recognized local informal members of the Saugus Formation in the Las Posas Hills area based on the abundance of volcanic clasts derived from the Conejo Volcanics in the nearby Santa Monica Mountains.

DeVecchio (2012b) interpreted the transition up section from dominantly crystalline clasts derived from the San Gabriel Mountains to clasts locally derived from the Santa Monica Mountains to indicate coeval diversion of the ancestral Santa Clara River to the north of the Las Posas and Camarillo Hills areas due to uplift of the Oak Ridge and South Mountain areas. Mongold (1996) studied the provenance of Plio-Pleistocene sandstones in the Ventura basin and Heirshberg (1997) recognized eight petrofacies in the Saugus Formation indicative of sediment sources in various crystalline rocks of the San Gabriel Mountains and from other local sources in highland areas bordering the Ventura basin during deposition of the Saugus Formation.

Coarse-grained Pleistocene deposits in the Grimes Canyon area were previously described as a delta deposit (State Water Resources Board, 1953; Dibblee, 1992b) and were mapped by Dibblee as a facies of the Saugus Formation. Based on additional field reconnaissance mapping conducted during this study, this distinctive unit was found to extend farther east than mapped by Dibblee, including the western Happy Camp Canyon area. The Grimes Canyon delta unit was also found to contain uncommon siltstone interbeds with marine invertebrate fossils, to interfinger westward with offshore marine siltstone of the Pico Formation, to be typically well sorted and cross bedded, and to contain well rounded and even polished clasts, all of which suggest the unit represents a littoral facies. Based on the marine aspect of this delta unit, it is reassigned herein as an upper facies of the Pico Formation, following the definitions of Winterer and Durham (1962); however, some nonmarine sands may be included in the section as currently mapped. In Happy Camp Canyon, this deltaic unit either overlies, and/or grades or interfingers to the east with undifferentiated shallow marine sand facies of the Pico Formation, and is overlain by, or grades laterally into, nonmarine sands of the Saugus Formation. West of Happy Camp Canyon and south of Grimes Canyon, the delta unit is overlain by a thin, discontinuous section of shallow marine sands assigned herein to the Las Posas Formation. The delta unit separates younger shallow marine sands of the Las Posas Formation up section to the west from undifferentiated shallow marine sands of the upper Pico Formation occurring east of and generally down section of the delta unit.

Las Posas Formation

In the western Ventura basin, shallow marine sands occurring up section of the basinal and outer shelf deposits of the Pico Formation and below nonmarine sands of the Saugus Formation are assigned to the Las Posas Formation, generally following the usage on Dibblee Foundation maps of the area. Use of the term “San Pedro Formation” is abandoned for this section in the Ventura basin, as suggested by Ponti (pers. comm. 2012), because the type area of the San Pedro is in the Los Angeles basin and there is no evidence for continuity of the shallow marine depositional environment between the Los Angeles and Ventura basins during Pleistocene time. Use of the term “lower marine Saugus Formation” for this section is also abandoned following the nonmarine definition of the Saugus Formation, per accepted usage in the type area (Winterer and Durham, 1962). The Las Posas Formation occurs up section of the Grimes delta facies, which distinguishes it from the shallow marine sand facies of the Pico Formation that occurs generally down section of the Grimes delta facies east of Moorpark. Various estimates of absolute age have been reported for the Las Posas Formation in different areas. Wehmiller and others (1978) reported ages of 205 ± 25 ka to 395 ± 50 ka for the “San Pedro Formation” north of Ventura. Wehmiller (2010 *in* DeVecchio, 2012) estimated the age of the Las Posas Formation in the Camarillo fold belt at 450 ka to 750 ka based on amino acid racemization; however, DeVecchio (2012) reported an OSL date of 141 ± 10 ka near the base of the section in the Las Posas Hills. Sarna-Wojcicki and others (1984) estimated the

base of the shallow marine sands (their “San Pedro”) at about 1.0 Ma in the South Mountain area, but also report an age of about 400 ka in the Ventura area.

Pico Formation

As originally defined by Kew (1923, 1924), the Pico Formation consists primarily of terrigenous to hemipelagic marine siltstone, sandstone, conglomerate and mudstone deposited in basinal, slope and sublittoral shelf environments. In the western portion of the onshore Ventura basin trough, this Pico Formation section is about 13,900 to 15,400 ft (4,200 to 4700 m) thick (Pico and Santa Barbara Formations of Bailey *in* Redwine, 1952), one of the thickest sections of this age in the world (Yeats and other, 1994), and it documents nearly continuous deposition during Pliocene to middle Pleistocene times (e.g. Nagle and Parker, 1971). As a result of this exceptional stratigraphic record and the abundance of foraminifers within the section, significant paleoecologic and biostratigraphic data has been gathered from the Pico Formation (e.g. Natland, 1933, 1952, 1957, 1967; Ingle, 1967, 1978, 1980). Winterer and Durham (1962) subsequently included shallow marine littoral and delta deposits within the upper Pico Formation in the eastern Ventura basin, and this convention has been extended herein to the Santa Susana Mountains and Oak Ridge area.

Early biostratigraphic work by Natland (1933) revealed the presence of foram assemblages indicative of the depth of deposition, which document shoaling of the basin during late Pliocene to Pleistocene infilling. These detailed studies also provided the ground work for Natland (1952, 1953, 1957) to define the benthic foram assemblages now in common usage to define biozones within Pliocene and Pleistocene strata of the Ventura and Los Angeles basins. Natland defined four benthic foram stages; the early Pliocene Repettian stage with its type section along Atlantic boulevard in the Los Angeles basin, and three younger stages that have their type sections in the hills north of Ventura: The Venturian and Wheelerian stages are based on type sections on the first ridge line east of and paralleling Wheeler Canyon, and the Hallian stage type section is defined in Hall Canyon (Natland, 1952). The results of Natland’s studies were summarized in a talk at the Coast Geological Society in January of 1953 and his correlation chart of Pleistocene and Pliocene stages in southern California was first published in a newsletter of the Pacific Section of AAPG (Natland, 1953). Natland (1933, 1952), noted that the distribution of these foram assemblages is controlled by depositional environment and therefore similar assemblages may not necessarily indicate contemporaneous deposition in different locations, and dissimilar faunas may be contemporaneous in different, nearby environments. Ingle (1967) and McDougall and others (2012) also note the time transgressive and provincial nature of the benthic foram stages. Strata containing Repettian, Venturian, Wheelerian and the lower portion of the Hallian benthic foram stage faunas are considered part of the Pico Formation in the Ventura basin.

In the eastern Ventura basin, benthic foram stages are not as well defined. Natland (1952) reported that the Repettian stage foraminifer *Nonion pompiliodes* is present at the type locality, but that Repettian zonules are difficult to recognize in the Castaic area. Winterer and Durham (1962) concluded that guide fossil benthic foraminifers of restricted age are generally lacking at the type locality of the Pico Formation and Durham and Yerkes (1964) report that the typical Repettian stage foram assemblage is lacking here as well. Winterer and Durham (1962) do report the presence here of *Uvigerina peregrina* and *Bulimina subacuminata*, which are reportedly characteristic of the Wheelerian and Venturian stages, but also occur in the upper Repettian stage (Squires and others, 2006; McDougall and others, 2012). However, some of the Repettian-age strata at the type section of the Pico Formation may have been

included in the Modelo Formation by Kew (1924), and this pre-Pico, early Pliocene section and correlative strata east of Pico Canyon originally defined as Pico Formation by Kew (1924) and as “Repetto formation” by Oakeshott (1958), are now included within the Towsley Formation as defined by Winterer and Durham (1962). The position of the benthic foram biozone stages relative to the Pliocene and Pleistocene epoch boundaries has evolved over time due to the evolving definition of the boundary between these two series (e.g. Bandy, 1967; Bandy and Wilcoxin, 1970; Berggren and Van Couvering, 1973; Berggren and others, 1985; Lagoe and Thompson, 1988; Blake, 1991; Powell and others, 2000; McDougall and others, 2012). Natland (1952, 1953, 1957) originally assigned the Venturian and Wheelerian stages to the upper Pliocene, but these stages are now considered Pleistocene with reference to the revised time scale of Gibbard and others (2010), as shown for example by McDougall and others (2012). Therefore, owing to the revised position of the Plio-Pleistocene boundary published in Gibbard and others (2010), reference to “Pliocene” strata in older literature is not always consistent with current usage.

Natland and Kuenen (1951) recognized that sandstone and conglomerate beds within the Pico Formation were originally deposited via deep water turbidity currents and submarine slide/flow movement. Many early workers interpreted the coarse-grained beds to represent shallow water deposition and the anomalous presence of deep water fauna in the interbedded siltstone beds was interpreted to be the result of recurrent depression of the basin (e.g. Cartwright, 1928). The work of Natland and Kuenen helped to unravel this enigma by providing a mechanism for deep water deposition of sandstone and conglomerate. Baldwin (1959) studied turbidity current deposits in the Ventura basin and Crowell and others (1966) and Johnson (1978) further documented characteristic sedimentary structures and deposits of deep water, complex, high energy currents within the middle portion of the Pico Formation at Santa Paula Creek. Hsu (1977) studied the distribution of sediments within the Ventura Avenue Oil Field and recognized the presence of feeder channels (e.g. Sexton Lake conglomerate) that transported sediments derived from mountains to the north toward the basin trough and were deposited along with an intervening mudstone facies on the basin margin slopes (Yeats, 1981; Hsu and others, 1988). The feeder channels were generally oriented perpendicular to the basin trough and fed submarine fans which spread out onto the basin floor. The fan sediments were subsequently transported by longitudinal currents down the axis of the basin toward the west (Hsu, 1977; Hsu and others, 1980, 1988). Refinements to the depositional environment interpretations of Hsu for the Pico Formation in the western Ventura basin are presented by Steel and Schwalbach (2014). These thick basin deposits are now uplifted along the Ventura Avenue anticline, where oil has been trapped during rapid uplift over the last 200 ka (Yeats, 1980; Lajoie and others, 1982; Rockwell, 1983).

Mudpit shale member (informal) of the Pico Formation

The informal name Mudpit shale member is used herein for poorly indurated, massive to vaguely bedded, bluish-gray to olive-gray mudstone to bentonitic claystone with local terrigenous sandstone interbeds and conglomerate lenses in the upper part of the marine Pico Formation exposed north of the Santa Clara River in the western Ventura basin. The mudstone contains locally abundant limonite nodules, plant remains (State Water Resources Board, 1953), and several thin ash beds. The most prominent of the ash beds is known informally as the Bailey ash, and has been found on both flanks of the Ventura Avenue anticline and south of the Santa Clara River in the South Mountain area (Blackie and Yeats, 1976; Yeats, 1981; Hsu and others, 1980; Sarna-Wojcicki and others, 1984). The base of the member is commonly defined at a variably conspicuous, light-gray conglomerate or sandstone bed

(Bailey, 1935; Dibblee, 1988), which Dibblee describes as containing pebbles of hard sandstone and white siliceous shale. A maximum thickness of over 5,000 ft (1,500 m) is noted by Nagle and Parker (1971). This member is distinguished lithologically from the lower part of the Pico Formation primarily by its higher clay content and the relative paucity of coarse-grained, turbidite interbeds. The top of this member coincides with the top of the Pico Formation in the western Ventura Basin, which is placed at the base of dominantly granular deposits assigned herein to the Las Posas Formation.

Mudpit shale strata were originally assigned to the upper portion of the Fernando Formation of Eldridge and Arnold (1907) as shown on mapping by McLaughlin and Waring (1914). This section was subsequently included in the Pico Formation by Kew (1924) and described as the upper Pico Formation by Cartwright (1928) and Driver (1928). Waterfall (1929) subsequently noted the similarity of molluscan fauna in the upper portion of the Pico Formation north of Ventura to fauna in the type Santa Barbara Formation and Pressler (1929) then referred to Waterfall's upper Pico as the "Santa Barbara horizon". The term Santa Barbara Formation was subsequently adopted for this section by the majority of later workers in the western Ventura basin (e.g. Bailey, 1935, 1943, 1951; State Water Resources Board, 1953; Ingle, 1967; Weber and others, 1973; Tan and others, 2003a and 2003b). Early workers in the Ventura Avenue/Rincon/San Miguelito oil fields also referred to the same stratigraphic interval on a more informal basis as the Mudpit (or Mud pit) shale, or as the Mud-pit member of the Pico Formation, based on its lithologic character (e.g. Natland, 1933; Stewart, 1943; McClellan and Haines, 1951; Rogers and Chesterman, 1957; Burnett, 1960; Natland, 1957, 1967; Nagle and Parker, 1971; Grigsby, 1988; Yeats and Taylor, 1990) and this interval was termed the Mudpit claystone member of the upper Pico Formation on Dibblee Foundation geologic maps of the Pitas Point, Ventura, Saticoy, Santa Paula Peak, and Fillmore quadrangles in the Ventura area (Dibblee, 1988, 1990a, 1990b, 1992h).

Usage of the term Santa Barbara Formation is abandoned in the onshore Ventura basin based on the following criteria:

- 1) The type section of the Santa Barbara Formation, southwest of Santa Barbara at Packard's Hill (Hill 406), is within the Santa Barbara depositional basin. Jackson (1981) and Jackson and Yeats (1982) suggest that Santa Barbara Formation strata deposited in the Carpinteria basin, an eastern, Pleistocene, shallow water subarea of the Santa Barbara basin, were geographically isolated from marine deposits of similar age in the Ventura basin (previously assigned to the "Santa Barbara Formation") as a result of uplift along the Red Mountain fault; if this interpretation is correct, this configuration would obscure or interrupt facies relationships between shallow marine sediments deposited in the Santa Barbara basin (both at Rincon Point and farther west at the type locality of the Santa Barbara Formation) and coeval sediments deposited in the Ventura basin. Powell and others (2009) have suggested that the Pleistocene marine strata at Rincon Point may be older than the type Santa Barbara section, but these strata are still constrained by the basin boundary suggested by Jackson and Yeats (1982).
- 2) Extension of the term Santa Barbara Formation from the Santa Barbara basin to the Ventura basin was originally based on reported similarities in the megafossil fauna (biostratigraphic criteria) rather than lithologic criteria (as noted by Jackson and Yeats, 1982); this criterion is not considered a valid basis for defining a lithologic formation per the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005).

- 3) In the Santa Barbara basin, the neritic Santa Barbara Formation includes two primary facies: 1) A dominantly granular facies, as described at the type locality (e.g. Arnold and Arnold, 1902; Carson, 1925; Dibblee *in* Keen and Bentson, 1944; Dibblee, 1966; Minor and others, 2009) that has been interpreted as an offshore biogenic bank deposit based on the presence of shallow water megafauna and the low percentage of terrigenous sand (Bullivant, 1969; Powell and others, 2002); and 2) a locally extensive, coeval, fine-grained facies deposited on adjacent portions of the shelf, as reported at the County Dump in Goleta and near Rincon Point (Upson, 1951; Powell and others, 2002; Powell, pers. comm. 2014). Although fine-grained strata in the Ventura basin previously assigned to the Santa Barbara Formation are reportedly lithologically similar to the fine-grained facies described in the Santa Barbara basin (Powell, pers. comm. 2014), neither a thick section of granular strata nor biogenic sands comparable with the type Santa Barbara Formation section have been reported within the Ventura basin section. In addition, the lower portion of the Mudpit shale was deposited at bathyal rather than neritic depths (Natland, 1933, 1967). The contrast in the composition and abundance of the sand, and in the depositional environment, between the type Santa Barbara Formation and strata previously correlated with this formation in the Ventura basin suggests that the two sections should not be assigned the same formation name.
- 4) Santa Barbara Formation strata in the Santa Barbara basin grade and interfinger up section into nonmarine strata assigned by Upson (1951) to the Casitas Formation. In the Ventura basin, however, the Mudpit shale section grades up section into a thick section of shallow marine granular deposits (Las Posas Formation), again suggesting a different Pleistocene depositional history in the Santa Barbara and Ventura basins. As a related comparison, the Casitas Formation is lithologically similar to the Saugus Formation (Jackson, 1981) but is assigned a separate formation name based on the apparent lack of depositional continuity between the two basins, which is analogous to the suggested distinction between the Santa Barbara Formation and the Mudpit shale.
- 5) Strata previously assigned to the Santa Barbara Formation in the Ventura basin span the 0.78 Ma transition from reverse (Matuyama) to normal (Brunhes) paleomagnetic polarity (Lajoie and other, 1982), and the base of this section is in close proximity to the 1.2 ±0.2 Ma Bailey ash (Sarna-Wojcicki and others, 1984), corresponding to an early to middle Pleistocene in age. However, strata at the type locality of the Santa Barbara Formation only show normal polarity, suggesting this section was deposited after 0.78 Ma and is therefore primarily middle Pleistocene in age (Powell and others, 2002; Minor and others, 2009; Powell, pers. comm. 2014). The base of the Ventura basin section is therefore about 0.42 m.y. older than the base of the type Santa Barbara Formation. In addition, Wehmiller and others (1978) and Lajoie and others (1982) show the top of Mudpit shale strata as older than the 0.6 Ma Lava Creek ash, but Powell and others (2002) estimate the top of the Santa Barbara Formation at 0.4 Ma. The Mudpit shale strata in the Ventura basin therefore appear to represent an older range of time than the Santa Barbara Formation in the Santa Barbara/Carpinteria basin.

Documentation and designation of a formal type locality for the Mudpit shale member is beyond the scope of this study; however, detailed descriptions of this unit already exist in the literature. Stewart (1943) reported that the term “mud pit” was derived from exposures along the east side of the Ventura River and south of the Ventura Avenue oil field where cuts were made to obtain material for making

rotary mud and bricks. This site became the location of the now abandoned Rocklite Quarry at the east end of Rocklite Road, where the mudstone was mined for expansible shale (Rogers and Chesterman, 1957; Burnett, 1960), and a representative section of this member is still well exposed in the quarry walls. Liddicoat (2001b) noted that this quarry was subsequently operated by the Lightweight Processing Corporation. This member underlies adjacent canyons on strike to the east and representative stratigraphic sections are described (as upper Pico) at Adams Canyon by Driver (1928) and at both Hall and Wheeler Canyons by Natland (1933, 1952, 1957,, 1967). A detailed, composite stratigraphic description of this member is also provided under the name Santa Barbara Formation by Bailey *in* Redwine (1952), who also note this unit can be subdivided biostratigraphically into a lower *Pecten* (now *Evola*) *bellus* zone and an upper *Pecten* (now *Patinopecten*) *caurinus* zone, as previously reported by Bailey (1935). Owing to the higher clay content and weakly consolidated nature of the Mudpit shale, this member is susceptible to landslide failure and sometimes to movement by earth flow, which is an uncommon mechanism in other, less cohesive siltstone sections of the Pico Formation (Swanson, 2013).

Strata of the same age and similar lithology also occur south of the Santa Clara River in the South Mountain area, and this section was delineated and mapped as the Santa Barbara Formation by Bailey (1951), apparently based on stratigraphic position, scarcity of sandstone interbeds, and similar fossil faunas. However, Lung (1958) concluded that the division between the Pico Formation and “Santa Barbara Formation” was not mappable in the South Mountain area based on lithologic criteria alone, suggesting there is a gradational or interfingering transition across the axis of the Ventura basin within the upper Pico Formation. The South Mountain section has therefore been mapped and described as undifferentiated Pico Formation by most subsequent workers (e.g. Brown, 1959; Weber and others, 1973; Cronin and others, 1983; Dibblee, 1992g). Based on the depositional, temporal and lithological affinity of strata mapped as Mudpit shale north of the Santa Clara River with strata mapped as undifferentiated Pico Formation in the South Mountain area, the rank of member rather than formation is considered more appropriate for the Mudpit shale.

Early invertebrate fossil workers considered the Mudpit shale strata to be of late Pliocene age based largely on invertebrate fauna and extinction rates (e.g. Waterfall, 1929; Grant and Gale, 1931). Natland, (1952, 1953, 1957) reported that benthic foraminifers in this unit represent upper Wheelerian and lower Hallian provincial benthic foraminiferal stages; the Wheelerian stage was originally assigned to the Pliocene (e.g. Natland, 1953 and Ingle, 1967), but is now assigned to the Pleistocene by McDougall and others (2012). Wehmiller and others (1978) and Lajoie and others (1982) reported that the “Santa Barbara Formation” (Mudpit shale) includes the 0.73 to 0.78 Ma Bishop Ash (Izett and others, 1988; Izett and Obradovich, 1991) and two older ashes derived from Glass Mountain (dated at 0.8 to 1.1 Ma), and that this formation occurs slightly up section of the 1.2 ±0.2 Ma Bailey ash and slightly down section of the 0.6 Ma Lava Creek B ash. Lajoie and others (1982) also reported a transition from reverse (Matuyama) to normal (Brunhes) polarity near the middle of the “Santa Barbara Formation”, and Liddicoat (2001a) identified the Olduvai Normal Subchron below the Bailey ash at Balcom Canyon. Sarna-Wojcicki and others (1984) stated that in the Ventura area, the Bailey ash is located near the contact between the “Santa Barbara Formation” and Pico Formation, and they suggested (on p. 19) the Lava Creek B ash occurs near the base of the overlying “San Pedro Formation”, although their correlation chart (Figure 2 on p. 4) suggests the Lava Creek B ash is within the upper “Santa Barbara Formation”. While the base of the Mudpit shale is generally considered conformable with underlying portions of the Pico Formation, Bailey (1935), Nagle and Parker (1971), and Hopps and others (1995) indicated that the

contact of the Mudpit shale with the overlying shallow marine sands is interfingering, time transgressive, and progressively older to the east of Ventura.

Natland (1967) reported that the “Mud pit shale” was deposited at depths ranging from 2,000 ft (600 m, bathyal) near the base of the unit to about 125 ft (38 m, neritic) near the top based on benthic foraminifers, reflecting continued infilling of the Ventura basin that initiated in latest Pliocene time. Cronin and others (1983) reported that correlative strata of the upper Pico Formation at Balcom Canyon were also deposited at bathyal to inner shelf depths.

Pliocene Nomenclature of the Los Angeles Basin

Pliocene strata in the Los Angeles basin consist of a monotonous series of shale, siltstone and uncommon sandstone interbeds that are difficult to subdivide on a lithologic basis. However, a complex nomenclature developed based primarily on geologic investigations for oil exploration and resulting faunal-based subdivisions (e.g. Wissler, 1943, 1958; Durham and Yerkes, 1959, 1964; Blake, 1991; Davis, 1998). The Pliocene nomenclature that developed in the Los Angeles basin has influenced the nomenclature of the Ventura basin, and vice-versa, owing to similarities in fossil fauna and regional-scale stratigraphy. Pliocene strata in the Los Angeles basin were initially assigned to the “Fernando Formation” following the work of Eldridge and Arnold (1907) and were subsequently assigned to the Pico Formation based on the work of Kew (1924), both based on studies of strata in the Ventura basin. Although the Pliocene section in the Los Angeles basin is typically lithologically monotonous, foraminifers are commonly abundant in the fine-grained beds, and early paleontologists recognized two major assemblages, which were referred to variously as upper and lower portions of the Pliocene, “Fernando”, or “Pico” (Wissler, 1943, 1958; Natland, 1952, 1953). It became apparent, however, that the lower foram assemblage is largely absent at the type locality of the Pico Formation in the Ventura basin, and the nomenclature was further complicated by the recognition of additional faunal subdivisions in the Pliocene strata (as summarized by Wissler, 1943 and Durham, and Yerkes, 1959).

To address the complex nomenclature that was developing for the Pliocene section, a committee was convened by the Pacific Section of the Society of Economic Paleontologists and Mineralogists (SEPM). In 1930 the committee proposed a classification system for the Pliocene strata of the Los Angeles basin, which was first published in a correlation chart compiled by Woodring *in* Gale (1932), and as a footnote by Reed (1932), as part of a guidebook prepared under the direction of Hoyt S. Gale for the 16th Session of the International Geological Congress. Strata containing the lower foram assemblage were assigned to the “Repetto formation” based on exposures in the Repetto Hills, and the type locality was designated along the west side of Atlantic Boulevard (Reed, 1932). The “Repetto Formation” was assigned an early Pliocene age based on its stratigraphic position and fauna. The term Pico Formation was retained for the section containing the younger foram fauna and reportedly became virtually synonymous with upper Pliocene strata in the Los Angeles basin (as noted by Durham and Yerkes, 1959). The Pico and “Repetto” strata were further subdivided based on microfossils (Wissler, 1943, 1958; Natland 1952, 1953, 1957). The distinctive Repetto fauna was also found in lower Pliocene strata near Ventura and the term “Repetto Formation” was extended by many geologists to lower Pliocene strata containing Repettian fauna in the western Ventura basin (e.g. Reed, 1932; Woodring and others, 1940; Wissler, 1943, 1958; McClellan and Haines, 1951; Vedder and others, 1969), and strata in the Placerita Canyon area were assigned to the “Repetto Formation” by Oakeshott (1950) and Willis (1952).

However, some field geologists objected to the classification and nomenclature recommended by the SEPM committee because the “Pico Formation” and “Repetto formation” have similar field characteristics and could only be differentiated based on foram fauna (Woodring, 1938). However, Woodring (1938) chose to use the term “Repetto formation” pending future consideration of this matter. Woodring also reported that it is doubtful whether the name “Pico Formation” is appropriate for the upper faunal division because the type Pico Formation section may contain Repettian-age deposits and the correlation to the Los Angeles basin “rests on faunal grounds”. Natland (1952) reported in his doctoral thesis that there is no consistent, definite lithologic change at the top or bottom of the “Repetto formation” and “consequently it is not a mappable unit and should therefore not be called a formation”. Natland also stated that the “Repetto” is “purely a division of the Pliocene, based on the limited ranges of Foraminifera” and concluded it was “reasonable to convert the name Repetto to the stage designation, Repettian, rather than to abandon the term altogether”. Natland retained the type section of the Repettian stage along Atlantic Boulevard in the Repetto Hills. Natland (1952) also noted that the type section of the Pico Formation contains Repettian age foraminifers and therefore “the lower Pico assignment, as used in the Los Angeles basin, is erroneous and must be redefined”.

Durham and Yerkes (1959) reported that the type locality of the Pico Formation in the eastern Ventura basin is largely of early Pliocene age but that the sediments here were deposited in a different facies than the lower Pliocene strata in the Los Angeles basin, and do not contain the distinctive Repetto foram fauna (Reed, 1932; Wissler, 1943). Based on the apparent discrepancies between the Pico Formation at the type locality in the Ventura basin and the usage of the term for upper Pliocene strata only in the Los Angeles basin, Durham and Yerkes (1959) concluded that it would be “desirable to replace the term Pico Formation in the Los Angeles basin with a new formational name”. They left the upper Pliocene strata of the Los Angeles basin unnamed pending the location of a suitable type locality, but temporarily retained the term “Repetto formation” for the lower Pliocene strata.

Durham and Yerkes (1964) subsequently presented revised, formal nomenclature for Pliocene strata in the Los Angeles basin. As previously reported by Woodring (1938) and Natland (1952), Durham and Yerkes noted that agreement on the upper and lower boundaries of the Repetto Formation could not be achieved based on lithologic character at the type locality, or elsewhere in much of the Los Angeles basin. They therefore concluded it would simplify the nomenclature of the Pliocene strata in the Los Angeles basin if the strata in question were assigned a single formational name. They concluded the term “Repetto” is an unsatisfactory choice because it is associated with a biostratigraphic rather than a lithologic unit, and they therefore abandoned this term as a formational unit. They concluded the term “Pico” is also unsatisfactory because in the Los Angeles basin it is associated with a biostratigraphic rather than a lithologic unit. The noted distinction between lithology based formations and faunally based stages (biozones) is consistent with the recommendations of the current North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 2005). Durham and Yerkes also concluded that “Pico” has been restricted to rocks of late Pliocene age in the Los Angeles basin, whereas at the type locality of the Pico Formation in the Ventura basin, fossils of both early and late Pliocene age are present. Durham and Yerkes (1964) therefore restricted the term Pico Formation “to areas outside of the Los Angeles basin” and removed it from the Fernando Group. They reduced the term “Fernando” from group status back to formational status and assigned Pliocene strata in the Los Angeles basin to this formation, which is reportedly divisible into upper and lower members. Characteristic exposures of the

upper and lower members were described; however, a type locality for the newly defined “Fernando Formation” was not specifically designated by Durham and Yerkes (1964).

Usage of the term Fernando Formation has been widely adopted in the Los Angeles basin (e.g. Jennings and Strand, 1969; Lamar, 1970; Dibblee, 1989b; Blake, 1991). Blake (1991) also chose to continue using the terms “Pico Formation” and “Repetto Formation” for subsurface descriptions in the Los Angeles basin. However, the recommendations of Durham and Yerkes (1964) are followed herein for surface mapping; the term “Repetto” is abandoned as a lithologic formation name and the term Pico Formation is restricted to strata deposited outside of the Los Angeles basin. Although abandoned as a formation name, the term Repettian, redefined as a benthic foram stage name by Natland (1952, 1953), is widely utilized as a biozone in both the Los Angeles and Ventura basins (e.g. Grigsby, 1988; Blake, 1991; McDougall and others, 2012).

Additional Notes on use of “Fernando Formation” in the Ventura and Los Angeles Basins

The term “Fernando formation” was originally defined by Eldridge and Arnold (1907) based on a very broad definition that included all deformed, post-Miocene strata in the northern San Fernando Valley area, and was then extended to equivalent age strata from the Los Angeles basin to Santa Maria shortly thereafter. As basin boundaries were recognized and distinctive “Fernando”-age sections were recognized during more detailed local studies, basin-specific formation names were adopted for these strata. In the Ventura basin, Kew (1924) divided the “Fernando” into the Pico Formation and the Saugus Formation, and raised “Fernando” from formation to group status. In the Los Angeles basin, the term “Pico Formation” was also adopted but it became synonymous with upper Pliocene strata only; lower Pliocene strata were assigned to the “Repetto Formation” based primarily on microfossil content. Recognizing that the definitions of these formations in the Los Angeles basin are not viable because they rely on faunal differences and that different faunas and different depositional facies occur at the type section of the Pico Formation in the Ventura basin, Durham and Yerkes (1964) recommended that the term Pico Formation be restricted to areas outside of the Los Angeles basin, and that the term “Repetto” be abandoned as a formational designation. However, rather than assigning a new name to the Pliocene section in place of these two names, Durham and Yerkes (1964) chose to recycle the term “Fernando”, and reduced its rank from group back to formational status in the Los Angeles basin. Jennings and Strand (1969) adopted this usage for the 1:250,000-scale Los Angeles Geologic Map Sheet.

Unfortunately, the above-mentioned stratigraphic recommendations have led to subsequent confusion in the Pliocene nomenclature of both the Ventura and Los Angeles basins. Some workers (e.g. Ricketts and Whaley, 1975; Yeats, 1976; Yeats and others, 1994) have interpreted that Durham and Yerkes (1964) and Jennings and Strand (1969) intended to replace the term Pico Formation with the older term “Fernando” in both the Los Angeles and Ventura basins. However, this was not the intention of Durham and Yerkes (1964) who specifically stated that the term Pico Formation should be restricted “to areas outside of the Los Angeles basin” rather than recommending complete abandonment. Durham was a coauthor on the concurrent USGS report on the geology of the eastern Ventura basin (Winterer and Durham, 1962), which includes the type area of the Pico Formation, and these authors continued to use this term. No subsequent recommendation for abandonment of the term Pico Formation in the Ventura basin could be found by either of these authors in the published literature. The USGS Lexicon indicates the term Pico Formation is accepted for use by the USGS, and there is no mention that it has been

recommended for abandonment (Keroher and others, 1966; Keroher, 1970; USGS, 2014). In addition, one of the primary bases for abandoning the term Pico Formation in the Los Angeles basin was because the Pliocene sections in the Los Angeles and Ventura basins are different, and it therefore follows that Durham and Yerkes (1964) did not intend to use the same formation name for the Pliocene marine section in both basins.

Another source of confusion in the current Pliocene nomenclature is that the term “Pico” is still used by some workers in the Los Angeles basin either as a late Pliocene biostratigraphic unit or formation name following the earlier association of Pico Formation with late Pliocene foram assemblages in the basin (e.g. Blake, 1991). “Pico” strata in the Los Angeles basin have also been defined biostratigraphically by the Venturian and Wheelerian benthic foram stages and these biozone terms seem more appropriate than continuing the confusing use of the term “Pico” in the Los Angeles basin (e.g. Woodring, 1938; Natland, 1952). As originally defined by Kew (1924), the term “Pico” refers to a lithologic formation rather than a biozone. Based on the conclusions and recommendations of Durham and Yerkes (1964) the term “Pico” is not used herein as a lithologic formation name in the Los Angeles basin.

Further complicating the Pliocene nomenclature morass is that the term “Fernando” was originally derived from the San Fernando Valley, which was associated with the Ventura depositional basin at this time. Paleogeographic reconstructions suggest that the Santa Monica Mountains were emergent by Pliocene time (e.g. Edwards, 1932, 1934; Figure 26 of Dibblee, 1995) and therefore marine deposition in the San Fernando Valley area was not spatially connected with coeval deposition in the Los Angeles basin. In addition, the specific type area of the original “Fernando Formation” was never published by Homer Hamlin (the original unpublished source of the term) and was not mapped or clearly described by Eldridge and Arnold (1907). No geologic map or description formally defining a type section for the “Fernando Formation” in the San Fernando Valley, or elsewhere in the Ventura basin, could be found in the published literature for either Eldridge and Arnold’s definition of “Fernando” (which included nonmarine Saugus strata), or the more recent usage encompassing only the marine section underlying the Saugus Formation. Also, the marine basinal section exposed in the San Fernando Valley is depositionally and tectonically attenuated in comparison with the thick, basinal, turbidite sequences characteristic of the Plio-Pleistocene section in much of the Ventura basin, and therefore is not a representative type area. *Considering that the original type area of the Fernando Formation is in the Ventura basin, optimally, a new name associated with a type locality within the Los Angeles basin would have been defined by Durham and Yerkes (1964) for the Pliocene section assigned to the “Fernando Formation” in the Los Angeles basin. However, formal definition of a new name for this section is beyond the scope of this study and the name “Fernando Formation” has been retained herein in the Los Angeles basin owing to widespread, currently accepted usage, and owing to the lack of a better term.*

APPENDIX B

Occurrence of geologic map units on 7.5' quadrangles (note: artificial fill (af) is not included in this list). Map units are listed alphabetically; quadrangle names are listed by the amount that the unit is exposed on the quadrangle, in decreasing order.

Map Unit	7.5' Quadrangle
Jeg	Mt. Wilson, Pasadena
Jsm	Topanga, Beverly Hills, Canoga Park, Van Nuys
JsmP	Beverly Hills
Jsms	Beverly Hills, Topanga, Canoga Park, Van Nuys
Kc	Calabasas, Simi Valley East, Thousand Oaks, Oat Mountain, Canoga Park
Kgd	Pacifico Mountain
Kgl	Pasadena
Kgr	Beverly Hills, Hollywood, Acton, Chilao Flat, Burbank, Canoga Park, Pasadena, Pacifico Mountain, Los Angeles
Kgrd	Condor Peak, Sunland, San Fernando, Chilao Flat, Pasadena, Mt. Wilson, Mint Canyon
Kp	Mint Canyon
Kt	Topanga, Beverly Hills, Malibu Beach, Point Dume, Hollywood, Canoga Park, Van Nuys
Ktb	Topanga, Canoga Park, Beverly Hills
Ktc	Topanga, Canoga Park, Beverly Hills
Ktd	Topanga
Kte	Topanga
Kto	Mint Canyon, Agua Dulce
Ktoqd	Mt. Wilson
Ktowd	Mt. Wilson, Chilao Flat, Condor Peak
Ktr	Canoga Park, Topanga
Mza	Pasadena
Mzd	Condor Peak, Mt. Wilson
Mzdbh	Pasadena
Mzdg	Burbank, San Fernando, Pasadena, Sunland, Condor Peak, Mint Canyon
Mzdhb	Pasadena

Map Unit	7.5' Quadrangle
Mzh	Chilao Flat, Condor Peak, Pasadena
Mzhd	Sunland, Pasadena, Condor Peak, Burbank
Mzm	Pasadena, Mt. Wilson
Mzmg	Condor Peak, Pasadena, Mt. Wilson, Sunland, Chilao Flat
Mzmgp	Pasadena, Condor Peak
MzPzsp	San Fernando
Mzqdb	Burbank, Pasadena, Sunland
Eagb	Condor Peak
Pan	Agua Dulce, Acton, Condor Peak, Chilao Flat, Sunland
Pfjb	Condor Peak
Pfjb	Sunland, Chilao Flat, Acton
Egb	Agua Dulce, Chilao Flat
Egbla	Mint Canyon, Agua Dulce
Eggn	Acton, Chilao Flat, Condor Peak
Egn	Mt. Wilson, Condor Peak, Pasadena, Acton, Agua Dulce
Phbgb	Acton, Condor Peak, Chilao Flat
Ejgb	Sunland, Agua Dulce, San Fernando, Condor Peak, Mint Canyon, Acton
Ejgba	Agua Dulce, Acton, Sunland
Elgb	Condor Peak, Chilao Flat, Agua Dulce, Sunland, Acton, Mint Canyon, San Fernando
Emgn	Chilao Flat, Sunland, San Fernando, Condor Peak, Mt. Wilson, Acton
Esy	Agua Dulce, Mint Canyon, Condor Peak, Sunland, Acton, San Fernando
Pzgn	Mint Canyon, Agua Dulce
Pzp	San Fernando, Sunland, Mint Canyon, Pasadena
Qa	Canoga Park, Van Nuys, Calabasas, San Fernando, Simi Valley West
Qb	Topanga, Point Dume, Triunfo Pass, Beverly Hills, Malibu Beach
Qe	Point Dume, Beverly Hills, Malibu Beach
Qf	Canoga Park, Pasadena, Mt. Wilson, Simi Valley West, Van Nuys, San Fernando, Simi Valley East, Burbank, Topanga, Malibu Beach, Moorpark, Beverly Hills, Fillmore, Newbury Park, Thousand Oaks, Piru, Calabasas, Sunland, Mint Canyon, Val Verde, Condor Peak

Map Unit	7.5' Quadrangle
Qi	Hollywood, Beverly Hills
Qlp	Moorpark, Newbury Park, Fillmore, Simi Valley West
Qls	Val Verde, Topanga, Piru, Fillmore, Malibu Beach, Condor Peak, Simi Valley East, Moorpark, Simi Valley West, Mint Canyon, Mt. Wilson, Chilao Flat, Oat Mountain, Triunfo Pass, Point Dume, Acton, Calabasas, Pacifico Mountain, Sunland, Newbury Park, Thousand Oaks, San Fernando, El Monte, Canoga Park, Agua Dulce, Newhall, Van Nuys, Burbank, Beverly Hills, Pasadena, Los Angeles
Qoa	Acton, Newbury Park, Thousand Oaks, Moorpark, Pacifico Mountain, Agua Dulce, Fillmore, Simi Valley West, Mint Canyon, Newhall, Val Verde, Condor Peak, Sunland, Pasadena, Oat Mountain, Malibu Beach, Triunfo Pass, Simi Valley East, Point Dume, Topanga, Piru, Chilao Flat, Hollywood, San Fernando, Calabasas, Mt. Wilson
Qoa ₁	Pasadena, Mt. Wilson, Simi Valley West, Fillmore, Piru, Simi Valley East, Los Angeles, Val Verde, Burbank, Condor Peak
Qoa ₂	Simi Valley West, Fillmore, Piru, Thousand Oaks, Mt. Wilson, Val Verde, Simi Valley East
Qoa ₃	Mt. Wilson,
Qoab	Sunland
Qob	Sunland
Qof	Simi Valley East, Newbury Park, Thousand Oaks, Simi Valley West, Hollywood, Fillmore, Piru, Los Angeles, Beverly Hills, Mt. Wilson, Calabasas, Sunland, Pacifico Mountain
Qof ₁	Pasadena, San Fernando, Oat Mountain, Mt. Wilson, Los Angeles, Canoga Park, Sunland, Burbank, El Monte, Van Nuys, Thousand Oaks, Point Dume, Malibu Beach, Piru, Hollywood, Newbury Park, Mint Canyon, Newhall, Topanga, Condor Peak
Qof ₂	Hollywood, Beverly Hills, Mt. Wilson, Los Angeles, Pasadena, Topanga, El Monte, Fillmore, Burbank, Canoga Park, Calabasas, Sunland, San Fernando
Qof ₃	Pasadena, El Monte, Los Angeles, Mt. Wilson, Burbank
Qof ₄	Los Angeles, El Monte, Hollywood, Pasadena, Burbank, Mt. Wilson
Qoft	Triunfo Pass, Point Dume, Malibu Beach
Qom	Beverly Hills, Point Dume, Malibu Beach, Topanga, Triunfo Pass
Qpa	Newhall, Mint Canyon, San Fernando, Oat Mountain
Qs	Moorpark, Simi Valley West, Fillmore, Piru, Simi Valley East
Qsc	Moorpark, Newbury Park, Simi Valley West
Qsp	Hollywood, Beverly Hills
Qsv	Simi Valley West, Moorpark

Map Unit	7.5' Quadrangle
QTfl	Los Angeles, El Monte, Hollywood
QTflc	El Monte
QTfu	El Monte, Los Angeles
QTfuc	El Monte, Los Angeles
QTfuf	El Monte
QTjh	Pacifico Mountain
QTjhc	Pacifico Mountain
QTjhm	Pacifico Mountain
QTjhr	Pacifico Mountain
QTms	Topanga
QTp	Val Verde, Moorpark, Piru, Oat Mountain, Fillmore, Newhall, Simi Valley East, San Fernando, Simi Valley West
QTpc	Val Verde, Moorpark, Piru, Oat Mountain, Newhall
QTpcu	Simi Valley West, Val Verde, Simi Valley East, Oat Mountain, Newhall
QTpg	Moorpark, Simi Valley West
QTpms	Fillmore
QTs	Newhall, Val Verde, Oat Mountain, Sunland, Mint Canyon, San Fernando, Simi Valley East, Canoga Park, Moorpark
QTse	Oat Mountain, San Fernando, Mint Canyon
QTsg	Mint Canyon
QTsr	Oat Mountain, San Fernando, Newhall, Mint Canyon
QTsrl	Mint Canyon
QTsru	Mint Canyon
QTsu	Oat Mountain, Newhall, Mint Canyon
Qvoa	Sunland, San Fernando, Hollywood, Beverly Hills, Mt. Wilson
Qvoa ₁	San Fernando, Oat Mountain, Van Nuys, Mt. Wilson, Pasadena, Canoga Park, Sunland
Qvoa ₂	Pasadena, Mt. Wilson, Mint Canyon
Qvof	Sunland, San Fernando
Qvof ₂	San Fernando, Oat Mountain

Map Unit	7.5' Quadrangle
Qw	Van Nuys, Burbank, Newhall, Fillmore, Sunland, Piru, San Fernando, Pasadena, Val Verde, Mint Canyon, El Monte, Moorpark, Simi Valley West, Newbury Park, Acton, Agua Dulce, Simi Valley East, Mt. Wilson, Oat Mountain, Condor Peak, Malibu Beach, Thousand Oaks, Point Dume, Calabasas, Pacifico Mountain, Chilao Flat, Topanga, Canoga Park, Los Angeles, Triunfo Pass
Qya	Newhall, Mint Canyon, Val Verde, Acton, Oat Mountain, Malibu Beach, Pacifico Mountain, Calabasas, Chilao Flat, Agua Dulce, Point Dume, Simi Valley West, Piru, Topanga, Simi Valley East, Triunfo Pass, Mt. Wilson, Thousand Oaks, Newbury Park, Sunland, Pasadena, Condor Peak, San Fernando, El Monte, Canoga Park, Beverly Hills, Van Nuys, Moorpark
Qya ₁	Moorpark, Los Angeles, Beverly Hills, Thousand Oaks, Simi Valley West, Newbury Park, Pasadena, Piru, Val Verde, Calabasas, Simi Valley East, Point Dume, Fillmore, Mt. Wilson, Hollywood, Condor Peak, Malibu Beach, Triunfo Pass
Qya ₂	Hollywood, Beverly Hills, Los Angeles, Moorpark, Simi Valley East, Simi Valley West, Newbury Park, Burbank, Fillmore, Piru, Val Verde, Thousand Oaks, Pasadena, Point Dume
Qya ₃	Moorpark, Fillmore, Los Angeles, Simi Valley West, Simi Valley East, Piru
Qya ₄	Fillmore, Moorpark, Val Verde, Piru
Qyf	Los Angeles, Mt. Wilson, El Monte, Point Dume, Newbury Park, Sunland, Chilao Flat
Qyf ₁	Van Nuys, San Fernando, Canoga Park, Oat Mountain, Pasadena, Sunland, Mt. Wilson, Moorpark, Fillmore, Simi Valley East, Simi Valley West, Piru, Newbury Park, Val Verde, Burbank, Los Angeles, Calabasas, Hollywood, Condor Peak
Qyf ₂	Van Nuys, Canoga Park, Burbank, San Fernando, Fillmore, Calabasas, Simi Valley East, Piru, Newbury Park, Oat Mountain, Simi Valley West, Moorpark, Sunland, Pasadena, Thousand Oaks, Val Verde, Los Angeles, Mt. Wilson
Qyf ₃	El Monte, Mt. Wilson, Van Nuys, Canoga Park
Qyf ₅	El Monte
Tcb	Calabasas, Malibu Beach, Topanga, Thousand Oaks, Simi Valley West, Newbury Park, Point Dume, Moorpark, Canoga Park, Simi Valley East
Tcbd	Malibu Beach, Point Dume
Tcbe	Point Dume
Tcbl	Point Dume
Tcbmp	Malibu Beach
Tcbn	Malibu Beach
Tcbs	Malibu Beach
Tcbs	Calabasas

Map Unit	7.5' Quadrangle
Tcbvc	Thousand Oaks
Tco	Newbury Park, Thousand Oaks, Simi Valley West, Malibu Beach, Triunfo Pass, Point Dume, Moorpark
Tcoa	Triunfo Pass, Simi Valley West, Newbury Park
Tcoaa	Newbury Park, Triunfo Pass, Point Dume
Tcoab	Newbury Park, Thousand Oaks, Triunfo Pass, Point Dume, Topanga, Malibu Beach
Tcoaf	Thousand Oaks, Newbury Park, Point Dume, Triunfo Pass
Tcob	Point Dume, Triunfo Pass, Newbury Park, Thousand Oaks, Calabasas, Simi Valley West, Topanga, Moorpark, Malibu Beach
Tcobb	Point Dume, Thousand Oaks, Malibu Beach, Triunfo Pass, Newbury Park
Tcobf	Point Dume, Malibu Beach, Thousand Oaks
Tcobz	Point Dume
Tcod	Thousand Oaks, Calabasas
Tcode	Thousand Oaks, Calabasas
Tcom	Malibu Beach
Tcop	Malibu Beach, Triunfo Pass, Calabasas, Topanga, Point Dume, Canoga Park
Tcor	Point Dume, Malibu Beach
Tcos	Point Dume, Malibu Beach
Tcs	Newhall, Mint Canyon, Val Verde, San Fernando
Tcw	Fillmore
Tcz	Fillmore
Ti	Topanga, Triunfo Pass, Malibu Beach, Newbury Park, Canoga Park, Point Dume, Van Nuys, Mt. Wilson, Simi Valley East
Tia	Triunfo Pass, Point Dume, Newbury Park, Acton
Tib	Triunfo Pass, Point Dume
Tid	Newbury Park, Triunfo Pass
Tim	Triunfo Pass
Tj	Sunland, San Fernando
Tl	Thousand Oaks, Simi Valley East, Point Dume, Calabasas, Malibu Beach, Oat Mountain, Simi Valley West, San Fernando

Map Unit	7.5' Quadrangle
Tlc	Simi Valley East, Oat Mountain
Tlv	Calabasas, Thousand Oaks
Tm	Calabasas, Thousand Oaks, Canoga Park, Simi Valley West, Van Nuys, Simi Valley East, Oat Mountain, Moorpark, Val Verde, Beverly Hills, Sunland, Topanga, San Fernando, Piru, Fillmore, Newbury Park, Burbank, Malibu Beach
Tm ₁	Piru, Fillmore, Simi Valley West, Oat Mountain
Tm ₂	Piru, Simi Valley West, Simi Valley East, Oat Mountain, Fillmore
Tm ₃	Piru, Fillmore, Simi Valley East, Oat Mountain, Simi Valley West, Val Verde
Tm ₄	Piru, Simi Valley East, Oat Mountain, Fillmore, Simi Valley West, Val Verde
Tm ₅	Piru, Fillmore
Tma	Fillmore
Tmasl	Fillmore
Tmb	Moorpark, Simi Valley West, Calabasas
Tmc	Mint Canyon, Val Verde, Newhall, Piru, Agua Dulce
Tmcd	Mint Canyon, Agua Dulce, Newhall
Tmcl	Mint Canyon, Newhall, Agua Dulce, San Fernando
Tmcm	Mint Canyon, Agua Dulce, San Fernando
Tmd	Canoga Park, Van Nuys, Calabasas, Oat Mountain, Simi Valley East
Tms	Canoga Park, Calabasas, Beverly Hills, Van Nuys, Val Verde, Sunland, Oat Mountain, Piru, Thousand Oaks, Burbank
Tmsu	Calabasas
Tmt	Point Dume
Tmtd	Point Dume, Malibu Beach
Tpbc	Pacifico Mountain
Tpbv	Pacifico Mountain
Tpds	Los Angeles, Hollywood
Tpn	Hollywood
Tpnsc	El Monte
Tpnsc	El Monte

Map Unit	7.5' Quadrangle
Tpnsq	El Monte
Tpny	El Monte
Tpsh	Los Angeles, Hollywood
Tpsl	Hollywood, Los Angeles
Tpss	Los Angeles, Hollywood
Tr	Fillmore, Point Dume, Piru, Malibu Beach, Triunfo Pass,
Tra	Triunfo Pass
Thdg	Pacifico Mountain, Acton, Chilao Flat
Thgb	Pacifico Mountain, Chilao Flat, Acton
Thgd	Mt. Wilson, Condor Peak, Pasadena, Acton
Thgdh	Acton, Chilao Flat, Condor Peak, Pacifico Mountain, Agua Dulce
Thgdp	Chilao Flat, Pacifico Mountain, Acton
Thgm	Mt. Wilson
Trn	Piru
Ts	Fillmore, Simi Valley West, Malibu Beach, Moorpark, Simi Valley East, Point Dume, Topanga, Thousand Oaks, Piru, Newbury Park, Canoga Park
Tsi	Simi Valley East, Calabasas, Thousand Oaks, Point Dume
Tsia	Oat Mountain
Tsic	Oat Mountain, Simi Valley East
Tsis	Oat Mountain
Tsp	Malibu Beach
Tss	Topanga, Simi Valley East, Calabasas, Thousand Oaks, Malibu Beach, Point Dume, Beverly Hills, Canoga Park, Hollywood, Triunfo Pass, Oat Mountain, Van Nuys
Tssl	Topanga
Tt	Burbank, Hollywood, Oat Mountain, Van Nuys, Malibu Beach, Beverly Hills, Canoga Park, Beverly Hills, Topanga, Simi Valley East, San Fernando
Tt ₁	Oat Mountain
Tt ₂	Oat Mountain
Tt ₃	Oat Mountain

Map Unit	7.5' Quadrangle
Tt ₄	Oat Mountain
Ttb	Hollywood, Burbank, Van Nuys, Sunland, San Fernando, Beverly Hills, Oat Mountain
Ttc	Point Dume, Malibu Beach, Topanga, Newbury Park
Ttcb	Triunfo Pass, Newbury Park, Thousand Oaks
Ttcc	Malibu Beach, Topanga, Beverly Hills, Calabasas, Van Nuys, Canoga Park
Ttce	Triunfo Pass, Newbury Park, Point Dume
Ttcf	Malibu Beach, Topanga
Ttcg	Burbank, Pasadena, Sunland, Hollywood, Los Angeles, Oat Mountain
Ttcs	Malibu Beach, Topanga
Ttk	Agua Dulce, Mint Canyon
Ttkc	Agua Dulce, Mint Canyon
Ttsl	Los Angeles, Hollywood, Burbank, Pasadena
Ttss	Los Angeles, Pasadena, Moorpark, Oat Mountain
Tv	Point Dume, Simi Valley West, Malibu Beach, Fillmore, Moorpark, Piru, Topanga, Triunfo Pass
Tvd	Triunfo Pass, Newbury Park, Point Dume
Tvn	Triunfo Pass, Newbury Park, Point Dume
Tvz	Mint Canyon, San Fernando, Agua Dulce
Tvza	Pacifico Mountain, Agua Dulce, Acton
Tvzb	Acton, Agua Dulce, Mint Canyon
Tvzc	Agua Dulce, Acton, Pacifico Mountain
Tvzs	Agua Dulce, Mint Canyon, Pacifico Mountain
Tw	Oat Mountain, San Fernando, Sunland, Simi Valley East, Mint Canyon, Val Verde, Newhall
Twc	Oat Mountain, Simi Valley East, Mint Canyon, Val Verde, Piru, Newhall
Twhc	Val Verde, Piru
Tws	Val Verde, Simi Valley East, Piru, Oat Mountain, Newhall
Tz	Point Dume, Malibu Beach, Triunfo Pass

APPENDIX C

List of changes to map and pamphlet from version 2.0 to version 2.1

Geologic Map

1. Polygons attributed as Ttc within the Triunfo Pass 7.5 minute quadrangle were changed to Ttcb. Appendix B was updated to reflect changes.
2. Polygon attributed as Tcod along the boundary of the Triunfo Pass and Newbury Park 7.5 minute quadrangles was changed to Tcoaf. Appendix B was updated to reflect change.
3. Several mis-attributed polygons along Highway 27 within the Topanga Canyon 7.5 minute quadrangle have been corrected.

Pamphlet

1. P. 29: Lithologic description added to description of the Modelo Formation, upper sandstone at Laskey Mesa (Tmsu).
2. P. 32: Minor change to description of the Monterey Shale, undivided (Tmt).
3. P. 34: Minor change to description of the Calabasas Formation, Volcanic conglomerate (Tcbvc)
4. P. 42: Minor change to description of the Trancas Formation, undivided (Tr).
5. P. A12: Modifications to the discussion on the Pacoima Formation
6. P. A14: Modifications to the discussion on the Saugus Formation and related strata of the Upper Pico Formation.