Geologic map of the San Bernardino and Santa Ana 30' x 60' quadrangles, California

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GEOLOGIC MAP OF THE SAN BERNARDINO AND SANTA ANA 30' x 60' QUADRANGLES, CALIFORNIA

by
D.M. Morton and F.K. Miller

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by
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[In this report, San Bernardino and Santa Ana quadrangles refers to the San Bernardino 30' x 60' quadrangle and Santa Ana 30' x 60' quadrangle, respectively and not to any previously published smaller scale (1:250,000-scale) quadrangle maps having the same name.]

INTRODUCTION

The area covered by the combined Santa Ana and San Bernardino 30' x 60' quadrangles includes highly diverse geologic, physical, and climatic features. Topographic relief ranges from subsea to rugged mountains reaching elevations of more than 3,000 m, and includes large areas of low relief that are largely urbanized. Climatic variations include moderate coastal, cool mountain, and hot desert. Having a current population exceeding five million people, much of the quadrangles are densely populated metropolitan areas and rapidly urbanizing areas, but they also encompass large tracts of undeveloped land and even remote wilderness areas.

Four sheets are included in this report. Sheet 1 is the geologic map; sheet 2, a fault map; sheet 3, faults that cut late Pleistocene and Holocene deposits, and Sheet 4, correlation of map units. In addition to the four map sheets, the report includes five figures. Figure 1 shows the location of most place names used in descriptive parts of the report. Figure 2 is a highly simplified diagram showing the location of the two quadrangles relative to physiographic provinces of southern California. Figure 3 shows the location of the major physiographic features including definable structural blocks having internally consistant characteristics. Figure 4 shows sources of geologic mapping used to compile the geologic map and digital database. In this figure, published and unpublished mapping by the compilation authors are distinguished from published and unpublished mapping by others, in addition to showing where work by more than one person overlaps. References for published mapping are given; information for unpublished mapping includes the year(s) the mapping was done, the scale at which it was done, and the individual(s) who did the mapping.
Figure 5 shows the historic lake levels of Mystic Lake and a projection of where the lake level (closed depression) is predicted to be in 2023.

Included in the two quadrangles is some of the most varied and complex geology in the western United States. Parts of three major physiographic provinces fall within the area, the Peninsular Ranges, Transverse Ranges, and Mojave Desert provinces, in addition to four herein informally designated basement rock assemblages, the San Gabriel Mountains, San Bernardino Mountains, Mill Creek, and Peninsular Ranges assemblages (figs. 1 and 2). Bounding and falling within these basement rock assemblages are elements of several seismically active fault zones, including the San Andreas, San Jacinto, Elsinore, Whittier, Cucamonga, and Sierra Madre Faults.

In the northern quadrangle , the Transverse Ranges are diagonally bisected by the San Andreas Fault Zone, separating the San Gabriel and San Bernardino Mountains. Although these two component ranges of the Transverse Ranges have physiographic similarities, they are very distinct from one another geologically . The northeastern side of the San Andreas Fault also includes the southern part of the Mojave Desert province (fig. 2), which although physiographically dissimilar from the San Bernardino Mountains, is underlain by the same bedrock geology. The southern half of the combined quadrangles is dominated by the northern part of the Peninsular Ranges Province and the southern part of the oil-producing Los Angeles Basin. The Peninsular Ranges Province is sharply bounded on the east by the San Andreas Fault Zone, but its northern extent is poorly defined beneath thick Quaternary and Tertiary cover. Within the area, Tertiary rocks of the Los Angeles Basin appear to be entirely depositional on pre-Tertiary basement rocks of the Peninsular Ranges and San Gabriel Mountains assemblages.

Geology of southwestern California is naturally divisible into a suite of Upper Cretaceous and older rocks unconformably overlain by a suite of younger Cretaceous and Cenozoic rocks. A complex of varied lithologic and spatially distinct rocks comprises the older suite. The age span of the older suite varies from place to place, and the point in time that separates the two suites slightly varies. In the Peninsular Ranges, the older rock suite ranges in age from Paleozoic to the end of Late Cretaceous plutonism, whereas in the Transverse Ranges the age of the older suite extends from the Proterozoic to metamorphism at the end of the Cretaceous. Within the Peninsular Ranges Province a profound diachronous unconformity marks the rock suite subdivision. Cretaceous plutonism-volcanism progressed from west to east forming the Peninsular Ranges Batholith and a now-discontinuous verneer of basaltic to rhyolitic volcanic rocks. Magmatic events were quickly followed by uplift and erosion. On the western edge of the batholith upper Cretaceous marine sediments (Turonian Stage) were deposited while plutons were being emplaced (85 Ma) in the eastern part of the batholith. Within the Transverse Ranges the division between the older and younger rock suites appears to be slightly younger than in the Peninsular Ranges, perhaps coinciding with the end of Cretaceous or even extending into the Paleocene. Initial docking of Peninsular Ranges rocks with Transverse Ranges west of the San Andreas Fault appears to have occurred in the later part of plutonism within the Peninsular Ranges (ca. 100 Ma). During the Paleogene a period of extensive weathering and discontinuous but widespread deposition of sediments occurred with little if any tectonic disruption of the amalgamated older rocks. Dismemberment of the Paleogene and older rocks by strike-slip, thrust, and reverse faulting began in the Neogene, primarily the Miocene, and is ongoing.

Within the older suite of rocks are three extensive, well-defined basement[1] rock assemblages, here termed the San Gabriel Mountains, San Bernardino Mountains, and the Peninsular Ranges assemblages, and a fourth assemblage, the Mill Creek assemblage that is restricted to a narrow block bounded by the San Andreas Fault and the Mill Creek Fault (fig. 1). Each of these basement rock assemblages is characterized by a relatively unique assemblage of rocks that was amalgamated by the end of the Cretaceous and (or) earliest Cenozoic. Tertiary sedimentary and volcanic rocks are both unique to specific assemblages, and overlap adjacent basement rock assemblages. A few Miocene and Pliocene units cross the boundaries of adjacent assemblages, but are dominant in only one. Tectonic events directly and indirectly related to the San Andreas Fault system partially to thoroughly dismembered the basement rocks during the Neogene, forming the modern-day physiographic provinces and established the basis for the bedrock assemblage subdivisions.

Boundaries of the three major basement rock assemblages only locally coincide with the younger physiographic province boundaries. The Transverse Ranges Province includes the San Gabriel Mountains, San Bernardino Mountains, and the Mill Creek assemblages. The San Bernardino basin and the area south of the Sierra Madre Fault (fig. 1), generally considered part of the Peninsular Ranges Province, are underlain by San Gabriel Mountains basement, and are here considered a part of that assemblage. The Mojave Desert Province is underlain by San Bernardino Mountains basement, and is here considered a part of that assemblage. Except for generic Quaternary deposits, this geologic summary, the CORRELATION OF MAP UNITS, and the DESCRIPTION OF MAP UNITS are organized by basement rock assemblage.

Based on offsets of many of the rock units found in this area, different amounts of lateral displacement and fault interaction have been proposed for the San Andreas Fault System in and south of the Transverse Ranges (e.g., Hill and Dibblee, 1953; Woodford, 1960; Crowell, 1975a; Matti and Morton, 1993; Powell, 1993). The Neogene evolution of the Transverse Ranges Province and its relationship to the San Andreas Fault system in particular, remains controversial due to considerably divergent interpretations (e.g., Dibblee, 1968; Gilluly, 1970; Baird and others, 1974; Campbell and Yerkes, 1976; Dillon and Ehlig, 1993; and Powell, 1993). In the vicinity of the Transverse Ranges, interpretations of the fault system's evolution are complicated by several abandoned segments of the San Andreas and the shifting locus of active fault strands during the late Cenozoic (e.g., Crowell, 1962, 1979; Matti, and others, 1993; Powell, 1993; Powell and Weldon, 1992). Based on paleomagnetic studies, most structural interpretations proposed in recent years include the requirement for relatively large rotations within the Transverse Ranges Province (e.g., Dickinson, 1996, Hornafius and others, 1986; Kamerling and Luyendyk, 1979; Luyendyk, 1991; McCulloh and Beyer, 2004; Nicholson and others, 1994).

Acknowledgements

Numerous individuals have provided constructive comments on the earlier versions of the Santa Ana (Morton, 1999 and 2003) and San Bernardino (Morton and Miller, 2003) 30' x 60' quadrangles. Prior

[1] In this report, we use the term basement to include not only crystalline rocks, but all pre-Quaternary rocks. Also, in several cases, formally and informally named Quaternary units that are restricted to specific assemblages are listed on the CORRELATION OF MAP UNITS, and the DESCRIPTION OF MAP UNITS as part of those assemblages.

to his untimely death, Perry Ehlig generously provided considerable, high-quality, detailed, unpublished mapping in the rugged central part of the San Gabriel Mountains. Jon Nourse contributed extensive unpublished mapping in the San Gabriel Mountains, and Miles Kenney provided detailed unpublished mapping on the north side of the San Gabriel Mountains. Omya AG (California) kindly made available company mapping of Howard Brown in the San Bernardino Mountains. Siang Tan provided new mapping in parts of Orange County. San Bernardino County Geologist, Wes Reeder and former Riverside County geologists, Steve Kupferman and Wayne Harrison contributed helpful information. Geologic data, mostly relevant to faults, including opportunities to visit trenches, were provided by Kerry Cato, Matt Clarke, Steve Dickey, Jim Goyich, Mike Hart, Katherine Kendrick, Miles Kenney, Mike Kennedy, Steve Mains, Jay Martin, Thane McCulloh, and Gary Rasmussen. Jack Vedder provided valuable discussions of the stratigraphy in the San Joaquin Hills area, as did Thane McCulloh and Russell Campbell for the Los Angeles Basin area. Ivan Colburn provided helpful information on numerous Paleogene deposits in the Santa Ana Mountains. John Foster, Ray Weldon, Kris Meisling, and Michael Woodburne provided helpful information on the Cajon Pass area geology.

Credit for the digitization of individual 7.5' quadrangles is given in figure 4. Rachel Alvarez, Kelly Bovard, and Pamela Cossette did extensive digital work, and Pamela Cossette was responsible for the final digital compilation and digital data bases.

PREVIOUS WORK

General

Geologic map compilations of the 1° X 2° (1:250,000-scale) San Bernardino quadrangle (Rogers, 1967; and Bortugno and Spittler, 1986) and the Santa Ana quadrangle (Rogers, 1965) published by the California Geological Survey (formerly the California Division of Mines and Geology) include the area covered by the San Bernardino and Santa Ana 30' x 60' quadrangles. Preliminary maps of the Santa Ana and San Bernardino 30' x 60' quadrangles have been previously released (Morton, 1999, and 2003; Morton and Miller, 2003), but in this report, both maps are updated and accompanying descriptive material and discussions are updated and expanded. Discussions of the regional geology that include the area within the quadrangles are found in California Division of Mines Bulletin 170 (Jahns, 1954). Miller (1946) also discussed the regional geology that includes the area covered by the San Bernardino 30' x 60' quadrangle, but much of that work has been superceded. An isostatic gravity map for the Santa Ana 30' x 60'quadrangle was produced by Langenheim and others (1991) and an aeromagnetic map for the San Bernardino 30' x 60' quadrangle by Jachens and Langenheim (1996).

Peninsular Ranges

Jahns's 1954 review of the Peninsular Ranges Province geology is dated but still a very useful summary. Basement of the northern Peninsular Ranges was mapped in reconnaissance fashion by Larsen (1948), but a more current review of the generalized distribution of basement rocks and interpretation of their history in southern California is given by Todd and others (1988). An excellent overview of the batholith and associated basement rocks in Baja California and southern California is given by Gastil (1981), Ortega-Rivera (2003), Schmidt and others (2002), Sedlock (2003), Umhoefer (2003), and Wetmore and others (2003). A geologic description of the Perris block was given by Dudley in 1935, and a description of its geomorphic history in 1936. General geologic synthesis of the geology of Orange County was given by P.K. Morton, and others (1979) and P.K. Morton and R.V. Miller (1981); these were the results of a long term cooperative study between the California Geological Survey and Orange County. Additional mapping by the California Geological Survey, in Los Angeles County includes that of Tan (2000a, 2000b). Engel (1959) mapped the Elsinore 15' quadrangle covering parts of the Elsinore Fault Zone and the eastern part of the Santa Ana Mountains. Gray produced a detailed report on the Corona South 7.5' quadrangle (Gray, 1961). Morton and coworkers have mapped most of the Perris block (Gray and others, 2002; Kennedy and Morton, 2003; Morton, 2001, 2003a, 2003b, 2003c; Morton and Cox, 2001a, 2001b; Morton and Gray, 2002; Morton and Kennedy, 2003; Morton and Matti, 2001a, 2001b; and Morton and Weber, 2001, 2003) as well as written topical papers on the granitic rocks (Miesch and Morton, 1977; Morton, 1969; Morton and Baird, 1976; Morton and others, 1969).

Schwarcz (1969) gave a detailed description of the metamorphic rocks and their mineralogy in the Winchester area of the Perris block. MacKevett (1951) mapped the Jurupa Mountains, refining and updating earlier work by Daly (1935). Osborn (1939) presented a very elegant and thorough structural analysis of the tonalite of the Val Verde Pluton. The Val Verde Pluton was also studied by Jenney (1968). A number of unpublished graduate studies cover parts of the northern Peninsular Ranges Batholith. Investigation in the Box Springs plutonic complex includes Menzie (1962), Joshi (1967) and Stock (1992).

The geology of the petroliferous Los Angeles Basin has been the subject of numerous studies (e.g., Kew, 1924, English; 1926, Vickery, 1928; Jenkins, 1943, Woodford and others, 1945, Shelton, 1946; Daviess, and Woodford, 1949; Olmsted, 1950; Woodford and others, 1954; McCulloh, 1960, Durham and Yerkes, 1964; Yerkes and others, 1965; Wright, 1991; Crouch and Suppe, 1993; McCulloh, and others,2000; McCulloh, and others, 2001; McCulloh, and others, 2002; Bjorklund, and others, 2002; and McCulloh, and others, 2004). See Yerkes and others (1965) for an extensive annotated bibliography of the geology of the Los Angeles Basin area up to 1961.

Comprehensive 1:24,000-scale geologic mapping by the U.S. Geological Survey was conducted in the San Joaquin Hills-Laguna Beach area (Vedder, 1957, 1960, 1972, 1975; Vedder and others, 1957), the Santa Ana Mountains (Schoellhamer and others, 1954, 1981), and Puente-Chino Hills (Durham and Yerkes, 1959, 1964; Woodford, and others, 1944; Yerkes, 1972). Much earlier but very insightful work on the San Onofre Breccia was done by Woodford (1925). McCulloh and coworkers produced a series of papers reexamining the geologic evolution of the greater Los Angeles Basin area (McCulloh, and others, 2000, 2001, 2002; McCulloh and Beyer, 2004), and Yeats (2004) provide an interpretation of the structural history of the San Gabriel basin and adjacent areas.

The Miocene (Glendora, El Modeno, and Conejo) and Oligocene volcanic rocks associated with the Los Angeles Basin have been studied by Shelton (1955), Yerkes (1957), Eaton (1958), Blackerby (1965), Nourse and others (1998), and McCulloh and others (2001, 2002). A thorough study of the El Modeno Volcanics in the northwestern Santa Ana Mountains was made by Yerkes (1957), and the volcanic rocks in the Temecula area were studied by Mann (1955), Hawkins (1970), and Morton and Morton (1979).

The continental Pliocene and Quaternary sedimentary rocks of the San Timoteo Badlands (photo 12) have been studied by Frick (1921), Fraser (1931), English (1953), Larsen (1962), Morton and others (1986), Kendrick (1996), Albright (1997, 1999) and Kendrick and others (2002). The Pliocene and Quaternary sedimentary rocks in the Temecula basin area have been studied by Mann (1955), and Kennedy (1977).

An early study of the groundwater, touching on the geology, in the San Jacinto River and Santa Margarita River drainage basins was produced by Waring (1918). Later, an in-depth study of the water-bearing sedimentary units over most of the area was conducted by Eckis (1934) who earlier studied the evolution of the broad alluvial fans at the base of the eastern San Gabriel Mountains (Eckis, 1928). The soil map of Eckman and others (1919) gives the best rendition of the distribution of surficial sediments on the distal part of the Santa Ana River alluvial fan in Orange County. Overlapping the San Bernardino basin and the northeastern part of the Perris block is the groundwater investigations of Dutcher and Garrett (1963). Anderson and others (2004) conducted a geophysical investigation of the structure in the San Bernardino basin area, and Bean (1955) produced a geologic report for the Perris block area with the emphasis on the relationship of geology to groundwater.

Dudley (1936) described the physiographic history of part of the Perris block. Larsen (1948) provided a geomorphic synopsis of the Perris block area. A more recent interpretation of the geomorphic history of the Perris block is given by Woodford and others (1971), and an interpretation of the geomorphic history of the northernmost part of the Perris block is given in Morton and Matti (1989).

Baird and others (1979, 1984) conducted a comprehensive study of the major elemental chemistry of the Peninsular Ranges Batholith, and Silver and Chappell (1988) presented new geochemical data and reviewed the chemistry and isotopic geochemistry of the batholith. Strontium, rubidium, oxygen, and common lead data were given by Kistler and others (2003). Neodymium and strontium isotope variations across the batholith was given by DePaulo (1981). Regional variation in ^{18}O values was presented by Taylor and Silver (1978) showing a regional step in the ^{18}O values that divided the batholith into western and eastern halves, and rare earth divisions of the batholith were given by Gromet and Silver (1987). Turi and Taylor (1971) conducted an oxygen and hydrogen isotope investigation on rocks from the Domenigoni Valley pluton. A synthesis of potassium-argon ages of the batholithic rocks was given by Krummenacher and others (1975) and Miller and Morton (1987) presented biotite potassium-argon values for the northern part of the batholith. Recognition of a systematic distribution of the magnetic properties of the batholithic rocks was made by Erskine (1982), whos initial work was followed up by a regional synthesis by Gastil and others (1990) and the establishment of a 'magnetite-ilmenite line' for the Peninsular Ranges batholith.

The unique mineralogy of contact metamorphic marble deposits in the Jurupa Mountains at Crestmore (photo 563), Glen Avon, Jensen (photo 564), and Henshaw quarries and the New and Old City quarries at Riverside are referenced in Murdoch and Webb (1966). The unique mineralogy, especially of Crestmore, early on attracted the attention of numerous mineralogists and is of continuing interest to mineralogists (e.g., Eakle, 1914, 1917; Rogers, 1929; Daly, 1935; Murdoch, 1961; Carpenter, 1963; Devito and Jefferson, 1972). The geology of the Crestmore quarries was studied by Woodford and others (1941, 1943), and a most insightful study by Burnham (1959).

San Gabriel Mountains

Miller (1928) described the geomorphology of the San Gabriel Mountains, including the Crystal Lake landslide, which he first interpreted as a glacial deposit (Miller, 1926) (fig. 1). Miller later described some of the basement rocks (Miller, 1934, 1946). Noble (1926, 1927, 1932a, 1932b, 1933, 1953, 1954a) published a number of reports and quadrangle maps centered on the San Andreas Fault, particularly the segment in the northwestern part of the San Bernardino quadrangle. He produced a generalized strip map (Noble, 1954b) from Soledad Pass to Cajon Pass that in places extends far enough south to include the Vincent Thrust. This map is a distillation of a more detailed map that Noble had completed by 1928, but was never published.

Ehlig (1958) was the first to map the geology of the Mount Baldy area in detail, including a very detailed map of the Vincent Thrust. He first recognized the regional significance of the thrust, the relationships between metamorphism and structure of lower plate rocks, and the mylonite zone overlying the thrust. Subsequent research by Ehlig (e.g., 1968, 1975, 1981, 1982, 1988a, and 1988b) refined the understanding of the regional, structural, and metamorphic history of the eastern San Gabriel Mountains. He generously provided unpublished mapping that is included in this compilation (see fig. 4).

A detailed history of rocks they designated the Triassic Mount Lowe Intrusive Suite is given by Barth and Ehlig (1988). Dibblee (1982) provided an interpretation of the geology of the San Gabriel Mountains based on reconnaissance mapping. May and Walker (1989) presented an interpretive history of the eastern part of the San Gabriel Mountains, and McCulloh and others (2001) studied the relationship of the Oligocene granodiorite of Telegraph Peak to the Mountain Meadows Dacite and the Glendora Volcanics (McCulloh and others, 2002). Nourse (2002) presented a comprehensive interpretation of the geology of the central and eastern San Gabriel Mountains and the adjacent Los Angeles Basin. He also conducted detailed mapping in all or parts of the Azusa, Glendora, Mount Baldy, and Telegraph Peak quadrangles, generously providing unpublished mapping for this compilation (see fig. 4).

Early work in the San Gabriel Mountains by the U.S. Geological Survey was restricted to that done by Noble (1926, 1927, 1932a, 1932b, 1933, 1953, 1954a), but later included reconnaissance mapping by Dibblee, who subsequently produced syntheses based on his and other peoples' work (e.g., Dibblee, 1982). Morton (1976), Morton and Matti (1990a, 1990b, 2001a, 2001b), and Morton, Woodburne, and Foster (1990, 2001) conducted detailed mapping in the eastern San Gabriel Mountains, and published regional syntheses that include large parts of the eastern San Gabriel Mountains (Morton, 1975; Morton and Matti, 1987; Matti and Morton, 1993; Morton and Matti, 1993). In addition, U.S. Geological Survey mineral resource assessments were completed for Wilderness and Roadless areas (Crowder, 1967; Evans, 1982; Cox and others, 1983; and Morton and others, 1983).

In addition to Ehlig (1958), other research on basement rocks includes Alf (1943 and 1948), who first described the mylonites in the southeastern San Gabriel Mountains; Hsu (1955), who described the mineralogy and metamorphic history of the rocks in the Cucamonga Canyon area; and Baird (1956), who worked out structural relationships in the Barrett-Cascade Canyon tributaries of San Antonio Canyon. Jacobson expanded his thesis work (Jacobson, 1980) on the structure of the Pelona Schist (Jacobson, 1983, 1990; Jacobson and others, 2000).

Isotopic studies include Conrad and Davis (1977), Hsu and others (1963), Joseph and others (1982), and Miller and Morton (1977, 1980). Blythe and others (2000, 2002), and Spotila and others (2002) provided fission-track and isotopic data on the uplift and erosion of the San Gabriel and San Bernardino mountains.

Mill Creek Block

A variety of metamorphic, granitic, and continental sedimentary rocks occur in the thin structural block between the active San Andreas Fault and the older Mill Creek and Wilson Creek Faults. Other than localized geologic mapping by Matti and others (2003) and Morton and Miller (2003), little has been published on the crystalline rocks in this block. Continental sedimentary rocks in the block constitute a thick sequence of Miocene fill deposited in a pull-apart basin. They were first described by Vaughan (1922) who named them the Potato Sandstone. These and adjacent sedimentary rocks have been the subject of a number of theses (Owens, 1959; Smith, 1959; Gibson, 1971; Demirer, 1985; West, 1987; Hillenbrand, 1990) and other publications (Dibblee, 1968, 1982; Morton and Miller, 1975; Matti and others, 1985, 1992b; Sadler and Demirer, 1986; Sadler and others, 1986; Sadler, 1993; Sadler and others, 1993; and Miller and Matti, 2001b). The sequence is now referred to as the Mill Creek Formation of Gibson (1971).

San Bernardino Mountains

Vaughan (1922) made the earliest reconnaissance geologic map of the central San Bernardino Mountains. His work has largely been supplanted by later studies, but he was the first to describe many of the rock units found in the northeasternmost part of the San Bernardino quadrangle.

Studies by Guillou (1953) and Richmond (1960) on rocks rocks just east of the quadrangle, revised Vaughan's stratigraphy and structure of the Precambrian and Paleozoic and although their work has been highly revised, some of it was projected into the quadrangle by Brown (1984, 1987, 1991), who conducted detailed studies on the Paleozoic rocks within and just east of the quadrangle. Prior to Brown's work, reconnaissance mapping by Dibblee (1964a, 1964b, 1974) retained a mix of the earlier nomenclature developed by Vaughan, Guillou, and Richmond.

Stewart and Poole (1975) correlated Late Proterozoic and Paleozoic units in the San Bernardino Mountains with similar sections in the Great Basin, establishing that the Great Basin stratigraphy did extend into the San Bernardino Mountains. Their correlations for the most part have been adopted by subsequent workers (e.g., Tyler, 1975, 1979; Cameron, 1981, 1982; Miller and others, 1998 and 2000).

Brown (1984, 1987, 1991), through very detailed, large-scale geologic mapping, was the first to make unit-by-unit correlations of the highly faulted, folded, and multiply deformed Paleozoic rocks in the northern San Bernardino Mountains with well established, relatively undeformed Basin and Range units. Miller and others (2000) published a geologic map of the Butler Peak quadrangle and Miller and Matti (2001b) one of the San Bernardino North quadrangle.

The Triassic, Jurassic, and Cretaceous granitic rocks have been studied by Cameron (1981), Frizzell and others (1986), Miller (1977a, 1977b, 1978), and Miller and Morton (1980). All of these studies report isotopic ages for the Mesozoic granitic rocks. Spotila (1999), Spotila and Sieh (2000), and Spotila and others (1998) provided uplift history for the San Bernardino Mountains.

Meisling and Weldon (1989) investigated the Late Cenozoic tectonics and uplift history of the northwestern San Bernardino Mountains, including work on the left lateral Cleghorn Fault and the Squaw Peak Thrust Fault (also see Meisling, 1984 and Weldon, 1986).

Spotila and others (1998) and Spotila (2000), utilizing a low-relief surface that is extensively developed in the western San Bernardino Mountains, developed an uplift history for a large part of the range. In addition, they discuss the relations between the thrust system bounding the north side of the range, the reverse faults in Santa Ana Canyon, and the San Andreas Fault. They consider the thrust system bounding the north side of the range to be the structure responsible for most of the uplift of this part of the mountain range.

Cajon Pass Area

For well over a century, numerous geologic studies have focused on the sedimentary rocks and structure within the Cajon Pass area. The earliest geologic description of the area was conducted in 1853 (Blake, 1856a) as part of a railroad feasibility study. The apparent similarity of the rocks of Cajon Valley Formation with the Punchbowl Formation lead early to an erroneous correlation of the two and an implied maximum offset of only 48 km along the San Andreas Fault (Noble, 1954b). Noble considered the overall displacement of the San Andreas in this area likely to be more than 80 km. Stratigraphy and biostratigraphy of the rocks of Cajon Valley and the differences between them and the Punchbowl Formation was treated in detail by Woodburne and Golz (1972).

Woodring (1942) described mollusks from the Vaqueros Formation. Regional geology of the Cajon Valley area was studied and reported in thesis work by Yerkes (1951). The Crowder Formation was described in reconnaissance form by Dibblee (1967), but the internal stratigraphy and what parts of the Late Tertiary and Early Quaternary section were included in the unit were unclear. Later, careful mapping by Foster (1980), Meisling (1984), Weldon (1986), and Meisling and Weldon (1989) established most of the currently accepted stratigraphy of the unit. Cox and others (2003) give a detailed description of the sedimentary units underlying the Victorville fan in the Victorville area north of the map area.

Faults

Active and inactive regional-scale faults within the area have been mapped and studied since the early part of the 20th century (Lawson and others, 1908). Regional tectonic and seismic syntheses have been developed by numerous authors (e.g., Baird and others, 1974; Hadley and Kanamori, 1977; Matti and others, 1985, 1992a; Matti and Morton, 1993; Powell, 1993; Powell and Weldon, 1992; Woodburne, 1975). Because of its extent, regional significance, and earthquake history in the state, most attention has focused on the San Andreas Fault. Apparently the earliest published recognition of the San Andreas Fault in southern California was a cryptic description by Schuyler (1896-97). Reconnaissance mapping by Lawson and others (1908) following the 1906 San Francisco earthquake included the San Andreas Fault and San Jacinto Fault. Detailed mapping of the San Andreas Fault in southern California began with the work of Levi Noble in 1910. He produced a series of maps and reports that included the San Andreas Fault on the north side of the San Gabriel Mountains (e.g., 1927, 1953, 1954a,1954b). Noble (1954) noted the San Andreas scarp at Pallet Creek and suggested it was formed by the 1857 Fort Tejon earthquake. He further noted the dissection of Pallet Creek through peat deposits, which were later trenched and dated by Sieh (1978). Major lateral displacement on the San Andreas Fault in southern California was apparently first proposed by R.E. Wallace in 1949. An outgrowth of his PhD thesis, Wallace (1949) extrapolated recent strike-slip amounts back 30 Ma and considered displacement could be approximately 120 km. Four years later in the now classic paper, Hill and Dibblee (1953) speculated offsets of 280 to 560 km. Subsequently, general overviews and syntheses of the San Andreas Fault were presented by Crowell (1960, 1975a, 1975b), Matti and others (1985), Powell (1993), Powell and Weldon (*in* Wallace, 1990), and Powell and Weldon (1992).

More recent work on the San Andreas Fault includes that of Matti and others (1986), Frizzell and others (1986), Harden and Matti (1989), Matti and Morton (1993), and Weldon and others (1993). Ross (1969) produced a map showing recently active breaks along the San Andreas Fault. Very detailed geologic mapping along the fault in Los Angeles County was conducted by the California Geological Survey (Barrows, 1980 and 1985; Barrows and others, 1985; and Barrows and others, 1987). Morton and Miller (1975) produced a generalized geologic map along the San Andreas Fault on the south side of the San Bernardino Mountains. Several detailed fault studies have been conducted along the San Andreas Fault in the Cajon Pass area (e.g., Weldon (1986), Weldon and Sieh (1985), Weldon and Springer (1988; Yerkes, 1951)). A paper by Langenheim and others (2004) relates basement rock properties with the location of the San Jacinto Fault Zone.

Numerous trenching-based studies with the goal of establishing recurrence, recency of displacement, earthquake recurrence intervals, and developing a characteristic earthquake model have been conducted on the San Andreas Fault. Early work at Pallet Creek conducted by Sieh (1978; Sieh, and others, 1989) established a firm foundation for later trenching-based studies at other locations (photos 1, 2, and 3). Trenching studies have been conducted at Wrightwood (Weldon and others, 2002), Lost Lake (Weldon and Sieh, 1985), and Pitman Canyon Creek in the Cajon Pass area (Seitz and others, 2000) and Plunge Creek (McGill and others, 2002) north of San Bernardino. Based on these various studies, the earthquake history at the west edge of the San Bernardino quadrangle appears to differ from that at the east edge; ground rupturing earthquakes recorded at Pallet Creek (fig. 1) are similar to the record north of the quadrangle, but quite different from that at Plunge Creek (fig. 1) to the east (e.g., the 1857 Fort Tejon earthquake extends to Pitman Canyon (fig. 1) but not to Plunge Creek). This difference may be due to the presence of the San Jacinto Fault southeast of Cajon Pass area.

The most detailed and comprehensive trenching work to date has been in the Wrightwood area where, over a period of years, trenches have been excavated and studied in detail (Fumal, and others, 1993, 2002). Analysis of the trench-derived data has led to new fundamental interpretations for this segment of the San Andreas Fault, and thus, may be establishing a new paradigm (Weldon and others, 2004). Dendrochronology has also been used in the Wrightwood area in attempting to establish a high precision short-duration recurrence interval along this segment of the San Andreas Fault (Meisling and Sieh, 1979).

Trenching-based investigations have been conducted on the San Jacinto Fault (photos 1, 2, and 3), especially in the vicinity of San Bernardino Valley College; the college was constructed over the fault zone. In addition to academic and government sponsered trenching, numerous trench studies have been conducted in the private sector as part of engineered developments, although results of these studies rarely appear in readily available literature.

Studies of older strands of the San Andreas Fault system include those along the San Gabriel Fault (Crowell, 1952; Ehlig, 1973; Nourse, 2002), Punchbowl Fault (Dibblee, 1967, 1968; Ehlig, 1968, 1981, 1982; Woodburne, 1975), and Cajon Valley Fault (Woodburne and Golz, 1972).

Widely varying interpretations of the relationship of the San Jacinto Fault to the San Andreas Fault, particularly where they are closest together in the easternmost San Gabriel Mountains, are discussed in a number of papers (Arnett, 1949; Dibblee, 1968; Morton, 1975; Morton and Matti, 1993; Nourse, 2002). Morton (1975), Morton and Matti (1993), and Morton and Miller (2003) also discuss the relationship between the San Jacinto Fault and southeast striking faults within the eastern San Gabriel Mountains. Active breaks along the San Jacinto Fault were mapped in the San Bernardino area by Sharp (1972), and Kendrick and others (2002) analyzed the spatial and temporal deformation of the northern part of the San Jacinto Fault zone in the northern San Timoteo Badlands. Farther to the southwest, the Elsinore Fault zone is the subject of work by Hull (1990), Hull and Nicholson (1992), Kennedy (1977), Milman and Rockwell (1986), and Weber (1976).

Reverse and thrust faults within and bounding the Transverse Ranges were recognized by Hill (1930), but systematic study of these faults only began after the 1971 San Fernando earthquake. Within the San Bernardino quadrangle, parts of the Cucamonga Fault (reverse) and southern Sierra Madre Fault (thrust), have been studied by Crook and others (1987), Dolan and others (1996), Morton (1973 and 1976), Morton and Matti (1987), and Proctor and others (1970).

Distribution and development of reverse faults on the north front of the San Bernardino Mountains is discussed by Meisling (1984), Meisling and Weldon (1982 and 1989), and Miller (1987). Reverse faults within the San Bernardino Mountains have been studied by Sadler (1982, 1985), Strathouse (1982), Jacobs (1982), and Meisling and Weldon (1982 and 1989). Meisling and Weldon (1989) also present evidence for left-lateral motion on the Cleghorn Fault and an estimate of displacement.

Focal mechanisms along the San Andreas Fault Zone were included in a comprehensive analyses by Jones (1988). A summary of the seismicity for the period 1978-1984 was included within a regional study by Ziony and Jones (1989). A detailed microseismic study for the eastern San Gabriel Mountains was provided by Cramer and Harrington (1987). Hauksson (1994) presents a tectonic analyses of earthquakes originating along the south side of the San Gabriel Mountains, and Hauksson and Jones (1991) present analyses for the 1981 Sierra Madre earthquake and the 1988 and 1990 Upland earthquakes.

GENERAL GEOLOGIC SETTING

In this report, geologic and geomorphic features are grouped and subdivided on the basis of (1) basement rock assemblages, (2) Upper Cretaceous and Tertiary rock distribution, or (3) structural-physiographic domains. Boundaries of the resultant subdivisions, especially geologic and geomorphic subdivisions, are rarely coincident. For the CORRELATION OF MAP UNITS and the DESCRIPTION OF MAP UNITS, the area is subdivided on the basis of the basement rock assemblages, resulting in three major basement rock assemblages, the San Gabriel Mountains assemblage, the San Bernardino Mountains assemblage, and the Peninsular Ranges assemblage. A fourth assemblage, the Mill Creek assemblage is arealy limited, forming a narrow wedge between the San Andreas Fault and Mill Creek Fault. With the exception of a limited number of formally named Pleistocene units, Quaternary deposits are described for the entire map area, without consideration of Upper Cretaceous and pre-Tertiary basement rock assemblages.

Peninsular Ranges Assemblage

The northern Peninsular Ranges consist of two distinct and vastly different basement rock suites. A western basement suite of blueschist and associated rocks (e.g., Jahns, 1954) is, with only a few exceptions, offshore and is prominently exposed on Santa Catalina Island (Woodford, 1925; Platt, 1975). The relevance of this western basement to onshore parts of the Peninsular Ranges is the blueschist debris that was shed eastward during the Miocene forming the widespread San Onofre Breccia (Tsob) (photos 4, 5, 6, 7, 8, 9, and 10). The San Onofre Breccia is characterized by blue schist and related rocks (Woodford, 1925). An eastern basement suite, the western limit of which coinsides roughly with the Newport-Inglewood Fault zone, is characterized by rocks of the Peninsular Ranges Batholith and pre-batholithic meta-sedimentary and-volcanic rocks (e.g., Jahns, 1954); it is overlain by thick, widespread Upper Cretaceous and Tertiary sedimentary units.

Physiographically, the onshore part of Peninsular Ranges Province is divided into three major, fault-bounded blocks that are, west to east, the Santa Ana Mountains, Perris, and San Jacinto Mountains blocks (fig. 1 and fig. 3). Upper Cretaceous and Cenozoic sedimentary rocks ranging in age from Upper Cretaceous through Holocene crop out over most of the western part of the Santa Ana block. The Neogene sedimentary rocks on the west side of the Santa Ana Mountains are the southern part of the Los Angeles Tertiary basin. East of the Upper Cretaceous and Cenozoic rocks in the Santa Ana Mountains is a basement assemblage of Mesozoic metasedimentary and Cretaceous volcanic and batholithic rocks. The northern part of the Santa Ana Mountains is a complexly faulted anticlinal structure. Overlying this basement is a thick section of upper Cretaceous, chiefly marine rocks, and Paleogene marine and nonmarine rocks. In the southern part of the Santa Ana Mountains the anticlinal nature of the mountains flattens into an extensive, nearly horizontal surface that was deeply weathered during the Paleocene and is partly and discontinuously covered by Miocene basalt flows.

North of the Santa Ana Mountains block, the relatively low Puente Hills (fig. 1) expose folded and faulted Neogene marine sedimentary rocks of the Los Angeles Basin (e.g., Yerkes and others, 1965). Up to 8,200 m of middle and late Miocene age rocks are exposed in the Puente Hills, strata equivalent to those from which most of the petroleum of the Los Angeles Basin has been produced (Durham and Yerkes, 1964; Yerkes, 1972). Located south of the Whittier Fault and the Puente Hills are several anticlinal structures exposing marine Pleistocene strata (Yerkes, 1972).

East of the Santa Ana Mountains block and west of the San Jacinto fault zone is the Perris block (fig. 1 and fig. 3), a roughly rectangular area of relatively low relief that has remained relatively stable and undeformed during the Neogene. The Perris block is underlain by lithologically diverse prebatholithic metasedimentary rocks intruded by Cretaceous plutons of the Peninsular Ranges Batholith. Supra-batholithic volcanic rocks are preserved in the western part of the block. Several erosion and deposition surfaces are developed on the Perris block (e.g., Dudley, 1936; Woodford and others, 1971) and thin to relatively thick sections of nonmarine, mainly Quaternary sediments discontinuously cover the basement rocks.

The San Jacinto Mountains block lies east of the Perris block, but only the northern part of the block, the San Timoteo Badlands (photo 12), extends into the map area. A thick section of Miocene through Pleistocene nonmarine sedimentary rocks covers most of the northern San Jacinto Mountains block so that only limited granitic and metamorphic rocks are exposed, mostly in the northeastern part of the Santa Ana quadrangle.

San Gabriel Mountains Assemblage

The San Gabriel Mountains assemblage is divided by the Vincent Thrust into a heterogeneous upper plate suite and a relatively homogeneous lower plate suite. The upper plate suite consists of a great variety of rocks that includes Proterozoic anorthosite, Proterozoic and Paleozoic gneiss and schist, and Mesozoic granitic rocks. The lower plate suite is the Cretaceous Pelona Schist (Kpu). Oligocene granodiorite of Telegraph Peak (Tgtp) stitches together the two basement suites by intruding both. Mylonitic rocks are common in the San Gabriel Mountains assemblage, principally where spatially associated with the upper plate rocks adjacent to the Vincent Thrust, but also along the southeast margin of the San Gabriel Mountains where they are not necessarily associated with the Vincent Thrust. Although most of this basement assemblage lies within the San Gabriel Mountains, it also underlies the adjacent San Bernardino basin where the rocks are largely covered by Quaternary alluvial fill.

Numerous faults throughout the San Gabriel Mountains have rendered the mountains a complex mosaic of fault bounded blocks (fig. 3). Within the blocks, myriads of small faults perturb the internal structure so that the blocks somewhat resemble acutely fractured glass in which all of the pieces were slightly rearranged to produce a somewhat obscure pattern.

Mill Creek Assemblage

The Mill Creek assemblage is small and restricted compared to the other three assemblages, forming a thin, wedge-shaped area bounded by the San Andreas Fault to the south and the Mill Creek Fault to the north (fig. 1). In the map area, most of the assemblage consists of complexly deformed gneiss (photo320) of unknown age (gg) that has no exact counterparts in either of the bounding assemblages. The gneiss is intruded by Mesozoic granitic rocks, and is overlain by the Miocene Mill Creek Formation of

Gibson (1971). The narrow western end of the assemblage is a fault bounded unit, mostly Miocene that may include fault bounded Paleocene and Late Cretaceous rocks.

San Bernardino Mountains Assemblage

The San Bernardino Mountains assemblage is restricted to the San Bernardino quadrangle, and is bounded on the south by the San Andreas and Mill Creek Faults. The assemblage as defined here, includes the southwestern part of the Mojave Desert geomorphic province, which is underlain by rocks similar to those exposed in the San Bernardino Mountains.

Cretaceous granitic rocks dominate the bedrock of the San Bernardino Mountains assemblage, although Jurassic and particularly Triassic granitic rocks are also abundant, the latter especially so east of the San Bernardino quadrangle. Composition of the granitic rocks ranges from syenite to tonalite, but monzogranite and granodiorite are by far the most aerially extensive. Most of the highly alkalic rocks are restricted to the Triassic, although at least one syenitic body is Jurassic. The overall relatively potassic composition of the San Bernardino Mountains assemblage granitic rocks noticably contrasts with the voluminous tonalitic rocks of the Peninsular Ranges and San Gabriel Mountains assemblages. Tonalitic rocks are essentially absent in the San Bernardino Mountains assemblage.

An extensive unit of mixed gneiss and granitic rocks lie along the San Andreas Fault east of Cajon Canyon and north of Wrightwood. In both areas, the unit is made up of gneiss of probable Proterozoic age, intruded by very heterogeneous Mesozoic granitic rocks ranging in composition from leucocratic monzogranite to gabbro. Screens and irregularly shaped bodies of schist and marble probably derived from Paleozoic or Late Proterozoic sedimentary rocks are abundant locally, but their sedimentary protoliths are unknown. This mixed gneiss unit differs from schist, gneiss, and marble of the Shay Mountain metamorphic complex of MacColl (1964), and similar rocks constituting the Mixed metamorphic rocks of Ord Mountain area. Both of these latter units, although highly recrystallized, are partly made up of recognizable Paleozoic or Late Proterozoic units to the east.

Major faults include the left lateral Cleghorn Fault, the south dipping thrust or reverse faults that bound the north side of the San Bernardino Mountains, the Squaw Peak Thrust Fault, and the western part of the reverse faults centering on Santa Ana Canyon.

Nearly half the bedrock of the San Bernardino Mountains assemblage in the map area is covered by thick aprons of Quaternary deposits emanating from the San Gabriel and San Bernardino mountains.

GEOMORPHOLOGY

The physiography of southern California is comprised of eight physiographic or natural provinces (e.g., Hill, 1928; Fenneman, 1931; Reed, 1933; Jenkins, 1938; Hinds, 1952; and Jahns, 1954). Included in the map area are parts of three provinces, the Peninsular Ranges, Transverse Ranges, and the Mojave Desert.

Peninsular Ranges Province

The Peninsular Ranges Province (as used in this section, province is a geomorphic feature and is not equivalent to the Peninsular Ranges basement assemblage) extends over 1,400 km from just south of the San Gabriel and Santa Monica mountains, (approximately the Cucamonga-Sierra Madre-Malibu Coast fault zones) and the Channel Islands into Mexico where it forms the Baja California peninsula. The province extends to the west offshore to the continental margin (Patton Escarpment) and the eastern boundary is the west side of the Salton Trough. Within the province the overall physiography and both Cenozoic and Mesozoic structural features are dominantly oriented northwest parallel to the coast. With the exception of the Los Angeles Basin and along major fault zones, the province has undergone only relatively minor internal deformation during the Tertiary. This relatively low level of deformation contrasts strongly with the pervasive Tertiary deformation in the Transverse Ranges, especially the San Gabriel Mountains. In the San Bernardino and Santa Ana quadrangles, the Peninsular Ranges Province can be divided into a series of fault-bounded blocks each of which has a set of uniform characteristics internally. The topographic Los Angeles Basin (not to be confused with the Tertiary Los Angeles Basin) is located at the northwest end of the Peninsular Ranges Province.

Included within the province is a large number of low-relief erosion surfaces developed during the Cretaceous and Tertiary. In the map area these surfaces have been displaced by mid-Tertiary and younger tectonism.

San Jacinto Mountains block

The San Jacinto Mountains block (Bean, 1955) (fig. 1), named for the San Jacinto Mountains southeast of the San Bernardino and Santa Ana quadrangles, narrows to the northwest toward the convergence of the San Andreas and San Jacinto Fault Zones. This northwest corner of the block extends into the eastern part of the quadrangles and has relatively low relief in contrast to the high mountainous parts of the block southeast of the quadrangles.

The San Bernardino pull-apart basin and the Crafton Hills, which are not part of the San Jacinto Mountains block, are located at the northwest end of the block (fig. 1). Southeast of the San Bernardino basin, the Crafton Hills (fig. 1) are bounded by normal faults (photo 11), and the San Timoteo Badlands (photos 12 and 13), the latter of which forms the northern end of the San Jacinto Mountains block. Just southeast of the Santa Ana quadrangle, the San Jacinto Mountains block is dominantly Cretaceous and older basement rocks, and elevations reach nearly 3,200 m.

At the southwest corner of the San Bernardino pull-apart basin is a restraining left bend in the San Jacinto Fault. Since the inception of slip on the San Jacinto Fault Zone, sediments on the east side of the fault have been deformed and uplifted as they pass through the restraining left-bend. The uplifted and compressed sediments form a zone of intensely deformed sedimentary rocks adjacent to the fault and a broad anticline further to the east (Kendrick and others, 2002). Separating the intensely deformed rocks and the broad anticline is a diachronous fault formed by the compressional deformation. This diachronous fault is interpreted as a consequent of slip along the seismogenic San Jacinto Fault and not as a primary seismogenic fault. In the steeply dipping foliated metamorphic rocks at the eastern edge of the area the restraining bend compression apparently is accommodated by displacement along foliation producing a series of foliation faults. After passing the restraining bend the uplifted sedimentary rocks are eroded forming the San Timoteo Badlands as the rocks enter the east side of the San Jacinto Valley. The extent of erosion progressively increases in a near linear way from north to south (Morton and others, 1990; Kendrick and others, 2002).

Perris block

The Perris Block (fig. 1), named by English (1925) for the city of Perris, is located west of the San Jacinto Mountains block. It is a rectangular shaped block, has low relief, and is bounded on the east by the San Jacinto Fault Zone and on the west by the Elsinore Fault Zone. The northwestern part of the block is somewhat ill-defined north of Corona where the Elsinore Fault becomes the more westward striking Whittier Fault, and in the Pomona-San Jose Hills area where it is poorly defined beneath thick Quaternary and Tertiary cover. In this area, we consider the concealed western margin of the Perris block to roughly coincide with the east edge of the Chino basin (fig. 3).

The Perris block consists of two distinct parts, a northern and a southern part. Upstream from Corona, the northern part consists of the largely alluvial valley area of the Santa Ana River. Most of the area north of the Santa Ana River is covered by late Pleistocene and Holocene alluvial fan deposits emanating from the high-standing San Gabriel Mountains. These fans consist of boulder deposits in the proximal parts and grade to sandy deposits in the distal parts. Elevations on these fans range from about 200 m in the south to 500 to 600 m near the mountain front. The alluvial fan deposits, party covered with eolian deposits, reach the southwest flowing Santa River except for the area on the south side of the Jurupa Mountains. South of the Santa Ana River, extensive, distinctly older Pleistocene alluvial fan deposits are gently northward sloping, mostly dissected, and are sandy and gravelly. This dissected older Pleistocene material is mostly deposited in the lower part of the Pleistocene fan surface, and the dissection appears to be Holocene. The dissected Pleistocene surface capping these deposits appears to be of the same age as the Paloma surface of Woodford and others (1971) and was graded to the Pleistocene location of the Santa Ana River. The Holocene dissection and deposition is considered to be the same as the San Jacinto surface of this report.

In early Pleistocene(?), an alluvial fan complex extended much further south from the San Gabriel Mountains than the present day fans. These older fans, now represented only by discontinuous lag gravels containing clasts of Pelona Schist (Kpu), covered the Jurupa Mountains and extended onto the 500-m-high Perris surface (photos 14, 15, 16, and 17) south of Riverside. The southern distal parts of this fan complex were flanked by an ancestral Santa Ana River, well south of the present day location of the river (Morton and Matti, 1989). Morton and Matti (1989) interpret the Perris block to have been elevated concurrent with offset on the San Jacinto Fault resulting in compression of the Perris block and the eastern San Gabriel Mountains. Attendant to this compression a section of the Perris block was down dropped along a fault zone north of the Jurupa Mountains and south of the San Gabriel Mountains; the active Fontana seismic zone (Hadley and Combs, 1974) may be a continuing expression this structure.

Pliocene marine rocks, perhaps correlative with the upper part of the Fernando Formation (Tfu), (pre 2.2 Ma) in the Norco and Home Gardens areas (fig. 1) were deposited along rugged sea cliffs that today have an elevation of about 220 m (Morton and Matti, 1989). Paleotidepools at Home Gardens contained deposits of the Tuffs of Blind Springs Valley that has been dated at 2.14 to 2.22 Ma (Sarna-Wojcicki, and others, in press) indicating a post 2.2 Ma uplift of 220 m for the northern Perris block.. Continental cobbly deposits overlying the tuff contain remains of *mammut* sp. that has an age range of 4 Ma to about 10,000 yrs bp (M.O. Woodburne, written commun., 2004)

The southern part of the Perris block consists of widespread exposures of basement and a series of interconnected alluviated valley areas. Most elevations range from 450 m to 700 m. Several erosion surfaces are developed on bedrock in this part of the Perris block and have been the subject of a number of papers. Dudley (1935) named some of these erosion surfaces; the most widespread he termed the Perris surface. The Perris surface has an average elevation of about 515 m, but ranges from 480 to 560 m. West of the Box Springs Mountains (fig. 1) the northern extent of the Perris surface is rather abruptly terminated by an erosional escarpment that grades to the Santa Ana River. Dudley also named the 636-m-high Gavilan-Lakeview surface after the Gavilan Plateau area (Lake Mathews and Steele Peak quadrangles) and the Lakeview Mountains (Lakeview 7.5' quadrangle) where it is well developed. A higher surface at about 757 m, recognized but not named by Dudley, was named the Rawson surface by Larsen (1948) for its development on both sides of Rawson's Gulch. Bean (1955) used much of the geomorphic terminology of Dudley and Larsen and identified and contoured deep buried basement topography. Later, Woodford and others (1971) described two additional surfaces and developed a temporal sequence for these surfaces. The Rawson surface was renamed the Magee surface (photo 61) by Woodford and others (1971) from the surface development on the northeast side of the Magee Hills south of Hemet (Sage 7.5' quadrangle).

Small erosion remnants of a monolithologic conglomerate composed of Poway-type exotic clasts (Woodford and others, 1968), mostly welded rhyolite tuff, some piemontite bearing (photos 18, 19, and 20), occur at elevations of 480 and 520 m at Arlington Mountain (fig. 1), Lake Mathews 7.5' quadrangle. A similar deposit occurs east of Lake Elsinore on a ridge top at an elevation of 560 m (Elsinore 7.5' quadrangle). These elevations are compatible with the elevations of the Perris surface (average elevation 515 m). Based on lithologic affinity with the Santiago Formation, these deposits are here considered to be Santiago Formation.

Cretaceous sediments were deposited on an older erosion surface in the Santa Ana Mountains. This surface was termed the Los Angeles surface by Woodford and Gander (1977), who interpreted it to extend onto the Perris block where it was modified by Tertiary erosion resulting in the formation of younger surfaces.

Woodford and others used the term 'bowl and narrow valley surface' for the surface on which the Miocene Lake Mathews Formation (Tlm) was deposited. The 'bowl' is apparently the surface around Lake Mathews and the 'narrow valley' is a buried channel east of Lake Mathews that is not connected to the 'bowl'. Based on the extensive development of this surface in the vicinity of Lake Mathews, the name Lake Mathews surface is used here for Woodford and others (1971) 'bowl and narrow valley surface'. The Lake Mathews surface has low relief ranging from 365 m at its western edge where the Lake Mathews Formation was deposited on the Silverado Formation, to 460 m in the northeast (photo 24). Although at about the same elevation as part of the Paloma surface, the Lake Mathews surface is pre 9 to 12 Ma and the depositional Paloma surface is Pleistocene. The elevation of the base of the 'narrow valley' of the Lake Mathews surface is about 424 m. Drill holes poorly define a buried erosion surface under the Paloma surface in the vicinity of March Air Force Base at elevations of 394-455 m. This buried surface may be an eastern extension of the Lake Mathews surface (Morton and others, 1997).

A surface connecting a series of broad flat-floor valleys at an elevation of about 450 m was termed the Paloma surface by Woodford and others (1971). Its name is after Paloma Valley in the southwestern part of the Perris Block (fig. 1), Romoland 7.5' quadrangle. Although referred to as an erosion surface by Woodford and others (1971), it includes multiple depositional surfaces capping the alluvial fill of a deep, buried drainage complex. Woodford's Paloma surface is a composite surface consisting of a Pleistocene age depositional surface and a Holocene age surface that is in part cut into the Pleistocene surface and in part caps deposits on the Pleistocene surface; it is graded to the present day San Jacinto River. Here, the name Paloma surface is restricted to the Pleistocene surface and the Holocene surface is termed the San Jacinto surface.

Over much of the Perris and Moreno valleys the Paloma surface is degraded. Elevation differences between the Paloma and San Jacinto surfaces are pronounced around the margins of the valleys where the depositional surface is at elevations slightly higher than the 515 m elevation Perris surface. Toward the center of the valleys, Holocene sediments have been deposited on the Paloma surface. There is no recognized expression of the Paloma surface on basement. Surfaces similar to the Paloma and San Jacinto surfaces are widespread in the northern Peninsular Ranges; these surfaces, like the Paloma and San Jacinto surfaces, are graded to a local base. Examples are the Pleistocene deposits on the south side of Lake Mathews (photo 21), which are graded to the Pleistocene elevation of Cajalco Creek, and surfaces in the Riverside area that are graded to the Pleistocene elevation of the Santa Ana River (photos 22 and 23).

Bean (1955) earlier showed that the surface Woodford and others (1971) would call the Paloma surface was underlain by a deep buried canyon system; Woodford and others (1971) later refined the buried canyon topography and termed the surface the deep valley surface. Here, we refer to this surface as the Moreno Valley surface after its development in the Moreno Valley[2] area (fig. 1). The geometry of the Moreno Valley surface indicates it supported a south flowing drainage system that inexplicably terminates in the subsurface on the Perris block (Woodford and others, 1971). The trunk drainage is as much as 300 m below the Paloma surface. A thick section of intensely decomposed tonalite at a subsurface elevation of 333 to 364 m was cored at the base of sediments at March Air Force Base (fig. 1), Riverside East 7.5' quadrangle. The nature of the decomposed rock appears to be similar to some of the Paleocene age decomposition on the west side of the Perris Block and in the Santa Ana Mountains.

At March Air Force Base a paleomagnetic study of a core from the alluvial deposits (Qvof) located the 780 ka Brunhes-Matuyama boundary at three meters below the top of the degraded Paloma surface (Morton and others, 1997). Near the site of the former Bernasconi Hot Springs (also called Lakeview Hot Springs) on the southeast side of the Bernasconi Hills, an excavation exploring the subsurface extent of a ground fissure in apparently an old channel of the San Jacinto River, exposed coarse-grained sands containing scattered wood fragments. ^{14}C dates from wood collected at a depth of 4.5 m is 10,000 years and wood from a depth of nine meters is older than 40 ka (Reynolds and Reynolds, 1991). At Romoland a drill hole begun in Pleistocene old alluvial fan deposits (Qof) encountered the 3.3 Ma Nomlaki Tuff (Sarna and others, in press) below the Qof at a depth of nine meters.

On the southern part of the Perris block we currently recognize six erosion surfaces, from oldest to youngest, the Santa Rosa Plateau surface, the Lake Mathews surface (photo 24), the Gavilan-Lakeview surface (photo 25), the Perris surface (photos 16 and 17), the Magee surface (photo 61), the Moreno Valley surface, and two depositional valley-filling surfaces, the Paloma surface and San Jacinto surface (photos 26, 16, and 17).

The oldest identified surface in the Perris block is the deeply and intensely weathered Paleocene, or older, Santa Rosa Plateau surface. This surface is in part overlain by the Paleocene Silverado Formation (Tsi) within and adjacent to Temescal Valley (Lake Mathews and Corona South quadrangles), and is named after its widespread development west of Temecula on Santa Rosa Plateau, Santa Ana Mountains. The elevation of this surface along the western edge of the Perris block is about 364 m. On the Perris block most of the Silverado Formation is overlain by the Miocene Lake Mathews Formation (Tlm) (photo 27, 28, and 29). East of the fringe of the Silverado Formation (Tsi), the Lake Mathews Formation was deposited on the Lake Mathews erosion surface; the elevation of the surface rises gently to the east and northeast to about 460 m. East of Lake Mathews, a shallow channel extends for about eight kilometers, and is apparently filled with Lake Mathews Formation (Bean, 1955; Woodford, and others, 1971).

In the Gavilan area, four isolated, small occurrences of thin conglomerate deposits (Tcg and Tcgr) are found on the Gavilan-Lakeview surface, Steele Peak 7.5' quadrangle. The elevation of the base of these deposits ranges from 666 m in the western two deposits, to 627 m in the central deposit, and 606 m in the eastern deposit. The age of these deposits is unknown; some of them contain red rhyolite clasts exotic to the northern Peninsular Ranges (photo 30). At several places in the Lakeview Mountains, thin, gray, locally-derived coarse-grained sandstone was deposited on this surface (Morton, 1972) (photo 31).

Woodford and others (1971) assigned ages to the Perris block surfaces. They considered the Lake Mathews surface to be the oldest, predating ten Ma. Succeding assigned ages include the Perris surface at

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[2] Note: The City of Moreno Valley incorporated in 1985, and includes what was then the unincorperated community of Sunnymead; the name, Sunnymead, no longer exists, but the name of the 7.5' quadrangle has not been changed as of the date of publication of this paper.

nine Ma, the Moreno Valley surface at seven (?) Ma, the Magee surface three (?) Ma, the Gavilan-Lakeview surface two (?) Ma, and the Paloma one Ma and younger.

The Woodford and others (1971) age assignment of the Lake Mathews surface is based upon the Claredonian age (9-12 my) of the Lake Mathews Formation (Tlm). They considered the Basalt of Hogbacks (Tvh) (Murrieta quadrangle) to be the same as the Santa Rosa basalt of Mann (1955) (Tvsr), and interpreted the basalt of Hogbacks to have been deposited on the Perris surface. Their age of the Perris surface was based on this correlation and the published age of 8.7 Ma for the basalt (Hawkins, 1970). Later the Santa Rosa basalt of Mann (1955) was dated at 6.7 and 7.4 Ma and the basalt of Hogbacks at 10.4 and 10.8 Ma (Morton and Morton, 1979). The basalt of Hogbacks was deposited on stream gravels that were deposited on fresh gabbro and tonalite. This basalt appears to have been deposited in a canyon and its present day topographic high apparently is due to inverted topography. The western end of the basalt of Hogbacks is at an elevation of 480 m and the eastern end, 2.5 km to the east, is at an elevation of 520 m. In contrast, the Santa Rosa basalt of Mann (1955) was deposited on a deeply weathered, essentially horizontal surface of Paleocene or earlier age. At Elsinore Peak, well-indurated, decomposed sedimentary rocks considered to be the Paleogene Silverado Formation (Tsi) lie between the deeply weathered surface and the basalt. Thus it appears Woodford and others (1971) were incorrect to correlate the surface on which the basalt of Hogbacks was deposited with the Paleocene or older surface on which the Santa Rosa basalt was deposited.

On the western edge of the Perris block, the topographically highest basement on which the Silverado Formation (Tsi) lies depositionally, is about 418 m, about 100 m lower than most of the Perris surface. The few occurrences of the Poway-type clast monolithologic conglomerate at elevations of 480 to 560 m suggest these deposits may be Eocene Santiago Formation (Tsa). The other surfaces have no datable material associated with them. The 2(?) Ma age assigned to the Gavilan-Lakeview surfaces (elevation 636 m) seems far too young as does the 3(?) Ma age for the Magee surface (elevation 758 m). It seems unlikely that the widespread Gavilan-Lakeview surface could have been developed in a one Ma interval. Supportive of an older age for the Gavilan-Lakeview and Magee surfaces is the presence of the 3.3 Ma Nomlaki Tuff at a depth of nine meters (elevation of 427 m) below the Paloma surface.

Apparently based on Woodford and others (1971), correlation of the Perris surface with the here termed Santa Rosa Plateau surface has led to the Perris surface to be considered part of a regional suface termed the Perris peneplain-Silverado Canyon-Runyon Canyon erosional surface (Colburn and others, 1988).

The only erosion surface that is reliably dated is the Paleocene or older 364 m Santa Rosa Plateau surface on which the Silverado Formation (Tsi) was deposited. If the few deposits of Poway-type clasts are of Eocene age (Santiago Formation) and are on the Perris surface (480-560 m) it would suggest that the Perris surface is the next youngest surface. The Lake Mathews surface is pre 9-12 my. The Magee and Gavilan-Lakeview surfaces are undated, but the areal extent and the degree of development of both surfaces and the presence of exotic red rhyolite clasts on the Gavilan-Lakeview surface (Gavilan Plateau) would suggest they are much older than 3 and 2 Ma. It is doubtful that the Gavilan-Lakeview surface could be developed on bedrock in only one million years.

A drill hole near the center of the main channel of the Moreno Valley surface encountered basement at 99 m and penetrated 13 m of weathered granitic rock before reaching fresh rock. Another drill hole in a tributary of the main channel encountered deeply weathered basement at 364 m. In both holes, the weathered basement is somewhat like the Paleocene weathered surface, but without the characteristic red clay. The buried Moreno Valley surface valley system has no known outlet and the base of the surface is at about 150 m. It seem more likely that this surface is Paleogene rather than as young as Pliocene.

The Paloma depositional surface is Pleistocene based on soil development and paleomagnetic data. Because it is currently or recently active, the Holocene San Jacinto surface is considered to be the youngest depositional surface.

Basins marginal to the Perris block

A number of fault bounded basins are located along the margin of the Perris block and within adjacent blocks (fig. 3). In the southeastern part of the area, the Temecula basin, is bounded on the north by the Hot Springs (Murrieta Hot Springs) Fault Zone. This east oriented basin is filled by the Temecula Arkose and younger sedimentary rocks. Northwest of the Temecula basin, a number of pull-apart basins are located along the Elsinore Fault Zone; most notablely, the Elsinore basin, a relatively shallow depression bounded on the northeast by the Willard Fault and on the southwest by the Wildomar Fault, both segments of the Elsinore Fault Zone. Further northwest, extending from the junction of the Whittier and Chino Faults, is the Chino basin bounded on the west by the Chino Fault and on the east by a concealed boundary that could be structural or depositional. The Chino basin contains a relatively thin sequence of Los Angeles Basin Tertiary rocks including petroleum producing units. Some of the younger parts of the basin are subject to subsidence and associated ground fissures.

The narrow and deep San Jacinto basin (fig. 3) is located in the northeastern part of the Santa Ana quadrangle between the Claremont and Casa Loma fault segments (fig.1) of the San Jacinto Fault Zone (photo 32). This basin is actively subsiding at a relatively rapid rate due to a combination of tectonism and groundwater mining. Northwest of San Jacinto basin, the San Bernardino basin is a major asymmetric pull apart basin apparently produced by slip stepping to the right at its north end from the San Jacinto Fault Zone to the San Andreas Fault Zone. Bounding the south end of the San Bernardino basin, the Crafton Hills block (fig. 3) is a fault complex made up of the Crafton Hills horst and small grabens south of the horst (photo 11). West of the San Jacinto Fault, adjacent to the San Bernardino basin, is an unnamed, smaller, narrow basin (see Anderson and others, 2004; and Dutcher and Garrett, 1963).

Santa Ana Mountains block

The Santa Ana Mountains block (fig.1 and fig. 3) is divided longitudinally into an eastern half consisting of the Puente Hills and the Santa Ana Mountains and a western half of relatively low lying sedimentary rocks extending west from the flank of the Santa Ana Mountains to the coast. At the north end of the Santa Ana Mountains, the low lying Puente Hills (fig. 1) are underlain by rocks of the Los Angeles Tertiary basin. South of the Whittier Fault and the Santa Ana River, the topography rises abruptly to form the Santa Ana Mountains which constitutes the bulk of the block. Structurally the northern part of the mountains is a northwest-plunging complexly faulted anticline (e.g., Schoellhamer and others, 1981) where upper Cretaceous and Tertiary rocks rest on older Cretaceous volcanic and plutonic rocks and Jurassic metasedimentary rocks. This anticlinal structure is asymmetrical with a gentler sloping westward flank and an abrupt east flank along the Elsinore Fault Zone. The erosion surface on which the Cretaceous sediments were deposited is the Los Angeles erosion surface of Woodford and Gander (1977), and was considered by them to have extended eastward from offshore, across the Los Angeles Basin, and onto the Perris block where the surface has been modified by Tertiary erosion. The type area for the Los Angeles erosion surface is between the crystalline basement and Turonian sedimentary rocks in the northwestern Santa Ana Mountains (Woodford and Gander, 1977).

The Santa Rosa Plateau surface, on which the Paleocene Silverado Formation (Tsi), rests is at an elevation of about 140 m at the Santa Ana River near the nose of the anticline. Four kilometers to the south, this surface along the west flank of the anticline is at an elevation of 740 m. The Silverado Formation in Temescal Valley on the east side of the mountains is at an elevation of 418 m, indicating that development of the anticline is younger than the Silverado Formation. The Santa Rosa Plateau surface extended across the area now occupied by the Santa Ana Mountains and was uplifted to at least 1,000 m at Elsinore Peak where the Santa Rosa surface is covered by a thin veneer of Silverado Formation (photo 212) that is in turn covered by basalt flows (Tvsr). These basalt flows have been dated at 11.6 Ma by conventional potassium-argon and 11.2 Ma by $^{40}Ar/^{39}Ar$ (R. Fleck, written commun., 1998). Thus the uplift of the Santa Rosa surface is more than 860 m over a distance of 21 km.

The tectonic development of the Santa Ana Mountains anticline appears to be the result of the angular discordance between the strike of the Elsinore Fault and the more westerly striking Whittier Fault. The length of the Santa Ana Mountains elevated by the discordance between the Elsinore and Whittier Faults extends south of the Santa Ana River about 35 km. Further south the summit elevation decreases to 600 to 800 m over a distance of about 12 km where it is the near-horizontal, low-relief Santa Rosa Plateau surface partly capped by basalt.

The Santa Ana Mountains (fig. 1) consist of three topographically distinct segments (Hauser and Morton, 1998). All three segments are bounded on the east by a steep escarpment along the Elsinore Fault Zone. The northern segment extends southward to the north end of Lake Elsinore at Leach Canyon where there is a distinct jog in the mountain front. The east flank of the mountains is deeply dissected and the crest of the range is at elevations of 1,200 to 1,700 m. Drainages extend four to six km into the mountains from the eastern margin, and head against extensively developed drainages on the west flank of the mountains. On the west side of the mountains, the northern segment extends south to the upper part of Hot Springs Canyon.

The east face of the central segment between Leach Canyon to about the Slaughterhouse Canyon (fig. 1) drainage basin area is moderately dissected but more subdued than the northern segment. Summit elevations are about 1,000 m to nearly 1,100 m; the highest elevation is Elsinore Peak (ca. 1,090 m). The physiography of the central segment is a broad low relief area having short, steep gradient drainages extending about two to three km from the east margin of the mountains and that are paired with extensive drainages on the western slope. There is no sharp difference between the north and central segments on the west side of the mountains.

The central segment grades into the southern segment, which is characterized by two types of drainage basins. Short, one- to two-kilometer-long, drainage basins are developed along the mountain front. These are steep gradient stream channels (gradients of about 200 m in 1,000 m). Some of these channels connect with older low gradient channels (gradients of about 200 m in 7,000 to 8,000 m) to form composite drainages. The low gradient drainages are developed on the Santa Rosa surface, and partly covered by basalt flows. Basement rocks beneath the basalt are deeply weathered (saprolitic) and immediately south of the map area, sedimentary rocks capped by basalt rest on the deeply decomposed basement. Erosion of the decomposed basement gives rise to a surface of very low relief having scattered core stone boulders. The Santa Rosa Plateau surface occurs beneath basalt flows that cap a number of mesas that collectively form the Santa Rosa Plateau (fig. 1). The Santa Rosa Plateau surface increases in elevation to the west and north, in part due to faulting and apparently in part to tilting. At Mesa de Burro, the southwestern part of the surface is at an elevation of about 580 m and at Mesa de Colorado it is about 600 m. West of Mesa de Colorado, at the western part of Avenaloca Mesa, the surface is about 700 m. At Redonda Mesa, 0.5 km west of Avenaloca Mesa and 0.2 km south of the map area (Fallbrook 7.5' quadrangle), the surface is at an elevation of 800 m. The Harris Fault separates Avenaloca Mesa and Redonda Mesa, and it is assumed that the elevation difference between the two mesas is due to vertical displacement on the Harris Fault. Further west at Miller Mountain (fig. 1), the surface is at about 840 m. To the north at Elsinore Peak, the elevation of this surface is 1020 m. Woodford and others (1971) correlated the Santa Rosa surface with the Perris surface of the Perris block (base of the basalt of the Hogbacks), and as discussed under the geomorphology of the Perris block, this correlation appears suspect.

Most drainages on the west side of the mountains are southwest flowing. Deeply dissected sedimentary rocks flank the west side of the Santa Ana Mountains, where a thick section of Upper Cretaceous sedimentary rocks rest on crystalline basement. Between the San Joaquin Hills (fig. 1) and the Santa Ana Mountains, the Upper Cretaceous rocks are overlain to the west by more-or-less uniformly progressively younger rocks. The younger rocks strike more northerly than the older rocks resulting in a south to southsouthwest flowing drainage system in relatively low lying terrane. South of the Puente Hills and north of the San Joaquin Hills the area is a gentle westward sloping broad alluvial fan complex dominated by the late Quaternary Santa Ana River fan. This area of Orange County is largely urbanized effectively concealing most of the surface materials. Eckman and others (1919) soil map appears to give the best rendition of the distribution of surficial material in this urbanized area.

Transverse Ranges

The east trending physiographic-structural grain of the Transverse Ranges Province lies athwart the northwest physiographic-structural grain of southern California and the rest of the state. This difference in structural trends is particularly apparent beyond the bounds of the map area north of the San Bernardino Mountains where northwest trending desert mountain ranges and strike-slip faults apparently abut against the San Bernardino Mountain range front. The San Gabriel Mountains form the central part of the Transverse Ranges Province and the San Bernardino Mountains the eastern part.

San Gabriel Mountains

The San Gabriel Mountains are a deeply dissected range having steep slopes that are mostly underlain by intensely fragmented basement (photo 298). Within the range, a number of large faults lie in, and control the locus of major drainages. The highly fragmented nature of the rocks combined with the steep slopes gives rise to high rates of erosion where, under normal conditions, dry season erosion rates exceed winter erosion rates (Anderson and others, 1959). It has been estimated that the average gradient is greater than 65 percent, exceeding the angle of repose for unconsolidated rock material (Krammes, 1963). Long term yearly erosion rates have been estimated at 0.15 cm (Morton, 1973) and 0.19 cm (LaMarche, 1965).

High points are in the eastern part of the range where 3049-m-high Mount San Antonio is located along with peaks such as Mount Hawkins, Mount Baden-Powell, Big Horn Peak, Telegraph Peak, and Mount Harwood (fig. 1), all in excess of 2,500 m. The mountain front is particularly abrupt east of San Antonio Canyon with a local relief of nearly 2,000 m between Cucamonga Peak and the alluvial fans at the mountain front, a distance of six kilometers. A dominant physiographic feature within the range is the east-trending topographic low developed along the San Gabriel Fault Zone, which extends in a near linear trace from the west edge of the map area to San Antonio Canyon.

Although much of the basement is thoroughly fractured the mountains are comprised of relatively discrete fault-bounded blocks (fig. 3) that have had somewhat different histories. A relatively large central block, the San Gabriel Mountain block, is surrounded by a number of smaller blocks. In general, the size of the blocks decreases eastward. Blocks in the eastern San Gabriel Mountains have been interpreted to be elements of an anticlinal schuppen-like structure (Morton and Matti, 1993). The easternmost block, the Lytle Creek block, consists of two distinct parts; a northwestern part located between the Lytle Creek Fault and the northwest striking eastern end of the San Gabriel Fault Zone and a southeastern part located between the San Gabriel Fault Zone and Glen Helen Fault. Compression and uplift in the eastern San Gabriel Mountains has resulted in the formation of seven relatively small, largely fault bounded blocks, the Baldy, Telegraph Peak, Cucamonga Peak, Frankish Peak, Deer Canyon, East Etiwanda Canyon, and San Sevaine blocks. Located between the Cucamonga Fault Zone on the south and Stoddard Canyon-South Fork Lytle Creek are four fault-bounded slightly offset blocks, the Frankish Peak, Deer Canyon, East Etiwanda Canyon, and San Sevaine blocks. North of these small blocks is the Cucamonga Peak fault-bounded block bounded on the north by the northern part of the Stoddard Canyon Fault-Middle Fork Lytle Creek Fault. This is an area of rugged high relief. West of the Cucamonga Peak block is the Telegraph Peak block that consists of two subblocks, divided by a fault connecting the South Fork Lytle Creek-Stoddard Canyon Fault and the San Gabriel and related faults in the Middle Fork Lytle Creek. The relief of the Azusa-Glendora block is moderate, and is less deeply dissected than the flanking Mount Wilson and San Dimas blocks. Upper surfaces of some of these blocks are capped by deeply weathered surfaces marked by the development of red-brown soils. Tertiary sedimentary rocks of the greater Los Angeles Tertiary basin and associated volcanic rocks flank the southern part of the Azusa-Glendora block.

Cajon Pass Area

The San Andreas Fault zone separates the San Gabriel Mountains and San Bernardino Mountains. Between the two mountain ranges is the relatively low lying Cajon Pass area (fig. 1). The dominant physiographic feature is Cajon Valley (fig. 3) developed in a section of sedimentary rocks ranging in age from Miocene to Quaternary. High bluffs, informally referred to as the 'inface bluffs', are cut into and behead the informally named Victorville fan (photos 590 and 591). These bluffs form the north side of the valley, and the San Andreas Fault at the foot of the San Gabriel Mountains forms the south side. Bedrock in the valley is dominated by two compositionally similar Miocene units that differ in erosional resistance, and have contrasting geomorphic expression. The Cajon Valley Formation (Tcv units) forms prominent flatirons, and the less resistant Crowder Formation (Tcr) generally forms low rounded hills.

San Bernardino Mountains

The San Bernardino Mountains physiography consists of four major elements (e.g. Sadler and Reeder, 1983), three of which occur in the San Bernardino and Santa Ana quadrangles. The dominate element is a broad, slightly dissected northern plateau which is topped by a prominent erosion surface (photos 32 and 33). This surface, apparently first noted by Vaughan, 1922) and delineated in detail by Spotilla (2000), is referred to as the San Bernardino Mountains surface by Sadler and Reeder (1983), who consider it to be Miocene age. The area included in Sadler and Reeder's San Bernardino Mountains surface roughly coincides with the area we show as the San Bernardino Mountains block on Figure 3. South of the San Bernardino Mountains block is an elongate elevated area Sadler and Reeder (1983) termed the San Gorgonio massif, that culminates with San Gorgonio Mountain, the highest peak in southern California (3,466 m). Between the two physiographic entities is the Santa Ana Fault, a major north-dipping reverse fault. The area we show as the Santa Ana Canyon block on Figure 3, roughly coincides with the western part of Sadler and Reeder's San Gorgonio massif. San Gorgonio Mountain and the higher parts of the massif lie east of the San Bernardino quadrangle.

South of the Santa Ana Canyon block is a narrow wedge of basement between the Mill Creek (North Branch of the San Andreas Fault Zone) (fig. 1) and the active San Bernardino strand (South Branch) of the San Andreas Fault Zone (Matti and others, 1992); this physiographic element was not named by Sadler and Reeder (1983). Although physiographically part of the San Bernardino Mountains, this elongate block is underlain by rocks that are similar to, but do not clearly belong to either the San Gabriel Mountains or San Bernardino Mountains assemblages. East of the San Bernardino Mountains and Santa Ana Canyon blocks is an area informally referred to as the eastern ramp. Here, the San Bernardino Mountains descend to the Mojave Desert in a relatively even progression, without interruption of prominent scarps or breaks-in-slope; this eastern ramp is entirely east of the San Bernardino quadrangle.

Scattered occurrences of quartzite clasts on the San Bernardino Mountains surface are interpreted by Sadler and Reeder (1983) as remnants of Miocene continental deposits correlative with the Crowder Formation of the Cajon Pass area and the Old Woman Sandstone exposed along the north side of the San Bernardino Mountains just to the east of the San Bernardino quadrangle. The principal source of the quartzite clasts is Late Proterozoic and Cambrian rocks in the eastern part of the San Bernardino Mountains block. On the eastern ramp, basalt flows dated at six to nine million years were deposited on the same surface as the scattered quartzite clasts in the western part of the San Bernardino Mountains surface (Sadler and Reeder, 1983).

Mojave Desert

The Mojave Desert (figs. 1, 2, and 3) extends north from the San Gabriel and San Bernardino Mountains. It is an area of low relief consisting of largely alluvial fan deposits punctuated by the relatively low but rugged Granite Mountains in the northeast corner of the San Bernardino quadrangle (fig. 1). Drainages emanating from the north side of the San Gabriel and San Bernardino Mountains drain to interior closed basins. Two small basins, termed playas, are formed between the large fans of the San Bernardino Mountains and small fans extending from the south side of the Granite Mountains.

Largest of the Mojave Desert fan complexes is the beheaded Pleistocene Victorville fan (fig. 3). This informally named fan had its source on the north side of the San Gabriel Mountains, but right-lateral displacement on the San Andreas Fault has separated it from its source. Subsequent headward erosion from the south that formed Cajon Valley removed the proximal part of the Victorville fan. A second distinctive fan, the Sheep Creek fan, is composed largely of Pelona Schist derived from debris flow material from Sheep, Heath, and Swarthout Creeks. The dark gray Pelona Schist (Kpu) debris in the Sheep Creek fan causes the fan to stand out prominently from adjacent fans that are dominated by lighter colored gneissic and granitic material.

The segment of Mojave Desert adjacent to the San Andreas Fault is an uplifted elongate area of basement, here informally termed the Table Mountain block (fig. 3). This block extends from the Cajon Valley area to the west edge of the San Bernardino quadrangle where it is less pronounced than further to the southeast. Uplift of the block is apparently due to compression produced as the Mojave Desert rocks are translated around the open curving trace of the San Andreas Fault.

FAULTS

Faults and fault systems in the San Bernardino and Santa Ana quadrangles dominate the neotectonic structure of the area, particularly faults of the active San Andreas Fault System (Allen, 1981, Wallace, 1990). Best known are the northwest-oriented right-lateral strike-slip fault zones, which in addition to the San Andreas Fault Zone, includes the San Jacinto Fault Zone (Sharp, 1967) and Elsinore Fault Zone (Hull and Nicholson, 1992; Langenkamp and Combs, 1974). Less well known are the compressional and rare extensional faults that are a result of displacement on the right-lateral strike-slip faults, and the left-slip Cleghorn Fault (Meisling and Weldon, 1989).

The neotectonic San Andreas Fault is a continuous fault that has well expressed physographic development in the quadrangles. Both the San Jacinto and Elsinore Fault zones consist of en echelon faults that have formed a series of extensional basins and compressional uplifts (Hull, 1990; Kennedy, 1977; Morton and Matti, 1993; Sharp, 1967; Weber, 1976). In addition to the neotectonic San Andreas Fault are inactive older strands, principally the San Gabriel, Punchbowl, Cajon Valley, and the North Branch of the San Andreas in the San Bernardino Mountains. A major triangular-shaped (plan view) extensional basin, the San Bernardino basin (fig. 3) occupies the area between the San Andreas Fault and the San Jacinto Fault Zone in the San Bernardino Valley area. Because of Quaternary cover, structures between the San Gabriel Mountains and the Jurupa Mountains are poorly understood, including the informally named Fontana seismic zone and the nature and location of the boundary between the Peninsular Ranges and San Gabriel Mountains assemblages.

The angular discordance between the San Jacinto and the San Andreas Fault Zones results in compression and movement on the Cucamonga Fault Zone along the south margin of the eastern San Gabriel Mountains as well as the uplift of the eastern San Gabriel Mountains (Morton and Matti, 1993).

The northern part of the San Jacinto structural basin, in the northeast part of the Santa Ana quadrangle, formed at a right step between the Claremont Fault on the east and the Casa Loma Fault on the west (photos 32, 33, and 34). The San Jacinto structural basin is the site of rapid subsidence, both long-term tectonic subsidence and more recent subsidence due to groundwater withdrawal (e.g., Morton, 1977;

Proctor, 1962) (photos 35 and 36). This narrow restricted basin is filled with Quaternary sediments estimated to be about 3000 m thick (Fett, 1968). Both Casa Loma and Claremont Faults of the San Jacinto Fault Zone display youthful fault features, and are considered to be the source of major earthquakes in the early part of the 20th century.

The Elsinore Fault Zone (fig. 3) consists of a complex assemblage of right-stepping and left-stepping en echelon faults (photo 37). Movements on these faults have produced a series of extensional basins that in aggregate result in an elongate, composite, structural trough. The trough includes numerous minor compressional uplifted domains (Hull, 1990; Kennedy, 1977; Weber, 1976), some of which separate the constituent extensional basins. Largest of these extensional basins, the Elsinore structural basin, is largely filled by Lake Elsinore. In the vicinity of Corona, the Elsinore Fault Zone either branches into or intersects two independent faults; the Whittier Fault which has a more westerly strike and the Chino Fault which continues for about 15 km with the same strike as the Elsinore Fault. The junction of these faults is obscured beneath young alluvium.

There are three large reverse fault systems in the area, the Cucamonga-Sierra Madre fault system bounding the south edge of the San Gabriel Mountains, the reverse faults bounding the north edge of the San Bernardino Mountains, and the reverse faults that project into the eastern part of the San Bernardino quadrangle from the Santa Ana Canyon area of the San Bernardino Mountains. The Cucamonga and Sierra Madre Faults are seismically active, north dipping reverse or thrust faults that in many places fault crystalline bedrock over Quaternary deposits (photo 411). Locally, the Cucamonga Fault, Cucamonga Peak and Mount Baldy 7.5' quadrangles, has well formed south facing scarps developed in young Quaternary deposits (Eckis, 1928; Morton, 1976; Morton and Matti, 1987) (photos 412 and 592).

The faults bounding the north side of the San Bernardino Mountains are south dipping reverse faults that in many places show high, well developed scarps, which are formed in older Quaternary deposits and are moderately degraded (Meisling, 1984; Meisling and Weldon, 1989; Miller, 1987). Where they are developed in the San Bernardino quadrangle, the faults that emanate from the Santa Ana Canyon area are relatively steeply north dipping and, although part of a seismically active zone, do not have recognizable scarps, probably because the very steep slopes in the area do not allow their preservation. Eastward, these faults coalesce into a single large and a few small north dipping reverse faults.

A much older fault, the Vincent Thrust (photo 566) (fig. 1), of probable early Tertiary age (Grove, and others, 2003), is well exposed in the high parts of the eastern San Gabriel Mountains (photo 565), and poorly exposed, but well located in the Crafton Hills (fig. 1). It typically is gently dipping to subhorizontal, but in places is near vertical, especially near younger faults that disrupt it. The fault, including what has been considered its offset equivalents in the Orocopia and Chocolate Mountains southeast of the map area, separates Pelona Schist (Kpu) in the lower plate from highly deformed metamorphic and granitic rocks in the upper plate. Where best exposed, the fault is well defined, typically represented by a variably thick zone above the fault in which the rocks are retrograded and more schistose, but distinct from the mylonitized rocks of the upper plate. The base of the fault is generally concordant with layering in the Pelona Schist.

Unlike the relative homogeneity of the Pelona Schist in the lower plate, rocks in the upper plate include a very wide variety of lithologies and ages (photo 38). Included are orthogneiss, paragneiss, mylonite, schist, and plutonic rocks that range in age from Proterozoic to Cretaceous. Many of the rocks have undergone repeated deformations.

Directly above the Vincent Thrust, a zone of pervasively, but variably mylonitized rocks, thought to be the result of movement along the thrust, ranges from a few meters to 600 m in thickness. The distribution of the mylonitized rocks, and the interpretation that they are associated with movement on the Vincent Thrust was first presented by Ehlig (1958). The variable thickness of the mylonite is probably due to post mylonization tectonic thinning, which may be the result of diapiric-like uplift of the Pelona Schist deforming rocks of the upper plate, or due to parts of the mylonitic rocks being cut out by the fault.

Above the mylonite is a mixture of gneissic-textured pre-Mesozoic metasedimentary and metaigneous rocks and Mesozoic granitic rocks that include elements of the Triassic Mount Lowe Intrusive Suite (Barth and Ehlig, 1988) and Cretaceous tonalite.

LANDSLIDES

The Quaternary sedimentary history associated with the San Gabriel Mountains assemblage is largely recorded in the area surrounding the assemblage, and not within the area encompassed by the assemblage itself. Uplift and dissection of the eastern San Gabriel Mountains is reflected in the complex array of alluvial deposits emanating from the range. Within the mountains, Quaternary deposits are largely restricted to alluvial valley, small alluvial-fan, alluvial wash, and landslide deposits, the latter being very common.

Volumetrically, numerically, and for societal reasons, landsliding is an important geomorphic process that has been and continues to be active in much of the upland parts of this area. Landslide deposits are particularly widespread and abundant in parts of the San Gabriel and San Bernardino mountains, the San Timoteo Badlands (photo 39), Puente Hills, and in the sedimentary rocks on the west side of the Santa Ana Mountains. The largest landslides are within the San Gabriel Mountains (Morton and Sadler, 1989a; Morton and others, 1989; Morton and Streitz, 1969) (photos 302 and 583). Tens of thousands of landslides are too small to be included on the accompanying geologic map; many of these smaller landslides are shown on individual 7.5' quadrangle maps published by the California Geological Survey and the U.S. Geological Survey.

The combination of steep, rugged topography, highly fractured rock, and susceptible lithologies are the underlying causes of the numerous, widespread, and in many cases, large landslides in the San Gabriel Mountains (Morton and Streitz, 1969). Most of the larger landslides appear to be rock avalanche deposits, and based on their dissected nature, many appear to be Pleistocene. In the eastern San Gabriel Mountains rock avalanche deposits appear to be localized in terrains of older plutonic rocks, gneiss, and mylonitic gneiss and are exclusive of the Pelona Schist (Morton and others, 1989).

The Crystal Lake (fig.1) landslide in the upper reaches of the San Gabriel River drainage is nearly three miles long and a mile wide(photos 302 and 303) and is the largest landslide in the range (Morton and Sadler, 1989a). Its size and canyon-modifying topography caused Miller (1926a) to misinterpret it as a glacial deposit. Adjacent to the Crystal Lake landslide, the Alpine Canyon landslide is of similar length and half the width. Both landslides are well dissected, cut by moderate sized canyons, and probably occurred in early Quaternary.

In the eastern San Gabriel Mountains are a number of large avalanche deposits. Originating from the area between Mount San Antonio and Harwood Peak (fig. 1), a large avalanche descended into San Antonio Canyon, where part of the deposit formed Manker Flats. Significant scarps occur as side-hill trenches near the source of this landslide near Mount Harwood (photo 306).

Landslides appear to be responsible for alterations of major drainage patterns in the San Gabriel Mountains. For example the headward part of San Antonio Canyon, more than 9 km from its mouth, probably was once the headward part of Cow Canyon (fig. 1). The distal part of a landslide (photo 603) originating high on the east side of San Antonio Canyon near the crest of Ontario Ridge, filled a reach of paleo-Cow Canyon, forming the low divide between Cow Canyon and present day San Antonio Canyon. Headward erosion of lower San Antonio Canyon after the Cow Canyon slide, captured the drainage that formerly flowed west down Cow Canyon (Morton and others, 1989).

Originating near Telegraph Peak (fig. 1), another large avalanche traveled north descending into the North Fork, Lytle Creek. North of Circle Mountain (fig. 1) in Cajon Valley is scattered remains of a dissected avalanche that was deposited on rocks of Cajon Valley. A large foliation-plane failure, mostly lacking characteristic landslide morphology is located just to the west of Blue Cut.

Among the large number of units in the two quadrangles, the Pelona Schist (Kpu) is particularly landslide prone. In contrast to rock avalanches, slow-moving landslides are abundant in areas underlain by the Pelona Schist. Many of these landslides are foliation-plane failures that commonly lack classic landslide topography (Morton and Sadler, 1989). Sackungen and sackungen-like features are common, resulting in numerous side-hill and ridge-top trenches (photo 309). Within the Pelona Schist on the south side of Lone Pine Canyon, Telegraph Peak 7.5' quadrangle (fig. 1) nearly every ridge has failed by slow moving landsliding (photos 310 and 589). This landsliding gives rise to ridges that terminate with a characteristic bulbous snout. Ridge-top trenches are commonly formed by spreading on both sides of a ridge; this geomorphic feature is common elsewhere in the Pelona Schist and is less common in other basement rock units (e.g. McCalpin, 2000).

Several large rotational landslides fill or had filled the headward part of Slover Canyon, Sheep Creek, and Heath Canyons in the Wrightwood area, Telegraph Peak 7.5' quadrangle (fig. 1) (photos 40 and 41). Mobilized debris from these landslides has formed large debris flow fans (photos 42, 43, and 44). Spring melting of snow on slowly moving landslides is apparently the major cause of these debris flows. Best known of these debris flows occurs at and around the community of Wrightwood in Swarthout Valley (Gleason and Amidon, 1941; Sharp and Nobles, 1953; Morton and Campbell, 1974; Morton and Kennedy, 1979), which is built on a debris flow-dominated fan (photo 45). Originating on Wright Mountain these debris flows are deposited on Sheep Creek fan. Other extensive debris flow deposits are located on the east side of Dawson Peak and Pine Mountain (fig 1).

Landslides are common in the San Bernardino Mountains, but are not as numerous as they are in the San Gabriel Mountains. At the western edge of the San Bernardino Mountains, Cajon 7.5' quadrangle, an avalanche descended west from Cajon Mountain crossing the San Andreas Fault so that the distal parts rested on Pelona Schist (photo 46). Slip on the San Andreas Fault has offset the distal part of the avalanche deposit. Numerous landslides are located on the steep south front of the mountains north of San Bernardino. Several moderate sized landslide areas occur locally along the steep south margin of the range in the upper reaches of Bear Canyon, on the east side of City Creek, and in canyons between Silverwood Lake and Lake Arrowhead. Movement in the active Running Springs landslide (Reeder, 1989) at the head of Fredalba Canyon, Harrison Mountain 7.5' quadrangle, has produced a readily visible scar in granitic rock. The Mill Creek Formation of Gibson (1971) (Tm units) in the lower part of Mill Creek has produced numerous large landslides (Matti, and others, 2003b).

Small rotational landslides are common throughout the San Timoteo Badlands (fig 1). Several large landslide deposits, some consisting of granitic debris resting on badlands sedimentary rocks, occur on the east side of the San Jacinto Fault near the north end of the badlands, Sunnymead quadrangle 7.5' quadrangle (Morton and Matti, 2001). A large bedding plane failure, the Live Oak Canyon landslide, having a width of about three km is located on the south side of Live Oak Canyon (fig 1) (photo 47) near the Riverside-San Bernardino County line (Morton and Sadler, 1989a). This landslide, now breached, formed a dam blocking Live Oak Canyon, and caused considerable ponding of sediment (photo 48) up-stream from the landslide.

Landslides are abundant in the Puente Formation (Tp units) throughout much of the Puente Hills (Tan, 1988; Tan and others, 1984). Most of these landslides are small to moderate sized rotational failures in bedrock. Shelton (1966) shows pictures of a particularly interesting, thin, rumpled landslide. Landslides are more abundant in the eastern part of the Puente Hills than elswhere, especially in the Yorba and Sycamore Members of the Puente Formation.

There are numerous landslides (e.g., Morton and Miller, 1981; Morton and others, 1979) in the Tertiary sedimentary rocks in southern Orange County. The Monterey, Sespe, Vaqueros, and Capistrano Formations are particularly landslide prone. Extensive structural damage has resulted from bedrock landslides in surburbanized areas. Renewed movement in apparently old landslides has been disasterous in the Bluebird Canyon area of Laguna Beach. Following high-rainfall winters a landslide occurred on October 2, 1978 (photo 577) and another on June 1, 2005 (photos 49 and 50) completely destroying many hillside homes.

Structurally deformed rocks adjacent to the Elsinore Fault Zone on the east side of the Santa Ana Mountains are particularly landslide prone (Gray, 1961). A relatively large number of rotational landslides occur in the Bedford Canyon Formation. Along the east side of the mountains north of Bedford Canyon, the remnants of a dissected landslide deposit consisting of Santiago Peak Volcanics rests on Paleocene and Miocene sedimentary rocks (Gray, 1961). At the north end of the Santa Ana Mountains another large landslide, composed of Santiago Peak Volcanics descended from the mountains into Santa Ana River canyon forming a dam across the river. Now dissected, the distal part of this landslide rests on Sespe and Vaqueros Formation on the south side of Scully Hill (Gray, 1961). In the San Joaquin Hills area Tertiary sedimentary units are in general landslide prone, particularly the Monterey Formation.

El Niño landslides

Thousands to tens of thousands of small landslides occur in southern California during exceptionally wet winters, and especially under El Niño conditions (Campbell, 1975; Rice and Foggin, 1971). These small landslides, termed soil slips (photos 51, 52, 53, ~~and 54),~~ develop during periods of heavy rainfall after a critical level of antecedent rainfall is met, so that the water content of the regolith exceeds the field capacity of the soil (Campbell, 1975). Most of these soil slips disintegrate into debris flows that travel various distances down slope. Where debris flows paths intersect man-made structures, considerable damage can result as well as loss of life (Campbell, 1975). Development of soil slips depends on a combination of rainfall conditions, soil slip prone geologic units, slope, and aspect (Hauser, 2000; Koukladas, 1999). In soil slip-prone units, extensive areas can be denuded by this process. For example, the upper and middle members of the San Timoteo Beds (Qstu and Tstm) are particularly debris flow prone (photos 51 and 53), and in the Puente Hills the Sycamore Member of the Puente Formation(Tpsc). The

Trabuco Formation (Ktr) along the west side of the Santa Ana Mountains is soil slip prone as is the Topanga Group units (Tt) in the San Joaquin Hills area. During extremely intense rainfall winters, such as 1969, devastating soil slip-debris flows can occur in basement rock units in the San Gabriel and Santa Ana Mountains (Campbell, 1975). Soil slip susceptibility maps for the area are given by Morton and others (2003). For a period of time, months to a year or more, after an El Niño winter bedrock landslides occur apparently as a result of the wet winter (photo 55).

Fire-Flood sequence

Devastating debris flows occur if summer and fall wildfires are followed by substantial winter rainfall. The sequential events of wildfire followed by heavy rainfall is commonly referred to as a fire-flood sequence. This temporal and spatial relationship appears to have been first published by Coleman (1953), who described the sequence of events that occurred during the 1933-34 rainfall season in the La Crescenta area at the base of the western San Gabriel Mountains.

Wildfires in southern California commonly result in the development of water repellant (hydrophobic) surface soils (DeBano, 1981; DeBano and others, 1998). The development of the water repellant surface soils results in subsequent rain running off slopes rather than seeping in (photo 56). Slopes on which water repellant soils have formed, generate few soil slips (e.g., Morton, 1989). The collective runoff transports large quantities of debris as hyperconcentrated flood flows and/or debris flows down channels and onto alluvial fans (photos 57, 58, 59, 60, ~~61,~~ and ~~62~~). Typically debris flows generated develop by fluidizing material in the channel bottom (photo 54), and not by soil slips on the hillsides. These hyperconcentrated and debris flows in many places have caused loss of lives and have been devastating to man-made structures. A recent example occurred when two large autumn 2003 wildfires in the eastern San Gabriel and western San Bernardino Mountains were followed by a moderate storm, about a ten-year-rainfall-storm, on Christmas day, 2003. Runoff from the storm generated widespread debris flows and hyperconcentrated flows which resulted in extensive damage to structures near the mountain front and the loss of 16 lives.

SUBSIDENCE FISSURES

Within the San Bernardino and Santa Ana quadrangles, subsidence fissures are relatively common in some fault bounded basins, forming in response to withdrawal of groundwater (photos 35, 63, 64, 65, and 36). They are most numerous in the San Jacinto Valley, but are also present in the Chino basin, southwestern San Bernardino basin, and at Dunlap Acres on the south side of the Crafton Hills (Burnham, 1952). A fissure reported by Engel (1959) and purportedly attributed by local residents to the time of the 1918 San Jacinto earthquake appears more likely to be a subsidence related fissure.

Only the fissures in the San Jacinto Valley are showed on the geologic map. Most of these are located within the San Jacinto pull-apart basin, which formed between the Casa Loma and Claremont strands of the San Jacinto Fault Zone. These fissures started to develop locally about 1950 and through time have spread over a considerable area (Morton, 1977). Formation of the fissures appears to be related to subsidence resulting from groundwater withdrawal principally in the area where formerly only artesian water was used (Waring, 1919).

Both tectonic subsidence and groundwater withdrawal subsidence occurs in the pullapart basin, but the current rate of groundwater subsidence far exceeds the rate of tectonic subsidence (Fett and others, 1967; Lofgren, 1976; Lofgren and Meyer, 1975; Morton, 1977; Proctor, 1962). Rate of tectonic subsidence is estimated to be 0.3 to 0.6 cm/yr while the estimate of subsidence due to groundwater withdrawal is 3.5 to 4.0 cm/yr (e.g., Morton, 1977). Some fissures have occurred in the fine-grained alluvium on the northeast side of the Lakeview Mountains, Lakeview 7.5' quadrangle (fig. 1) and along the course of the San Jacinto River west of the pull-apart basin. The westernmost of the fissures, near the site of the former Bernasconi Hot Springs (also called Lakeview Hot Springs) (fig. 1) trenched to a depth of about 20 m revealed a cone-shaped (in cross-section), complex structure similar to liquefaction structures (photo 66; compare with photo 67 and 3).

On the northeast side of the San Jacinto Valley, adjacent to the San Timoteo Badlands, El Casco and Lakeview 7.5' quadrangles, on gently slopeing surfaces subsidence in the valley produces very slow moving, lateral-spread-like landslides. These lateral-spread-like landslides have been observed to move over a period of several years and produced an one meter high scarp (photos 68 and 69). No toe has been observed in these landslides; the strain appears to be largely intergranular. Extension in the landslide body commonly forms sink-hole-like subsidence fissures and irregular shaped depressions (photos 70 and 71).

Parts of the San Jacinto Valley contain relatively low density sediments that are subject to hydroconsolidation and subsidence. Where hydroconsolidation occurs at a point source in relatively brittle material, circular fissures occur (photo 72). In unconsidated material a gentle cone of subsidence occurs.

GEOLOGIC SUMMARY

Peninsular Ranges assemblage

Rocks of the Peninsular Ranges assemblage range in age from Quaternary to Paleozoic; the assemblage contains no documented Precambrian rocks. Most of the Peninsular Ranges assemblage is represented by the Jurassic and Cretaceous Peninsular Ranges Batholith and the pre-batholithic metasedimentary and metavolcanic rocks into which the batholith was emplaced (e.g., Jahns, 1954a). In the Santa Ana and San Bernardino quadrangles, all granitic rocks of the batholith are Cretaceous; all Jurassic granitic rocks identified as being part of the batholith are found south of the Santa Ana quadrangle. Thick sequences of Late Cretaceous to Tertiary post-batholithic sedimentary and volcanic rocks flank the batholith on its western side.

Physiographically, onshore rocks of the Peninsular Ranges assemblage are divided into three major, fault-bounded blocks which, from west to east are, the Santa Ana Mountains block, the Perris block, and the San Jacinto Mountains block (figs. 1 and 3). The latter block is represented only by limited granitic and metamorphic rocks and the thick section of Miocene through Pleistocene nonmarine sedimentary rocks east of the San Jacinto Fault. Only the southern part of this block, which is located between the San Jacinto and San Andreas Fault Zones, is floored by the Peninsular Ranges assemblage; the northern part, including the Crafton Hills, is floored by the San Gabriel Mountains assemblage (fig. 1).

Cenozoic sedimentary rocks ranging in age from Holocene through Paleocene underlie most of the western part of the Santa Ana block; these rocks extend north of the block to include the low Puente Hills. East of, and underlying these Tertiary and Quaternary rocks in the Santa Ana Mountains, is a thick section of primarily Late Cretaceous marine rocks and Paleogene marine and nonmarine rocks that rest unconformably on Mesozoic basement consisting of metasedimentary and Cretaceous volcanic and batholithic rocks. The basement and Late Cretaceous and Paleogene rocks now constitute part of a highly faulted anticlinal structure. In the southern part of the Santa Ana Mountains the anticline passes into an extensive, nearly horizontal surface that was deeply weathered during the Paleocene and is partly covered by Miocene basalt flows.

East of the Santa Ana Mountains block and west of the San Jacinto Fault Zone, the Perris block (fig. 3), forms a roughly rectangular area of relatively low relief that has remained relatively stable and undeformed during the Neogene. The Perris block is underlain by lithologically diverse prebatholithic metasedimentary rocks intruded by plutons of the Peninsular Ranges batholith. Supra-batholithic volcanic rocks are preserved in the western part of the block. Several erosional and depositional surfaces are developed on the Perris block (e.g., Dudley, 1936; Woodford and others, 1971) and thin to relatively thick sections of nonmarine, mainly Quaternary, sediments discontinuously cover the basement.

In the Elephant Hill area (fig. 1) west of Pomona, deeply weathered tonalite (Keh) is poorly exposed in a few road cuts. It is lithologically similar to Peninsular Ranges batholithic rocks and contrasts with tonalite (Kgp) three kilometers to the north at Ganesha Park, which has affinities (e.g., initial Sr ratio) to San Gabriel Mountains granitic rocks. These two localities provide the limited surface control for placement of the boundary between the Peninsular Ranges and San Gabriel Mountains assemblages west of San Antonio Canyon.

Paleozoic Metamorphic Rocks

Metamorphic rocks that include thick sections of marble (₽zmp) (photo 73) in the Riverside-Colton area are considered to be of Paleozoic age based on general lithologic affinities with dated Paleozoic rocks further to the south in the Peninsular Ranges. Based on lithology, marble bearing units in the Mount Eden area (fig. 1) and on the east side of the Lakeview Mountains are also interpreted as being Paleozoic (photo 74). Ordovician conodonts have been recovered from somewhat similar carbonate rocks in the Coyote Mountains in western Imperial County (Dockum, 1982; Miller and Dockum, 1983). All of these metamorphic rock sections do not appear to be derived from familiar Paleozoic sections in the Great Basin, partly because they are southwest of the San Andreas Fault. Where marble is sparse or missing in metamorphic sections of the Peninsular Ranges, the protolith could also be Mesozoic. Metamorphism related to batholithic emplacement and pre- and syn-metamorphic deformation preclude direct unit-by-unit stratigraphic correlation with any known sedimentary sequences.

Paleozoic metasedimentary rocks in the Jurupa Mountains and at Slover Hill (fig. 1) include biotite schist(Pzsg) and gneiss (Pzspg), impure quartzite (Pzq), and lesser marble lenses(Pzmp) (photo 75); relatively thick sections of marble in the eastern part of the Jurupa Mountains and at Slover Hill have been utilized in the manufacture of Portland cement (e.g., Crestmore (photo 563), Jensen (photo 564), and Slover Hill (photo 75) quarries). Slover Hill Quarry, east of Crestmore, is purported to be the oldest continuous mining operation in California.

Schist and gneiss in these sequences, typically composed of biotite, quartz, and feldspars, are well foliated and occur both as screens and as isolated bodies surrounded by Cretaceous granitic rocks (photo 76). Two thick marble layers separated by a section of schist occur at both Slover Hill and Crestmore quarries, suggesting they may be the same sequence of rocks. At the New City Quarry there are two marble layers, but unlike at Slover Hill and Crestmore, a section of metaquartzite and pyroxenite separate the marble layers. In Riverside, marble was quarried for industrial purposes at the Old City Quarry, the New City Quarry (also known as the Victoria Ave. Quarry) (fig. 1), and at the southward extension of the marble at the New City Quarry.

Massive, coarse-grained to extremely coarse-grained calcite, calcite-dolomite, and predazzite marble is found at a number of localities (photos 77, 78, 79, and 80). The marble ranges from pure calcite marble to marble containing relatively large quantities of calc-silicate minerals (photos 81, 82, 83, and 585). Generally the carbonate rocks are transformed partly to skarn where they are in contact with granitic rocks. Commonly, Cretaceous granitic rocks are very finely intermixed with the marble and skarn over fairly wide zones. Upper pyroxene hornfels facies mineral assemblages are present at some localities (e.g., Crestmore), but lower grade pyroxene hornfels facies assemblages and hornblende hornfels facies assemblages are more common.

Many of the marble deposits are best known for the occurrence of a large number of minerals including a variety of unusual minerals (photo 585). The most famous mineral locality is the Crestmore Quarries located at the east end of the Jurupa Mountains (fig.1). Nearly 150 mineral species have been found at the Crestmore Quarries (Murdoch and Webb, 1966) including many that had not been previously described . The geology of the Crestmore Quarries was given in great detail by Burham (1959). Burnham determined metasomatism associated with the emplacement of a quartz monzonite magma having relatively high water content was responsible for the formation of a number of high temperature calcium silicate minerals as well as more common skarn minerals. He also determined the contact zone around the quartz monzonite consisted of an inner zone of garnet-wollastonite-diopside skarn, an intermediate zone characterized by idocrase, and an outer zone characterized by monticellite. The outer zone contains the high temperature phases such as spurrite, gehlenite, scawtite, merwinite, and tilleyite. Beyond the monticellite zone the marble has a distinctive blue color (photo 585). Early work on the unusual minerals at Crestmore was by Eakle in 1914 and 1917. The mineralogic setting of the Crestmore Quarries is given by Woodford and others (1941, 1943), Murdoch (1961), and Devito and others, 1971) (see Murdoch and Webb, 1966, for additional references to Crestmore minerals). The mineralogy of the Henshaw and Jensen quarries, also located in the Jurupa Mountains, was studied by Cooney (1955).

Contact metamorphism at other marble occurrences in the northern part of the Peninsular Ranges assemblage was formed by the interaction of tonalite magma with marble. Metamorphic rocks at Slover Hill have been penetratively deformed by slip folding giving rise to uniform northeast oriented folds and lineations. Nodular, fine-grained silicous rock thought to be metachert occurs as small masses and contains wollastonite in outer parts of the metachert. At Slover Hill relatively thin skarn zones, generally not over 30 cm thick, occur at contacts between tonalite and marble. At these contacts, contaminated tonalite is about one meter thick and is characterized by the presence of pyroxene rather than hornblende, larger amounts of potassium feldspar and noticeable allanite. The pyroxene is commonly altered to nontronite(?). Skarn in the contact zone includes diopsidic pyroxene with or without grossularitic garnet, wollastonite, scapolite, and apatite. In some places skarn is zoned with a pyroxene layer adjacent to the tonalite, an intermediate zone of grossularite and diopsidic pyroxene, and an inner zone of wollastonite. Small amounts of pyrrhotite occur within the pyroxene layer. Marble is in part dolomitic and locally contains brucite, apparently after periclase. Minor graphite flakes occur principally in thin layers. The marble includes some small quantities of pyrrhotite and phlogopite, and apatite occurs as scattered small green crystals.

Two marble layers, now largely removed by quarrying, occur at the Old City Quarry, and separated by a relatively thin biotite schist layer and tonalite. Small blue apatite crystals occur in some of the marble and locally idocrase, grossularite, and chrondrodite and (or) clinohumite is a common varietal mineral. Slip-folded interlayered wollastonite, diopsidic pyroxene quartzite, and quartzite (Pzq) occurs locally (photo 86). Thin, heterogeneous skarn zones are extensive at the Old City Quarry, mainly consisting of garnet-pyroxene bearing skarn (photos 84 and 85). These thin skarns are compositionally zoned with the outer part of the tonalite containing large amounts of scapolite. The outer part of the marble has been converted to grossularitic garnet. Separating the garnet from the marble is a zone of wollastonite (photo 87). The borate, vonsenite, part of the ludwigite-paigeite series, was first described from this quarry. Slip-folded wollastonite-quartz rock (photos 86, 88, and 89) and mylonitic marble occur locally (photos 90 and 91). Also local are small masses of axinite-sphene-epidote rock. Nontronite, a decomposition product of pyroxene, from this quarry was used as an analog for Martian surface material analyzed by the first Martian lander.

At the New City Quarry, two relatively uniform marble layers are separated by layered pyroxene-quartzite rock and tonalite. The marble consists of alternating layers of calcite marble and predazzite (photos 77, 78, 79, and 80). Chrondrodite is a sparse mineral in the marble and pervoskite is extremely rare. Graphite is common as dispersed flakes. Most of the periclase has altered to brucite, but locally brucite has a core of periclase. Only the thicker marble layer was quarried exposing a skarn zone on the west side of the marble. The skarn ranges in composition from scapolite-pyroxene-sphene skarn to magnetite-borate skarn with relatively little garnet-pyroxene skarn. Within the magnetite-borate skarn, iron-rich opaque paigeite occurs on the side nearest the tonalite. Iron content is lower in the borosilicate skarn, grading from massive paigeite to small needles of pleochroic green-brown ludwigite in marble (photos 92 and 93). The rare borosilicate serendibite occurs very locally in the skarn. Serendibite is relatively common in a small quarry just south of the New City Quarry. There, vugs in serendibite skarn are lined with subhedral serendibite and dark blue spinel (photos 94 and 95). Within the larger marble layer at the New City Quarry, is a large elliptical-in-plan-view mass of dark brown idocrase skarn composed mostly of idrocrase and a small amount of garnet that resembles the idocrase. Small vugs are lined by subhedral idocrase crystals and some thin needle-like white apatite crystals. The pyroxene-quartz rock layer between the marble layers consists of alternating pyroxenite, largely diopside, and quartz layers. The pyroxenite layers are extensively boundinaged; the distance between the boudins indicates the rock is highly strained (photos 81 and 83). In these rocks, the pyroxenite layers extended brittlely and the quartz layers deformed ductically.

Mesozoic Metamorphic rocks

Rocks of Mesozoic age include Cretaceous to Triassic metasedimentary and metavolcanic rocks that range from high to low in metamorphic grade.

Triassic

Rocks of Menifee Valley

Prebatholithic rocks in the northern Perris block were termed the Elsinore metamorphics by Dudley (1935). Larsen (1948) extended the name Bedford Canyon Formation south and east from the Santa Ana Mountains onto the Perris block for rocks in the vicinity of Domenigoni and Auld valleys (fig.1), but noted differences in the lithology of the rocks of the Perris block at many places from those of the Santa Ana Mountains. East of Domenigoni Valley he termed the metamorphic rocks Paleozoic schists and quartzites. Larsen's (1948) age assignment was based upon a report of a Mississippian coral (Webb, 1939) from the dump of the Hemet Magnesite mine located in the central part of Searl ridge, (informal local name for the ridge located between Diamond Valley and San Jacinto Valley, fig.1, Winchester 7.5' quadrangle). Larsen characterized the coral as being from schist…"which contain limestone beds from which Webb (1939) has described Mississippian fossils." Schwarcz (1969) later showed that the single coral specimen cited by Webb, which was found as float by a mineral collector, could not have originated where it was reportedly found.

In 1966 M.A. Murphy (University of California at Riverside) collected poorly preserved and deformed fossils from a calc-silicate rock outcrop east of Sun City, in the Romoland 7.5' quadrangle. Included in the collection were large crinoid stems and pelycepods. Murphy sent a latex impression of a pelycepod to E.C. Allison, who in turn sent the impression to G.E.G. Westermann for identification. Westermann (written commun. to E.C. Allison dated 10/16/68) stated,…"This is a poorly preserved, obviously distorted specimen which cannot be identified at the generic or specific level. I dare only the following: Right valve of the Bivalvia family Aviculepectinidae; possible ?? *Claraia* ex. gr. *C. himaica*

(Bittner) and *C.*(?) *occidentalis* (Whiteaves) which would be late Lower Triassic. However, almost any age within the Triassic or even Permian is possible." Based on the single fossil occurrence of Murphy we tentatively consider the metasedimentary rocks in the Menifee Valley, French Valley, Domenigoni valleys, and Diamond Valley area to be of Triassic age.

For the Winchester area Schwarcz (1969) retained Larsen's usage of the Bedford Canyon Formation, but noted the lithologic differences between the unit there and in the Santa Ana Mountains. Schwarcz (1969) renamed the Paleozoic schists and quartzites of Larsen (1948) the French Valley Formation after exposures in the area of French Valley (fig.1). Schwarcz considered the French Valley Formation to be of Mesozoic age stating: "The French valley Formation interfingers with the Bedford Canyon Formation at their contact" (Schwarcz, 1969). Based on mapping in the Winchester area (fig.1), Morton found this interfingering is probably structural (slip folding) rather than stratigraphic. Schwarcz described within his French Valley Formation a remarkable metamorphic gradient increasing from low grade (sub andalusite) to high amphibolite grade over a distance of about three kilometers. He interpreted the metamorphic facies to be a low pressure, high temperature Buchan type.

Based on later mapping in the Winchester area (fig.1), Morton divided the French Valley Formation of Schwarcz into a western, low-metamorphic-grade, Mesozoic assenblage and an eastern high-metamorphic-grade assemblage of possible Paleozoic age. The questionable Paleozoic age by was based chiefly on metamorphism, as there is no recognizable lithologic break in the metamorphic rocks east of the French Valley area that would distinguish Mesozoic rocks from Paleozoic(?) rocks. Morton's western Mesozoic assemblage includes Larsen's Bedford Canyon Formation, and the eastern package, based only on subtle lithologic differences, was considered probably to be correlative with Paleozoic rocks to the south and east in the Peninsular Ranges.

Subsequent U-Pb isotopic age dating on zircons within the eastern package, however, found inherited Mesozoic zircons indicating the rocks labeled Paleozoic(?) by Morton are of Mesozoic age (Premo and others, 2002). In light of the U-Pb dating, Morton now interprets the western assemblage of low metamorphic-grade rocks to have been structurally juxtaposed with the eastern assemblage of high metamorphic-grade along a major suture. At the time of suturing the rock assemblage east of the suture was at an elevated temperature (upper amphibolite facies) and the rock assemblage to the west was at a much lower temperature (low- to sub-greenschist grade). Suturing resulted in structural readjustments on both sides of the suture. The thermal effects of the juxtaposition of the high termperature and the relatively cool rocks produced the metamorphic gradient described by Schwarcz (1969).

The suture zone varies in thickness and includes a mixture of rocks derived from both sides of the suture as well as metaserpentinite and associated rocks. Rocks from the western assemblage found in the suture zone include sillimanite-biotite schist, lithic greywacke, and impure quartzite; one large mass of lithic greywacke, now submerged beneath Diamond Valley Reservoir, appears to be a mega boudin. Rocks from the eastern assemblage found in the suture zone include gneiss and anatectic granitic gneiss.

The metaserpentinite (TRmds) and associated rocks (TRmdx and TRmdc) are unique to the suture zone and are not present in either the western or eastern assemblage. The ultramafic and related rocks are most abundant on Searl ridge, (fig. 1), where the least altered metadunite (metaserpentinite) is composed of olivine-talc rock (photo 96), in which some talc crystals are more than five centimeters in diameter. Several bodies of metadunite are thoroughly altered to a mixture consisting largely of clay minerals containing numerous veinlets of magnesite (photos 97 and 98). At and near the outer margins of most of the metadunite is a layer consisting of essentially enstatite (photo 99), and in some places an outer thin layer (few centimeters) of spinel-rich rock.

In the metasedimentary rocks (TRmu) surrounding metadunite, a selvage 0.5 to 6 meters thick of massive rock contains a large proportion of two- to five centimeter-long poikiloblastic cordierite in sillimanite-biotite rock (photo 99). Cordierite was apparently formed from magnesium derived from the metadunite during metamorphism. Coarse-grained impure marble adjacent to metadunite on Searl ridge (photo 100), consists of calcite and variable amounts of forsterite, pyroxene, amphibole, chromium spinel, and opaque minerals. Some silicate minerals are concentrated in layers. This marble appears to be a metamorphosed silica-carbonate rock associated with serpentinite. Granitic pegmatite dikes intruding metadunite have outer parts containing andalusite, sillimanite, dumortierite, and cordierite. Metadunite adjacent to pegmatite was altered to an inner layer of biotite, now largely hydrobiotite and vermiculite; and an outer layer of chlorite and amphibole. Spatially associated with the metaserpentinite on Searl Ridge and on the eastern part of Double Butte and east of Rawson Valley is a wide variety of amphibole and pyroxene bearing rocks. These rocks range from white to green to black amphibolite and pyroxenite and pink anthophylite bearing rock.

Two periods of metamorphism and attendant deformation can be identified in the metasedimentary rocks within the Perris block. An early regional period of metamorphism predates 120 Ma. This age is based on the age of plutons emplaced into phyllite (Ŧmp) having the mineralogy and fabric of the phyllite in the western part of the Perris Block. Thermal metamorphism of rocks in the eastern part of the area occurred about 100 Ma based on the age of metamorphic zircons from rocks within and to the east of the suture in the Winchester area (Premo and others, 2002). The age of this metamorphism is contemporaneous with plutonism to the east.

On the Perris block most bedding in metasedimentary rocks has been transposed into mechanical layering, S_1. A few occurrences of original sedimentary bedding (S_0) are preserved in these rocks in the western part of the block. In the vicinity of Railroad Canyon Reservoir (fig. 1), essentially all bedding in the rocks of Menifee Valley is structurally transposed (photo 101) into a 1^{st} generation mechanical layering, $S_{1,}$ (pre 120 Ma) (photo 102). The suturing of the high-metamorphic-grade rocks with the low-metamorphic-grade rocks resulted in structural readjustments on both sides of the suture. In the western part of the Domenigoni Valley area, the 1^{st} generation layering in these rocks has been folded, and progressively eastward, transposed into 2^{nd} generation mechanical layering, S_2 (photos 103 and 104). Further east toward the suture, the 2^{nd} generation layering is progressively transposed into a 3^{rd} generation layering (photo 105), S_3, which apparently was produced by deformation accompanying the suturing (photos 106, 107, and 108). Intersection of S_2 by S_3 commonly produces well lineated rocks (photo 109). In the area of the suture, only S_3 is present (photos 110 and 111). In places S_3(?) is in turn folded (photos 107 and 108). Based on the100 Ma age of metamorphic zircon in the rocks within the suture zone the suturing and development of S_2 and S_3 occurred at 100 Ma. East of the suture, S_3 transposes an older compositional gneissic layering. S_3 diminishes in intensity eastward, and only the older gneissic layering is present in rocks (Ŧmgn) at the eastern edge of the Santa Ana quadrangle (eastern Winchester 7.5' quadrangle) (photos 112 and 113).

Jurassic

Bedford Canyon Formation

Part of the Bedford Canyon Formation (Jbc) in the Santa Ana Mountains was early referred to by Smith (1898) who used the name "Santa Ana" for limestone within the very low metamorphic grade prebatholithic sedimentary rocks. Later he applied the name Santa Ana Slates, extending coverage to include the clastic rocks that make up the bulk of the section (Smith 1914); this name was retained by Engel (1959). Merrill (1914) referred to the metamorphic rocks in the Santa Ana Mountains as the Santa Ana metamorphic strata. Larsen (1948) introduced the name Bedford Canyon Formation for exposures of these rocks in Bedford Canyon in the northern Santa Ana Mountains and extended the name to metamorphic rocks on the Perris block to the east. In this report, we have followed the usage of Larsen (1948), but restrict the name to the rocks in the northern Santa Ana Mountains. The southern part of the Bedford Canyon Formation (Jbc$_1$) is mostly massive appearing quartz rich metasandstone and impure quartzite.

Fossils collected by W.C. Mendenhall (U.S. Geological Survey) from about 1905 to 1908, were studied by Willis (1912) who identified *Rhynchonella*, *Spiriferina*, *Terebratula*, and crinoid stems. Later, Smith (1914) described a new fossil from the Mendenhall collection, *Daonella sanctaeanae*, and on the basis of *Rhynchonella sp* assigned a Triassic age to the limestone from which it was collected. Subsequent fossil collections from the northern Santa Ana Mountains were identified as being Jurassic (Imlay, 1963; 1964; 1980; Silberling and others, 1961). An ammonite assemblage studied by Silberling and others (1961) included *Holcophylloceras*? sp. juv., *Partschiceras* cf. sp. *P. grantzi* Imlay, *Lyotoceras*? sp., *Hecticoceras* (*Sublunoloceras*?) sp., and *acrocephalites* sp. The Jurassic age (Callovian) they assigned was based on *Hecticoceras* (*Sublunoloceras*?) sp., and *H. acrocephalites* sp.

Brachiopods collected on a ridge southeast of Bedford Canyon (fig. 1) were sent by Silberling to D.V. Ager of the University of London. Apparently based on these specimens, Ager (1968; see also, Ager and others, 1972) established a new genus and species, *Anarhynchia gabbi* Ager. In later work, brachiopods identified as *Anarhynchia gabbi* Ager from a limestone body are interpreted to be from a cold-seep paleoenvironment (Sandy, and Campbell, 2003). Based on the main body and most current fossil evidence, we consider the type Bedford Canyon Formation and related (?) rocks in the northern Santa Ana Mountains to be of Jurassic age.

Original sedimentary features are preserved within most strata in the Bedford Canyon Formation in the northern Santa Ana Mountains (e.g., Gray, 1961; Schoellhamer and others, 1981). South and east from Bedford Canyon, original sedimentary beds, S_0, are progressively obliterated by structural transposition into mechanical layering, S_1. The transposed bedding, S_1, is interpreted as the western extent of the pervasive S_1 layering found mainly in the dominently Triassic metasedimetary rocks on the Perris block.

The Bedford Canyon Formation consists of a thick section of brown to black and gray, thoroughly fractured, complexly folded sequence of interbedded shale or mudstone (argillite) (photo 114), graywacke, conglomerate, impure quartzite, and minor, scattered limestone. Shale beds are dark gray to black and contain rare sponge spicules (Moran, 1973); locally, silty argillaceous beds are gray, possibly due to locallized bleaching. Most of the shale is highly fractured, forming poor exposures that consist mainly of elongate chips less than five centimeters in length; most fracturing appears to be across, and not parallel to bedding. Dark gray conglomerate layers are massive and contain subangular clasts of a wide variety (photos 115 and 116).

Massive graywacke, lithic graywacke, and arkosic arenites consist of subangular quartz, feldspar, and rock fragments. Quartz comprises a third to half of the graywacke and feldspar 10 to 15 percent. The lithic graywacke contains 12 to 20 percent lithic clasts. Matrix generally constitutes less than 10 percent. Some graywacke beds are crudely graded. Discontinuous beds of conglomerate consist of subangular pebbles and cobbles; most are matrix supported, some clast supported. Locally, some gray beds appear to be tuffaceous.

Impure quartzite in the unit consists of fine-to medium-grained, subrounded to subangular quartz and lesser amounts of feldspar. Gray to black, massive appearing, commonly fossiliferous limestone occurs as scattered small masses ranging from one meter to 60 m in thickness and a few meters to 100 m in length. The limestone includes mudstone, peloid wackestone, ribbon limestone, peloid packstone, sandstone, siltstone, shale, and contains scattered small pelecypods, ostracods, crinoids, bryozoans (?), and corals (Moran, 1973).

Thickness of most beds in the unit is on the order of a few centimeters, but locally beds up to about one meter thick are common (photo 117). In the area of Bedford Canyon, the unit is made up of well indurated sedimentary rocks having a variety of sedimentary structures such as ripple marks and cross-bedding. Typically, in this northern part of the unit, primary sedimentary structures are pristine and the rocks appear as a folded section of well preserved, well indurated sedimentary rocks. South and east from Bedford Canyon, primary sedimentary structures appear to be progressively obliterated by structural transposition. Bedding in many places is transposed by slip folding, and the extent of transposition ranges from slight to thorough. Flexural slip folds are common in the areas where bedding is intact (e.g., Gray, 1961; Schoellhamer and others, 1981). Except along roads and in scoured canyon bottoms exposures are generally nonexistent.

Moran (1973) interpreted detrital mineral suites in the Bedford Canyon Formation to have been derived from a variety of sources including silicic and mafic igneous rocks, both low and high rank metamorphic rocks, and reworked sedimentary rocks. He considered that the overall immature nature of the protolith to be a characterizing feature of the unit, and interpreted the shale graywacke assemblage to have formed from alternating turbidite sand and pelagic shale deposition proximally located to the continental margin (Moran, 1973). In the vicinity of Bedford Canyon, Moran measured a constant northwest paleocurrent direction in the sandstone beds. These current directions were based on flute and groove cast lineations and cross-laminations. He interpreted the limestone bodies to be allochthonous and deposited by submarine mass flows simultaneous with the deposition of the graywacke. Sandy and Campbell (2003) interpret the limestone to have formed in a cold-seep paleoenvironment.

The Bedford Canyon Formation is unconformably overlain by the Santiago Peak Volcanics (Kvsp).

Cretaceous

Volcanic and hypabyssal rocks

A large area of the Santa Ana Mountains and the western part of the adjacent Perris block are underlain by an assemblage of Cretaceous volcanic rocks and shallow intrusive rocks, which also include some volcaniclastic and sedimentary rocks. Collectively, the Santa Ana Mountain volcanic rocks were originally termed the Black Mountain volcanics by Hanna (1926), but the name was pre-empted, so Larsen (1948) renamed them the Santiago Peak Volcanics (Kvsp). The name was for exposures in the vicinity of Santiago Peak (fig. 1), northern Santa Ana Mountains (photo 118). The Santiago Peak Volcanics rest uncomformably on the Bedford Canyon Formation (Jbc) and related rocks, and range in composition from basaltic andesite to rhyolite. Zircon ages from these volcanic rocks range from 123 to 134 Ma, indicating they are coeval with older granitic rocks of the Peninsular Ranges Batholith (Anderson, 1991). Included in the Santiago Peak Volcanics in the Santa Ana block, is a small serpentine body and associated carbonate-silicate rock (Gray, 1961).

Overall, the Cretaceous volcanic rocks of the Perris block are more silicic than those of the Santa Ana Mountains block. They were named the Temescal dacite-porphyry by Dudley (1935), Temescal Wash dacite porphyry by Woodford and others (1946), and Temescal Wash quartz latite porphyry by Larsen (1948). Based on a more recent, detailed study, Herzig (1991) renamed the rocks the Estelle Mountain volcanics (Kvem) after their extensive distribution in the vicinity of Estelle Mountain, Lake Mathews 7.5' quadrangle (fig. 1). Included in the Estelle Mountain volcanics is a relatively homogeneous rhyolite (Kvr) (photos 119 and 120). The uranium-lead age of zircons from these volcanics just west of Lake Mathews, is 125.8 Ma (Anderson, 1991).

Interlayered volcanic and sedimentary rocks (Kvs) are found along the southwest and south sides of the Arroyo del Toro pluton (Katg), Lake Elsinore and Lake Mathews 7.5' quadrangles. There, although the volcanic rocks are part of the Estelle Mountain volcanics (Kvem), because of the large proportion of interbedded sedimentary rocks, the sequence is mapped as a separate unit (Kvs). The sedimentary rocks, in which primary bedding features are well preserved, consist of conglomerate (photos 121 and 122) and thinly bedded very fine grained sedimentary rocks (photo 123).

Descriptions of the Estelle Mountain and related volcanic rocks suggested they had been subject to low grade metamorphism. Herzig (1991), in a thorough examination of the Santiago Peak Volcanics linked mineral assemblages, previously considered to have resulted from regional low grade metamorphism, to hydrothermal activity associated with volcanism. Southward in San Diego County, sedimentary rocks interbedded with volcanic rocks that have been correlated with the Santiago Peak Volcanics in San Diego County, have yielded Late Jurassic fossils (Fife and others, 1967). The San Diego County Jurassic volcanic rocks may be the supra part of Jurassic batholithic rocks not found in the Santa Ana quadrangle, but alternatively and more likely, their correlation with the Cretaceous Santiago Peak Volcanics may be incorrect.

Peninsular Ranges Batholith

The Jurassic and Cretaceous Peninsular Ranges Batholith extends from approximately the San Gabriel Mountains southward for several hundred miles into Baja California (e.g., Larsen, 1948; Gastil and others, 1975; Silver and Chappel, 1988; Todd and others, 1988). Within the San Bernardino and Santa Ana quadrangles, all of the granitic rocks making up the batholith are apparenty Cretaceous, but south of the Santa Ana quadrangle in San Diego County, Jurassic granitic rocks have been described (Todd, and others, 1991; Girty, and others, 1993; Thomson and Girty, 1994; Shaw and others, 2003). Todd and others (2003) also discuss the relationship between the Jurassic and Cretaceous plutons in that area. The Jurassic granitic rocks described to date are intensely deformed gneissic granites and migmatites located in the central part of the batholith (Shaw and others, 2003).

Early descriptions of parts of the batholith in the San Bernardino and Santa Ana quadrangles include those by Dudley (1935), Osborn (1939), Miller (1946), and Engel (1959). The first major synthesis of the batholith was by Larsen (1948), who conducted field work discontinuously from 1906 to 1938. More recent investigations in the northern part of the batholith have largely centered on topical investigations (e.g., Baird and others, 1974 and 1979; Krummenacher and others, 1975; Taylor and Silver, 1978; Baird and Miesch, 1984; Gromet and Silver, 1987; Silver and Chappel, 1988; Premo and others, 1998), and on investigations of individual plutons (Morton, 1969; Morton and others, 1969; Morton and Baird, 1976; Miesch and Morton, 1977).

The northern part of the Peninsular Ranges Batholith has been subdivided into various longitudinal zones based on a variety of parameters including age, chemistry, isotopic variations, and magnetic and gravity properties (Baird and others, 1974 and 1979; Taylor and Silver, 1978; Baird and Miesch, 1984; Gromet and Silver, 1987; Silver and Chappel, 1988; Todd and others, 1988; Gastil and others, 1990). Taylor and Silver (1978) described a remarkable step in ^{18}O that extends for 600 km from well within Baja California to the northern part of the batholith. Gromet and Silver (1987) divided the batholith into three zones based on rare earth elements. In the northern part of the batholith Baird and Miesch (1984), using Q-mode factor analysis, developed a mixing model with four end members for major elemental chemistry. They interpreted the western part of the batholith being largely derived from oceanic crust and the eastern part largely derived from continental crust; the boundary being nearly coincident with the San Jacinto Fault. The boundary determined by Baird and Miesch (1984) is essentially coincident with the ^{18}O step of Taylor and Silver (1978). Based on a combination of chemistry and age, Silver and Chappel (1988) divided the batholith into five generally longitudinal zones. Three (?) of their zones occur within the Santa Ana and San Brenardino quadrangles. Todd and others (1988) summarized the various subdivisions of the batholith. Erskine (1982) while conducting paleomagnetic studies in the batholith noted the systematic variation in magnetic properties, which led to subdividing the batholith into a magnetically high western and a magnetically low eastern part (Gastil and others, 1990).

Based upon initial strontium and lithologic criteria, Morton and Kistler (1997) subdivided the northern part of the batholith into four major zones; three of their regional zones occur within the Santa Ana and San Bernardino quadrangles. Their western zone consists of high-level (shallow) plutons, which is flanked on the east by a central zone of relatively high-strain, moderate to deeply exposed plutons; an eastern zone consists of moderate depth, mostly very large, moderate strain plutons. Plutons within the western zone typically consist of massive textured rock containing equant shaped mafic inclusions. These plutons have sharp contacts with their wall rocks, and have sparse foliation and (or) layering or are devoid of foliation and (or) layering. Pressures of crystallization in western zone rocks range from 2 to 3 Kb (Smith and others, 1991), and emplacement ages range from 110 to 126 Ma (Premo and others, 1998). In contrast, central zone plutons have well-developed planar fabrics (foliation) contain discoidal to pancake-shaped mafic inclusions, and lack sharp contacts with wall rocks. Pressures of crystallization in central zone plutons range from 4.5 to 6.5 Kb (Smith and others, 1991) and emplacement ages range from 98 to 106 Ma (Premo and others, 1998). The eastern zone is represented only by a few exposures of tonalite in the San Timoteo Badlands, El Casco 7.5' quadrangle. In the eastern zone pressures of crystallization are about 4.5 Kb.

Emplacement ages of plutons generally decrease from west to east across the three zones (Premo and others, 1998). Isotopic ages cited in this report are from W.R Premo and L.W. Snee (Premo and others, 1998, and per. commun., 1999 and 2005), and include uranium-lead ages for a number of selected granitic rocks in the Santa Ana quadrangle (Premo and others, 1998). Uranium-lead ages followed by the subscript $_{id}$ are isotope dilution ages and $_{ip}$ are ion probe ages. Uranium-lead ages are interpreted as emplacement ages. Conventional and $^{40}Ar/^{39}Ar$ ages of hornblende, biotite, and potassium feldspar are interpreted as cooling ages.

An extensive strontium and rubidium isotopic database developed by R.W. Kistler (U.S. Geological Survey) clearly demonstrates that initial Sr values (Sri) increase from west to east reflecting a progressive increase in continental crust source for the granitic rocks. Granitic rocks in the western zone have Sri values of 0.7036 to 0.7045, indicating very low to moderate continental crust component (Morton and Kistler, 1997; Kistler and others, 2003). Rocks of the central zone of the batholith mostly have Sri values ranging from 0.7045 to 0.7055, indicating a larger continental crust component than in the more westerly rocks. In the eastern zone, plutons have yet higher Sri values, mostly between 0.7065 and 0.7080. Within the eastern zone, the distribution of Sri values is distinctly bimodal with Sri values of 0.7055 to 0.7065 at the division between the modes; this division appears to be coincident with the ^{18}O step of Taylor and Silver (1978). Variation in Sm values is in accord with the Sri ratios (De Paulo, 1981; Premo and others, 1998).

Pegmatites—Considerable attention has been given to the pegmatite areas or districts within the Peninsular Ranges Batholith. The best known districts are the gem-bearing pegmatites south of the map area at Pala (Jahns and Wright, 1951), Mesa Grande (Jahns, 1979), Rincon (Handley, 1951), and Ramona (Foord, and others, 1991); an overview of the gem-bearing pegmatites is given in Foord, and others (1991). Of the 14 pegmatite districts related to the batholith (e.g., Jahns and Wright, 1951), only one, the Lakeview district in the Lakeview Mountains (fig. 1), is located within the map area. Most of the pegmatites (Klmp) within the Lakeview Mountains pluton are tabular and consist of symmetrical border and wall zones of biotite, sodic plagioclase, potassium feldspar, and quartz. Larger dikes have an intermediate zone that includes schorl, garnet, muscovite, sodic plagioclase, potassium feldspar, and quartz. Where present a core zone consists of quartz and potassium feldspar (microcline). Graphic textures are common.

A few bulbous pegmatites occur and were mined for quartz and potassium feldspar. The best known of the Lakeview Mountains pluton is the Southern Pacific Silica Quarry pegmatite located in the northwestern part of the Lakeview Mountains pluton. This pegmatite has attracted mineralogists and mineral collectors for many years (photo 124). A map of the Southern Pacific Silica Quarry is given in Jahns (1954b). A second somewhat bulbous pegmatite is located in the central part of the pluton at a roll or flattening of the dip of the dike.

Bulbous pegmatites have zoning similar to that of the tabular pegmatites, but they have thicker intermediate and core zones. In addition, they are fracture-filling and replacement units. Crystal size is greater in the bulbous pegmatites than in the tabular pegmatites; they commonly have giant crystals of biotite, schorl, and microcline (perthite). Schorl, in some cases occurs as fractured and healed crystals up to one meter in length. Accessory minerals from pegmatites of the Lakeview Mountains pluton include magnetite, monazite, xenotime, zircon (cyrtolite), thorite (uranothorite), thorogummite, allanite, samarskite, yttrotantalite (photo 586) (manganoyttrocolumbite), laumontite, stilbite, epidote, bismuthinite, bismutite, pucherite, beyerite, ilmenite, columbite, beryl , pyrochlore, sphalerite, chalcocite, uranophane, and fergusonite.

Within the Paloma Valley ring complex, pegmatites (Kpvp) are mineralogically simple mixtures of biotite, quartz, potassium feldspar, and plagioclase; no unusual minerals have been found (photos 125 and 126).

Plutons—The Peninsular Ranges Batholith in the map area consists of nearly 90 discrete plutonic units. Relative ages for several of these units are incompletely understood, particularly where widely separated units have close to the same isotopic ages. The following descriptions of discrete and (or) recognizable batholith units are presented in order of their known or inferred age of emplacement—oldest to youngest. Plutons in the map area are grouped into three zones, a western, central, and an eastern zone. Generalized (generic) units are non-discrete-pluton-forming units, and many are time trangressive; all of these generalized units are here treated as undifferentiated or undivided units.

Plutons of the western zone—Plutons of the western zone were passively emplaced, and represent higher levels of the batholith. They have sharp contacts with country rock, contain equant-shaped inclusions, and consist mostly of isotropic textured rock; ring structures are common. Gabbro, mostly hornblende gabbro (photo 127) is widespread and commonly intruded by younger granitic rocks.

Paloma Valley ring complex—The Paloma Valley ring complex is a composite ring complex consisting of an older ring dike of granodiorite (Kpvg) (photo 128) cored and interleaved with gabbro (Kgb) into which it was emplaced, and a complex of numerous, pegmatitic, and texturally zoned pegmatitic-granitic (photos 125, 126 and 129) younger ring dikes (Kpvp) emplaced into the older dike rock and the gabbro (Morton and Baird, 1976). The older ring dike is steep-walled and elliptical-in-plan; it is an almost continuous single ring-dike, but is accompanied by several subsidiary short-arced dikes. The older ring dike is 14 km long and seven kilometers wide, and is composed mostly of massive granodiorite and monzogranite grading outward in the eastern part to tonalite. Planar fabric produced by oriented biotite is rare, but present. The dike was emplaced into gabbro by ring fracturing and magmatic stoping. Stoped masses of gabbro are common to abundant in much of the dike rock; locally the amounts of granodiorite dike rock and included gabbroic rock are nearly equal (photo 130). The largest stoped blocks of gabbro attain a length of up to three kilometers. Many of these large gabbro blocks are plate-like or elliptical, and are oriented with the long axes ranging from near vertical to horizontal. Continuity of the dike is interrupted for only 0.5 km by a mass of metasedimentary rock that was apparently more resistant to stoping. Uranium-lead ages of zircon from atypical hornblende-bearing granodiorite from the western part of the outer dike are 121 Ma_{id} and 118.5 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of hornblende is 117.7 Ma and biotite is 118.8 Ma.

The younger ring dike complex consists of hundreds of thin, relatively short arced, granitic pegmatite and layered pegmatitic-granite dikes (photos 126 and 131) that geometrically define a domal structure of steeply dipping outer dikes that merge into progressively more shallowly dipping dikes toward the center where the dikes are subhorizontal. The pegmatite dikes are mostly 30 cm to one meter thick, and are texturally and compositionally zoned. Outer zones are coarse-grained granite composed of quartz, perthite, and sodic plagioclase, and in some, biotite and minor amounts of magnetite are present. Inner zones consists of pegmatitic-textured perthite, sodic plagioclase, quartz, biotite and (or) muscovite, and some have accessory magnetite, schorl, garnet and epidote. Quartz-crystal-lined vugs (or small pockets) occur locally. Graphic intergrowths of quartz and perthite are common in rock transitional between coarse-grained granite and pegmatitic textured granite. Dikes that lack pegmatitic cores consist entirely of coarse- to extremely coarse-grained granitoid textured rock with or without graphic intergrowths. Based on their domal arangement, the younger ring complex dikes are interpreted as products of volatile-charged magma that filled a domal set of fractures formed by cauldron subsidence.

Horizontal and near-horizontal floored masses of granophyre (Kpvgr) occur in the central part of the ring complex. Where fresh, the granophyre is pale gray but typically weathers to form reddish-brown outcrops due to oxidation of pyrite, an ubiquitous accessory mineral in the rock (photo 132). The very fine grained porphyritic granophyre consists of phenocrysts of altered plagioclase in a groundmass of granophyric intergrowths of quartz within potassium feldspar and sodic plagioclase. A network of pegmatitic-textured stringers, averaging 2.5 cm thick, cuts much of the granophyre. These pegmatitic stringers are compositionally and texturally zoned, having fine-grained margins and coarse-grained interiors. Vertically oriented pegmatite stringers are symmetrically zoned, but horizontal stringers are asymmetrically zoned and have plagioclase crystals growing upwards from the base and potassium feldspar crystals growing down from the top. The thickness of the potassium feldspar crystals increases downward from the top. The granophyre is interpreted as the product of pressure quenching pegmatite magma and attendant loss of volatiles. The granophyre has a much lower potassium content than the pegmatite dikes suggesting much of the potassium in the pegmatite magma left the system with the volatiles.

Domenigoni Valley pluton—The Domenigoni Valley pluton was passively emplaced by magmatic stoping. The exposed level is near the roof of the pluton (photo 133), which is composed of massive, isotropic, gray, medium-grained biotite-hornblende granodiorite and tonalite (Kdvg) (photos 134 and 135); some rock in the southeastern part of the pluton is foliated and there are masses of relatively mafic rocks. Biotite, especially in the northeastern part of the pluton consists of felted aggregates. Common accessory minerals include zircon, sphene, apatite, and magnetite-ilmenite. Minute oriented rutile crystals impart a faint blue opalescence to quartz. Small masses of epidote and (or) tourmaline rocks occur locally and appear to replace the granodiorite-tonalite. At the present level of exposure the pluton consists of two halves separated by a broad septa of metasedimentary rocks and gabbro. A small apophysis between the two halves was emplaced into the metasedimentary rock and is well exposed in a road cut on U.S. 215 at Sun City. The granodiorite-tonalite contains common to abundant equant-shaped mafic inclusions, but inclusions are rare or lacking around the margins of the pluton. In the apophysis exposed on U.S. 215 inclusions range from thermally metamorphosed metasedimentary rocks to all stages of transformation into mafic inclusions (photos 136 and 137). Two relatively consistent, steeply dipping, joint sets are present throughout the pluton; one strikes northeast, the other northwest. A dacite-quartz latite dike swarm (Kld) was emplaced along the northwest striking joints.

Contacts between the pluton and country rocks are sharp. Grain size of the granodiorite-tonalite at the contact is the same as it is within the interior of the pluton, but the granitic rocks near the contact are devoid of mafic inclusions (photo 138). Up to about 20 to 30 meters from the contact the tonalite typically contains a uniform quantity of equant-shaped mafic inclusions (photo 137). At a few places phyllite at the contact contains small crystals of tourmaline, but it is not clear if the tourmaline is metasomatic or if it crystallized from the phyllite. Characteristically there is little change in the mineralogy or fabric of the host rocks surrounding the pluton, except for local deflections of schisosity within a few meters of the contact. An exception is in the northeastern part of the pluton, where the schistocity in places shows deflections 60 to 90 meters from the contact.

Uranium-lead ages of zircon from a sample in the western part of the pluton are 117.8 Ma_{id} and 124.0 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 104 Ma and of potassium feldspar 95.5 Ma.

A quartz latite dike (Kld) swarm consists of numerous light to dark gray, fine grained, porphyritic, massive to well foliated biotite, biotite-hornblende, and hornblende dacite and quartz latite (photos 139 and 140). The dike swarm is included as part of the Domenigoni Valley Pluton based on its spatial association with the pluton. Most of the dikes are located in the eastern part of the pluton, but a few extend into the surrounding metasedimentary county rock or occur entirely within the metasedimentary rock pendant separating the two halves of the pluton. Almost all of the dikes consist of foliated and lineated rock; a texture that contrasts sharply with the massive texture of the enclosing granodiorite-tonalite. Some dike rocks contain small needle-like hornblende prisms. Streaks of biotite and less commonly oriented hornblende crystals gives rise to a pronounced and regular lineation plunging to the southeast (photo 140). Some of the foliation is curvilinear. The dikes are more resistant to erosion than the granodiorite-tonalite and form conspicuous ribs and walls (photo 139).

Cajalco pluton—The Cajalco pluton is a relatively large pluton that extends from south of Lake Mathews (Lake Mathews 7.5' quadrangle) northwest to the Norco-La Sierra area (Corona North 7.5' quadrangle). The pluton was emplaced by magmatic stoping of largely volcanic and volcaniclastic rock (Kvem) in the western part and of gabbro (Kgb) in the center and eastern part. The pluton is composed mostly of biotite and biotite-hornblende monzogranite and granodiorite (Kcg). Grain size is quite variable ranging from fine to coarse grained. Large parts of the body are fine grained leucocratic monzogranite, especially northwest of Lake Mathews. The western part of the pluton is mainly medium grained, equigranular, hypautomorphic-granular to subporphyritic (photos 141 and 142). Subporphyritic textures are common, and phenocrysts of quartz have a beta quartz habit. Locally the subporphyritic rock contains small miarolitic appearing cavities, and is cut by hypabyssal porphyritic dikes, which consist of distinctive feldspar phenocrysts in a dark gray very fine-grained groundmass (photos 143 ~~and 580).~~ Near the western contact with volcanic rocks, parts of the unit consist of subequal amounts of granodiorite and quartz latite porphyry. Based on textural changes, the western part of the pluton is exposed at a higher level than is the eastern part.

Most of the eastern part of the pluton is medium-grained, equigranular, hypautomorphic-granular granodiorite and subordinate monzogranite. Granodiorite contains variable amounts of angular mafic inclusions. Equant shaped masses of stoped Estelle Mountain volcanic and volcaniclastic rocks are abundant south and west of Lake Mathews (fig. 1). Small to mappable scale (1:24,000-scale) stoped blocks of gabbro are abundant north of Lake Mathews where, volumetrically, gabbro is about equal to the Cajalco pluton rocks (photo 144).

In the shallow western part of the pluton, near the roof and extending into overlying volcanic and volcaniclastic rock, autometamorphic tourmalized rock (Kcto) is widespread (photos 145, ~~144,~~ 146, and 147). The tourmalized rock ranges from incipient fracture-filling films to large masses up to hundreds of meters in length that consist of essentially only tourmaline. These large tourmaline bodies are locally termed tourmaline blow outs, and in them, the tourmaline is very fine-grained to aphanitic. The first stage of tourmalization is fracture filling, the second is replacement of mafic minerals, the third is replacement of feldspar, and the final is replacement of quartz. Where only quartz remains unreplaced, the tourmalized rock is a very distinctive, white-dappled, black rock resembling porphyry. Northeast striking joints are preferential sites for the most extensively tourmalized rock, which is more resistant to weathering than un-tourmalized rock and stands out as small, bold black hills (photo 146).

Locally, durmortierite is present rather than tourmaline, occurring as large sprays of pink to violet acicular to prismatic radiating crystals. An exceptionally large tabular body of dumortierite is located in Temescal Canyon near the east side of the Corona South 7.5' quadrangle. Cobbles of tourmalinized rock are locally abundant in the Miocene Lake Mathews Formation and Quaternary fluvial deposits in the Lake Mathews 7.5' quadrangle.

Tourmalinized rock contains small amounts of iron sulfide minerals, and very locally cassiterite (photo 148). Most of the extensively tourmalinized rock has been prospected for tin, which was discovered about 1853 in a large body of tourmalized rock in the Eagle Valley area, Lake Mathews 7.5' quadrangle. Cassiterite-bearing tourmalinized rock was intermittently mined from 1860 to about 1892 and a smelter constructed (Sampson, 1935). Over 250,000 pounds of tin was smelted in 1891 to 1892.

Uranium-lead ages of zircon from the coarse-grained monzogranite of the Cajalco pluton are 109.5 Ma_{id} and 111.5 $Ma_{ip.}$

Granites of the Riverside area and Mount Rubidoux—Discontinuous masses of biotite granite (Krg), and locally hypersthene and fayalite granite (Kmrg) occur in the Riverside area. Most of the granite is medium to coarse grained, massive to faintly foliated biotite granite that averages one to three percent biotite. Inclusions are sparse in these bodies, except locally in some western exposures where the granite contains two to eight percent biotite and sparse to abundant inclusions of quartz diorite, granodiorite, and fine-grained mafic rock. At Mount Rubidoux, the granite contains sparse hypersthene and fayalitic olivine and a higher concentration of dark-gray fine-grained inclusions. Also at Mount Rubidoux, a second body, informally named the granite of Mount Rubidoux, is a coarse-grained phase that is characterized by fayalite and hypersthene (photo 149). This latter granite is massive, unequigranular, and has an average grain size of five millimeters; potassium feldspar crystals are up to 12 mm in length. Biotite and hornblende aggregate about five percent and fayalite and hypersthene are sparse constituents. Mafic inclusions are sparse. Uranium-lead ages of zircon are 109 Ma_{id} and 106.1 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 98.2 0.3 Ma and K-feldspar is 86.5 to 90.3 Ma.

Gavilan ring Complex—The discontinuously exposed, elliptical in plan, composite Gavilan ring complex consists of a variety of granitic rocks that range from hypersthene monzogranite (Kgg) (photos 150, 151, 152, 153 and 154) to biotite-hornblende tonalite (Kgt, Kgtf,, Kgtri, and Kgct). Located in the center of the ring complex is the near-circular Arroyo del Toro pluton, which may or may not be genetically related to the ring complex.

Based on textural differences across the ring complex, the body was tilted westward, exposing deeper levels on the east side. Textures within the ring complex grade from hypabyssal to hypautomorphic granular (photo 155) from west to east. The hypabyssal textures (Kgh) in the western part of the body, in places appear to grade upward into volcanic textured rocks. Because of the volcanic textures, some of these rocks were previously mapped as intrusive rocks related to the Santiago Peak Volcanics (Weber, 1976).

Restricted to the northern part of the complex is brown weathering, massive, hypautomorphic-granular hypersthene-bearing biotite-hornblende tonalite (Kgt). It contains abundant, equant shaped mesocratic to melanocratic inclusions (photo 156).

In the northeastern part of the complex is a body of hypersthene monzogranite (Kgg) somewhat similar to the granite of Mount Rubidoux. This monzogranite is black where fresh (photo 154), and weathers to form slopes covered with distinctive dark-brown boulders (photo 150). The monzogranite contains hypersthene, clinopyroxene, hornblende, and biotite as mafic phases, and also contains sparse small mafic inclusions that are commonly lighter colored than the fresh monzogranite.

Hypersthene is a characteristic mineral of many of the rocks of the complex, although several non-hypersthene bearing granitic rock bodies are also present. In the northern part of the complex a body of atypically textured, foliated, medium-grained biotite-hornblende tonalite (Kgtf) and a moderately fine-grained tonalite (Kgtri) having abundant, small, platy mesocratic inclusions contain no hypersthene (photo 156). A coarse-grained, relatively light colored biotite-hornblende tonalite (Kgct) that somewhat resembles a schlieren-free tonalite of the the Lakeview Mountains pluton lies between the fine-grained and medium-grained biotite tonalites. This tonalite weathers to form giant boulders of disintegration.

A number of gold mines (e.g., Good Hope, Gavilan, and Santa Rosa (fig. 1)) were developed in rocks of this complex and together, constitute the Pinacate mining district (Sampson, 1935). The gold apparently occurred in arsenopyrite-bearing quartz veins. In addition to metallic mining, the black monzogranite (Kgg) was quarried early by plug-and-feather method to produce relatively small prismatic blocks. Some rock was quarried in the late 1960's to early 1970's as 'black granite' building stone used to face buildings (photo 153).

Uranium-lead zircon age of the tonalite is 112.9 Ma_{id} and 113.6 ±1.8 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 106.2 ±1.0 Ma and K-feldspar 95 to 103.5 Ma. Uranium-lead zircon age of the black monzogranite is 109.0 ±0.4 Ma_{id} and 113.6 ±1.8 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 104.5 ±0.3 Ma and K-feldspar 98 to 100.5 Ma and has an apatite fission track age of 89.9 ±12.7 Ma. Uranium-lead zircon age of the fine grained tonalite in the northern part of the complex is 108.5 ±0.42 Ma_{id} and 109.1 ±1.0 Ma_{ip} and uranium-lead age of sphene is 103.9 ±1.28 Ma_{id} . $^{40}Ar/^{39}Ar$ age of hornblende is 106.4 ±0.2 Ma, biotite is 103.1 ±0.4.5 Ma and K-feldspar 97 to 101 Ma.

Arroyo del Toro Pluton—The near circular Arroyo del Toro pluton is located in the center of the Gavilan ring complex, Steele Peak and Elsinore 7.5' quadrangles. The relationship of this pluton to the Gavilan ring complex is not clear, but its age appears to overlap that of the youngest elements of the Gavalin rocks. The pluton is composed of light gray, medium-grained, very homogeneous, massive, biotite-hornblende granodiorite (Katg). Some of the granodiorite in the western part of the pluton is slightly porphyritic. Small, equant shaped mafic inclusions are rare. The granodiorite weathers to form large boulders of disentigration (photos 157 and 158). Where exposed, the contact with surrounding rock is sharp (photo 159). Granodiorite was locally quarried by the plug-and-feather method (photos 157 and 160). Uranium-lead ages of zircon are 108.6 ±0.46 Ma_{id} and 111.2 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 104.3 ±1.0 Ma and K-feldspar is 94 to 102.5 Ma.

Plutons of the central zone—The central zone of the Peninsular Ranges Batholith varies in width from about 22 km in the northern part of the area, narrowing to nearly zero in the southeast corner of the Santa Ana quadrangle. Rocks of the central zone reappear south of the Santa Ana quadrangle in the Sage 7.5' quadrangle as a narrow elongate pluton of foliated tonalite. Discrete plutons make up the bulk of the granitic rocks in this zone. Gabbro is relatively common in the central zone, contrasting with its near absence in the eastern zone. Most of the gabbro is hornblende gabbro although there are relatively small amounts of olivine gabbro. Not including unrelated gabbro bodies, three discrete plutons, each having multiple parts, are located within the central zone; the Val Verde pluton, the Lakeview Mountains pluton, and the Box Springs plutonic complex.

Green Acres gabbro—The Green Acres gabbro (Kga series) is a heterogeneous gabbroic body, the northern half of which consists of intermingled olivine, pyroxene, and hornblende gabbros intruded by biotite-hornblende quartz diorite and tonalite. Within the unit, quartz diorite and tonalite decompose more readily than the gabbro giving rise to slopes covered by gabbro rubble that in most places masks the presence of the quartz diorite and tonalite (photo 161). Locally, there are small masses of orbicular structured gabbro (photo 162).

The southern half of the body is mainly olivine gabbro (Kgao) (photo 163), containing olivine (Fo_{75} to Fo_{87}) that ranges from a few percent to about one-third of the rock. Anorthite (an_{90}) makes up 30 to 90 percent of the gabbro as anhedral to subhedral, complexly twinned crystals. Hypersthene and augite are widespread; commonly augite is mantled with brown and (or) green hornblende. Light green hornblende occurs primarily in kelyphyitic reaction rims intergrown with spinel around olivine. Thin, planar, vein-like hornblende-spinel masses are common in gabbro that contains abundant olivine. Protoclastically deformed olivine gabbro (flaser gabbro) occurs locally, and contains abundant light green chlorite. Locally, the rocks consist of nematoblastic textured hornblende gabbro, which is typically 46 percent brown hornblende, seven percent green hornblende, nine percent clinopyroxene, two percent olivine, 34 percent calcic plagioclase, and two percent opaque minerals. A variety of small gabbroic dikes cut the olivine gabbro. These dikes consist of equigranular, fine to coarse grained mesocratic to melanocratic hornblende gabbro, porphyritic hornblende-olivine gabbro, and porphyritic anorthite olivine gabbro.

Two small elliptical masses of distinctive troctolite (Kgat) (photo 164) in the southern part of the unit contains about 45 percent Anorthite (an_{90}), 36 percent olivine (Fo_{85}), 11 percent clinopyroxene, three percent orthopyroxene, two percent hornblende, two percent spinel, and five percent iddingsite. Kelyphitic rims mantle most olivine crystals, and large subhedral anorthite crystals impart a slight porphyritic texture to the troctolite. Clinopyroxene and hornblende occur as large poikiolitic crystals inclosing large areas of plagioclase and olivine crystals. Locally, masses of leucocratic gabbro (Kgaa) consist largely to entirely of labradorite-anorthite and small quanities of olivine and (or) pyroxene. This anorthitic gabbro weathers to form gray weathering slopes.

Pegmatite dikes (Kp) are common throughout the Green Acres gabbro. Euhedral garnet and tourmaline (schorl) are common accessory minerals, and some pegmatite dikes contain andalusite, apparently produced by the interaction between the pegmatite and gabbro. One pegmatite dike contains a mass of gabbro altered to biotite, hydrobiotite and vermiculite enclosing individual andalusite crystals up to six centimeters in length. Some andalusite crystals have euhedral dark blue corundum cores up to one centimeter in length. Webb (1943) interpreted this relationship as resulting from the incorporation of metasedimentary rock into the pegmatite, but we interpret it to be the result of interaction between the pegmatite and olivine gabbro. Some of the pegmatite dikes are mylonitically deformed, in extreme cases having a very planar fabric and a pronounced mineral lineation (photo 165).

The mixed granitic rocks at the south end of the Lakeview Mountains pluton contain several small bodies of metamorphosed gabbro (Kgam) apparently derived from the Green Acres gabbro. This metagabbro contains abundant masses of chlorite and blue-green hornblende.

Val Verde Pluton—The Val Verde Pluton is a relatively large body extending from south of Perris, northward to the Riverside area (fig. 1). It is a steep walled, elongate pluton that is eroded to an intermediate depth in the body and is composed of relatively homogeneous, foliated, medium to coarse grained, hypautomorphic granular biotite-hornblende tonalite (Kvt). Potassium feldspar constitutes less than two percent of most rocks in the unit, except along the west margin of the pluton where a zone of relatively potassic tonalite (Kvtk) ranges between two and ten percent potassium feldspar.

Most of the foliation in the tonalite is northwest striking, parallel to the regional structural grain of the batholith, and is moderately to steeply dipping to the northeast (photos 166 and 167). The tonalite contains abundant elliptical-shaped mafic inclusions oriented parallel to the foliation. In the central part of the pluton much of the rock is massive or has incipiently developed foliation, and the inclusions are more equant shaped. Also in this part of the body are segregation masses of mesocratic to melanocratic tonalite. An elegant investigation of the modal mineralogy and structure of the tonalite was conducted by Osborn (1939).

Pegmatite dikes (Kp) are rare in this pluton, unlike the Box Springs plutonic complex and the Lakeview Mountains pluton. One tabular shaped pegmatite has a length of two kilometers and contains line rock layering; this type of layering was not seen in any other pegmatite in either the Santa Ana or San Bernardino quadrangles.

Uranium-lead age obtained from zircon is 105.7 ± 0.55 Ma_{id}. $^{40}Ar/^{39}Ar$ age of hornblende is 100.5 ± 0.2 Ma, biotite is 94.7 ±0.2 Ma, and potassium feldspar 86.5 to 90.3 Ma.

Lakeview Mountains pluton—The Lakeview Mountains pluton is a steep walled, curved, teardrop-shape in plan pluton eroded to an intermediate depth in the body. Emplacement of the pluton, is interpreted to have been at least partly forceful. The body is located at a major deflection of the typical northwest oriented structural grain within the batholith. This deflection is interpreted to have been caused by outward growth of the pluton.

The pluton is composed of foliated tonalite (Klmt) consisting of biotite, hornblende, plagioclase, and quartz, but it is characterized by extreme mineralogic heterogeneity. Potassium feldspar occurs only as rare antiperthite, and some hornblende crystals are cored with colorless cummingtonite crystals. The extreme mineralogic heterogeneity in the overall pluton appears to be related to very abundant schlierern having highly variable composition and irregular distribution. The tonalite forms relatively bold outcrops (photo 562).

The Lakeview Mountains pluton is characterized by ubiquitous schlierern that range in composition from essentially plagioclase-quartz rock to biotite-hornblende rock; these schlieren range from a few centimeters to several meters in most of the pluton. Typically, the schlieren are near planar (photo 168), but some are wispy and folded (photos 169, 170, 171 and 172). Locally, alternating sheet-like concentrations of plagioclase-quartz rock and biotite-hornblende rock produce a pronounced layering, commonly with leucocratic quartz-plagioclase juxtaposed with a melanocratic hornblende-biotite layer. In addition to the schlierern, ellipsoidal- to pancake-shaped mafic inclusions are common.

Geometrically the schlieren fall into three groups based on orientation, one group is parallel to the shape of the pluton, one oriented northwest, and a third oriented northeast (Morton, 1969). A few outcrops have readily visible interpenetrating northwest and northeast striking schlieren, each containing mafic inclusions oriented parallel to planar schlieren. Based on macroscopic fabric analysis, most of the rock contains two sets of planar fabric, one pronounced, the other subtle; some outcrops have three sets of planar fabric, one pronounced and the other two subtle (Morton, 1969).

The northwest and northeast striking schlieren are parallel to regional joint sets in adjacent plutons. In addition to schlieren that range from a few centimeters to several meters, masses of plagioclase-quartz rock (Klml) and biotite-hornblende rock (Klmm) form mappable-sized bodies. These rock masses constitute selective concentrations of the essential minerals making up the main intrusive rock of the pluton. Except for form and scale, mappable-sized bodies are similar to the wispy schlieren. Leucocratic rock masses consist of andesine and quartz that have minor amounts of poikilitic biotite and hornblende. Muscovite occurs in these rocks as a rare accessory mineral interstitial to plagioclase. Melanocratic rock masses range in composition from about 50 percent biotite-hornblende to entirely biotite-hornblende.

In places along the southern margin of the pluton, thin septa of foliated, porphyritic-appearing rock contain stumpy hornblende phenocrysts in a granoblastic (protoclastic?) textured matrix of biotite, quartz, and plagioclase. Along the southwest margin of the pluton is an elliptical-in-plan body of comb-layered gabbro (Klmc). The layering in the gabbro consists of alternating layers of labradorite gabbro and hornblende or augite gabbro. Labradorite crystals are oriented normal to the layering and branch upward from the base of a layer to form feather-like crystals. Folded layering, having fold amplitudes of one centimeter, is common. Concentrated near the center of the Lakeview Mountains pluton, are masses of hypersthene gabbro (Klmg) that were clearly not in equilibrium with the tonalite magma.

In addition to the hypersthene gabbro, numerous granitic pegmatite dikes (Klmp) are concentrated in the center of the pluton. Most of the dikes are tablular, steeply dipping, and most strike northeast and southwest. A few dikes are bulbous and a few have thickened parts at a roll in the dip of the dike (photo 173). Almost all dikes are symmetically zoned compositionally and texturally (photo 174). Most have a wall zone of coarse and extremely coarse grained intergrowths of alkali feldspar, quartz, and biotite that commonly have graphic granite intergrowths of feldspar and quartz (photo 175). Intermediate zones commonly contain giant schorl, perthite and quartz and a variety of accessory minerals (photo 124). Replacement units and fracture filling units (photo 176), generally of tourmaline and garnet, are common in the larger dikes. An inner core zone consists of extremely coarse-grained (‘giant’) pegmatitic-textured alkali feldspar (mostly perthite) and quartz.

Epidote, magnetite, ilmenite, and zeolites, including laumontite and stilbite, are widespread accessory minerals, and larger dikes commonly contain rare-earth minerals as accessories. Monazite is the most common rare-earth mineral; less common is microlite, samarskite, yttrocolumbite-tantalite (including manganoyttrocolumbite)(photo 586), zircon (cyrtolite), allanite, pyrochlore, uranophane, thorite (uranothorite), fergusonite, and thorogummite; columbite-tantalite and beryl are unusual accessories. A few dikes contain bismuth minerals (bismuthinite, bismutite, beyerite, and pucherite), sphalerite, and chalcocite. Many of the pegmatites were prospected for potassium feldspar and the larger ones were mined.

The bulbous pegmatites have zoning similar to that of the tabular pegmatite, but have thicker intermediate and core zones and commonly have fracture-filling and replacement units. Crystal size is larger in the bulbous pegmatites than in the tabular pegmatites, commonly having giant crystals of biotite, schorl, and microcline (perhite). Some schorl occurs as fractured and healed crystals up to a meter in length.

The best known of the bulbous pegmatites is the Southern Pacific Silica Quarry pegmatite located in the northwestern part of the pluton. (A map of the Southern Pacific Silica Quarry is given in Jahns, 1954b). The outer part of the dike contains large radiating sprays of biotite (photo 174), most of which have a nucleus of magnetite or fergusonite(?). Nuevite was described as a new mineral from this pegmatite (Murdoch, 1946), but was later determined to be samarskite. Monazite from Southern Pacific Silica Quarry pegmatite has a uranium-lead age of 99.6 Ma (Premo, written commun., 1999) the same age as the tonalite of the pluton. Another somewhat bulbus pegmatite is located in the central part of the pluton.

Although masked by extreme localized chemical variation produced by irregularly distributed schlieren having highly variable mineralogy, there is a pluton-wide systematic variation in chemisty resulting in a slightly more mafic (Fe, Ca, and Mg) center part and a less mafic outerpart (Morton, and others, 1969). Also, even though the Lakeview Mountains pluton is located in a relatively low magnetic part of the Peninsular Ranges Batholith, the center part of the pluton is relatively magnetic; and disproportionately more magnetic than the outer part (Langenheim and others, 2004).

uranium-lead ages from zircon in the Lakeview Mountains pluton are 100 ±0.15Ma_{id} and 98 ±1.2 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of hornblende is 98.6 ±0.3 Ma and conventional potassium-argon age of biotite is 92.4 Ma. The pressure of crystallization of hornblende is 5 to 5.5 Kb (Smith and others, 1991)

Rheinhardt Canyon Pluton—An arcuate-shaped pluton, the Reinhardt Canyon pluton, Lakeview 7.5' quadrangle, borders the east side of the Lakeview Mountains pluton (photo 177). Tonalite (Krct) of this pluton lacks the schlieren that are so ubiquitous in the adjacent Lakeview Mountains pluton. Most of the tonalite of the Reinhardt Canyon body has a well developed planar fabric parallel to the outline of the body, and contains abundant mafic inclusions that in places are vertical and rod-shaped (photos 178, 179, and 180). Heterogeneous granitic rocks bordering the Lakeview Mountains pluton in many places contain complex, composite, irregular to planar shear zones that appear to be protoclastic. Ellipsoidal mafic inclusions are transposed and attenuated where cut by the shear zones, which are interpreted to result from the outward expansion of the pluton.

Box Springs plutonic complex—The Box Springs plutonic complex is an elliptical-in-plan, flat-floored, bathtub-shaped plutonic complex defined by a number of granitic units ranging in composition from monzogranite to tonalite (photos 181 and 182). The long direction of the plutonic complex is oriented northwest and the sides tilted up on the northeast. Most of this flat-floored structure, including its sides and the south end, underlies the Box Springs Mountains (photo 183); the northern end is located in the La Loma Hills (fig. 1). The lowest part of the structure consists of a steeply inclined funnel-shaped body of tonalite centered over Blue Mountain (fig. 1). Steeply dipping foliation (photo 184) developed in the tonalite there contrasts with the otherwise moderate to shallow dipping foliation elsewhere in the complex.

Box Springs plutonic complex consists of an inner part of homogeneous, equigranular, massive, relatively fine grained biotite tonalite (Kbt) (photo 185) containing equant shaped mafic inclusions (photos ~~186~~ and 187). Although lacking the foliation found in most of the complex, the central part of this interior tonalite has an indistinct shallow dipping to horizontal magmatic layering produced by variation in mafic mineral content. Inclusions in this rock tend to be aligned parallel to the compositional layering and the rims of some of the inclusions are relatively more mafic than the inner parts. Uranium-lead ages of zircon from this interior tonalite are 98.6 ±0.27 Ma_{id} and 100.4 ±1.6 Ma_{ip}.

The interior massive biotite tonalite grades outward into medium to coarse grained well foliated biotite tonalite and granodiorite (Kbfg) which contains sparse elliptical-shaped mafic inclusions (photo 186). In most places, a zone of heterogeneous, foliated, porphyritic granodiorite and subordinate tonalite lies outward in the complex from the biotite tonalite and granodiorite. Mafic minerals, chiefly biotite and lesser amounts of hornblende are unevenly distributed in this outer unit (Kbhg), imparting a heterogeneous appearance to the rock. The granodiorite contains subhedral potassium feldspar crystals up to 2.5 cm in length. Discoidal shaped mafic inclusions are common and widespread, and in this unit on the east side of the complex they are abundant (Kbfgi). Further outward in the complex the heterogeneous granodiorite passes into more homogeneous foliated porphyritic granodiorite containing mafic minerals that are more uniformly distributed than in the heterogeneous granodiorite (Kbg). Potassium feldspar phenocrysts are up to 2.5 cm in length. In places, potassium feldspar crystals appear to replace parts of the mafic inclusions, suggesting some of the potassium feldspar may be metasomatic. The outermost parts of the Box Springs plutonic complex consist of a variety of granitic rocks including medium- to coarse-grained, well foliated biotite-hornblende tonalite (Kbft) that contains abundant discoidal to pancake-shaped mafic inclusions (photo 188).

Pegmatite dikes (Kpd) within the Box Springs plutonic complex are mostly small tabular bodies. The few larger bodies are compositionally zoned, having biotite, quartz, and alkali feldspar outer parts and centers consisting of giant crystals of perthite and quartz and accessory muscovite, schorl and garnet. A few of the larger dikes contain some rare-earth minerals similar to the pegmatites in the Lakeview Mountains pluton. Monazite is an accessory mineral and locally dikes contain radiating crystal groups of samarkskite having overgrowths of columbite-tantalite.

Granitic rocks in the Bernasconi Hills area—A wide variety of granitic rocks occur in the Bernasconi Hills, located between the Lakeview Mountains pluton and the Box Springs plutonic complex. From the southern part of the Bernasconi Hills to north of Bernasconi Pass is the monzogranite of Bernasconi Pass (Kpbg). North of Bernasconi Pass, the monzogranite weathers to form bold outcrops, is slightly foliated, and contains few inclusions (photo 189). South of Bernasconi Pass, it is irregularly porphyritic biotite and biotite-hornblende monzogranite that weathers to form large, massive outcrops (photo 190). Unlike the monzogranite north of Bernarsconi Pass much of the monzogranite contains large quanities of ellipsoidal-shaped mafic inclusions (photos 191 and 192). Most of the monzogranite has moderately well developed planar fabric, and includes masses of migmatitic-appearing rock in which the volume of mafic inclusions commonly exceeds the volume of granitic rock. A mappable migmatitic zone (Kbpm) occurs within the monzogranite on the south side of Bernarsoni Pass and extends both to the west and east of Bernasconi Hills (photos 193, 194, 195 and 196).

North of the monzogranite of Bernasconi Pass, a mixture of brown-weathering sillimanite-cordierite schist (Pzs) is intruded by heterogeneous granitic rocks (Khg) and a series of tonalite plutons, the tonalite of Bernasconi Hills (Ktbh) (photo 197). The tonalite weathers to form distinctive gray bold outcrops; it is relatively fine grained, commonly massive, and has common to abundant, small, ellipsoidal mafic inclusions.

Plutons of the eastern zone—The eastern zone of the batholith is characterized by large tonalitic composition plutons generally having less well developed foliation than plutons of the central zone. Tonalite of Lamb Canyon is the only representative in the map area of these large plutons. Sphene is a characterizing minor mineral in the tonalite, where it commonly occurs as readily visible large euhedral crystals; megascopically visible sphene is uncommon to nonexistent in the plutonic rocks of the central and western zones. Garnet and white mica granitic plutons, essentially lacking in the central and western zones, are present in the eastern zone, but sparse. Granite of Mount Eden is representative of white mica bearing plutons. Gabbro composition bodies are likewise sparse and generally limited to the western part of the zone.

Tonalite of Lamb Canyon—The Tonalite of Lamb Canyon (Klct) is a distinctive sphene-bearing tonalite that occurs as several noncontiguous bodies in the northeastern part of the El Casco 7.5' quadrangle surrounded by sedimentary rocks of the San Timoteo beds. It is informally named for the excellent exposures of large bouldery blocks at the head of Lamb Canyon just east of the map area (fig. 1). Most of the unit is homogeneous appearing, massive to slightly foliated, biotite and hornblende-biotite tonalite that in most places contains large euhedral sphene crystals. Mafic inclusions are uncommon. The uranium-lead age of zircons from rocks at the head of Lambs Canyon is 94 Ma_{id} and uranium-lead age of sphene is 92.8 Ma_{id} (W. Premo, written commun., 2002). This tonalite is the sole constituent of monolithic debris flow deposits in the Miocene Mount Eden Formation.

Granite of Mount Eden—A small elongate pluton in the vicinity of Mount Eden, Lakeview and El Casco 7.5' quadrangles (fig. 1), is composed of garnet-muscovite granite, and is here informally named the granite of Mount Eden (Kmeg) (photos 32, 198, and 199). Rocks of this pluton are nearly white, but weather to form very pale brown bold outcrops (photo 199). Where fresh, bright pink garnets impart a distinctive appearance to the otherwise white rock. Grain size in the rock ranges from fine to coarse grained, but varies little. The adjacent metamorphic rocks contain a number of sills and dikes of the granite. Most of the sills and dikes are foliated, the foliation oriented parallel to the metamorphic rock foliation. Similar, small garnet-muscovite granite plutons occur at several localities southeast of the quadrangles where they have been termed adamellite by Sharp (1967). Except for pegmatite dike rocks, garnet-muscovite-bearing granitic rocks are sparse in the Peninsular Ranges Batholith.

Post batholithic rocks

Post batholithic rocks are dominated by sedimentary rocks, both marine and nonmarine, with widespread, lesser amounts of volcanic rocks. In the map area the northwestern and eastern part of the Peninsular Ranges assemblage consists almost of entirely post batholithic age rocks, mostly of marine origin. Thick sections of Upper Cretaceous sedimentary rocks flank the west side of the Santa Ana Mountains. Best known sedimentary rocks are the Miocene and Pliocene rocks that comprise the petroliferous Los Angeles Basin.

Upper Cretaceous

Sedimentary rocks

Upper Cretaceous marine and continental sedimentary rocks were first recognized in the Santa Ana Mountains by the California Geological Survey before 1865 (Whitney, 1865). These rocks were later included with the Chico Formation of northern California by Packard (*in* Dickerson, 1914) where it was subdivided into six units. The upper unit was later determined to be of Paleocene age. In the Santa Ana Mountains, Packard (1916, 1922) named the basal nonmarine conglomerate unit the Trabuco Formation and grouped the remaining marine rocks into the Ladd Formation and the Williams Formation. Popenoe (1942), Woodring and Popenoe (1942, 1945), Schoellhamer and others (1954), Morton and others (1979), and Morton and Miller (1981) modified Packard's nomenclature. In current usage the nomenclature of the Upper Cretaceous rocks is, in ascending order, the basal Trabuco Formation, the Ladd Formation that includes the Holz Shale Member and the Baker Canyon Conglomerate Member, and the Williams Formation that includes the Pleasants Sandstone Member, Schulz Ranch Member, and the Starr Member. In the northern Peninsular Ranges, exposures of Upper Cretaceous sedimentary rocks are restricted to the Santa Ana Mountains area. South of the Santa Ana quadrangle, marine and nonmarine Upper Cretaceous rocks extend into Mexico. In the San Diego area the Trabuco equivalent is the Lusardi Formation, and the Point Loma and the Cabrillo Formations of the Rosario Group are correlated in part to the Williams Formation (Kennedy, 1975).

Trabuco Formation—The nonmarine Trabuco Formation (Ktr) consists primarily of reddish clayey conglomerate and sandstone interbedded with minor amounts of clayey siltstone. It attains a thickness of about 166 m, but is discontinuous in the Santa Ana Mountains and areas to the south. Clasts are derived from varied basement source rocks, in places they attain a size of nearly a meter, but most fall in the range of eight to 16 cm.

Beyond the Santa Ana quadrangle, the Trabuco Formation occurs to the northwest in the Santa Monica Mountains, where the conglomerate is similar to that in the Santa Ana Mountains. The equivalent Lusardi Formation (Nordstrom, 1970) south of the map area, in San Diego County, is mainly a coarser-grained conglomerate and includes a greater percentage of Peninsular Ranges Batholith clasts than typically found in the Trabuco Formation, but occupies the same stratigraphic position as the Trabuco Formation. Overall the Lusardi Formation is considered an alluvial fan deposit, and in places lacks the reddish coloration of the Trabuco Formation. Typically clasts in the Lusardi Formation are larger and less rounded than clasts found in the Trabuco Formation.

Ladd Formation—The Ladd Formation (Kl) consists of marine and nonmarine conglomerate, sandstone, siltstone, and shale. Popenoe (1942) retained the name proposed by Packard (1916, 1922) for exposures just west of the mouth of Ladd Canyon, but he further divided the formation into the Baker Canyon Conglomerate Member (Klbc) and the Holz Shale Member (Klhs).

The Baker Canyon Conglomerate Member, named for exposures in Baker Canyon in the Santa Ana Mountains, ranges between zero and 425 m in thickness (Popenoe, 1942). It has a lower part consisting of greenish gray conglomerate containing clasts up to two meters in length. At least some of the lower part of the section is nonmarine. Most of the clasts are granitic, siliceous volcanic, and hypabyssal rocks. The upper part of the section is yellow-brown conglomeratic sandstone (photos 200, 201, 202, 203) containing smaller clasts than in the lower part.

The base of the Baker Canyon Conglomerate Member grades into and intertongues in places with the similar looking underlying Trabuco Formation (Ktr) (Schoellhamer and others, 1981). In the Black Star Canyon area (fig. 1), the Trabuco is the stratigraphic equivalent to the lower part of the Baker Canyon Conglomerate Member (Schoellhamer and others, 1981). Based on ammonites (*Subprionocyclus*) the Baker Canyon Conglomerate Member is assigned to the late Turonian Stage (Schoellhamer and others, 1981).

Gradationally above the Baker Conglomerate Member is the Holz Shale Member, named for exposures at the Holz Ranch on the north side of Silverardo Canyon (Popenoe, 1942) (fig.1). It consists primarily of thin to thick beds of sandy siltstone, siltstone, and shale (photo 436). Most of the unit weathers to form rounded slopes interupted locally by cliff-forming conglomerate and sandstone beds up to 60 m thick. In the Santa Ana quadrangle, the unit ranges in thickness from about 210 to 450 m, and from drill core data, is about 730 m thick in the subsurface (Schoellhamer and others, 1981). The Holz Shale Member contains forminifers, and locally in the lower part of the member, abundant megafossils which are assigned to the Turonian Stage. The remaining part of the member is assigned to the Campanian Stage. Sundberg (1975) described a large megafauna assemblage, mostly bivalves and gastropods, from the Holz Shale Member at Silverado Canyon, and interpets the fauna to indicate depositon in shallow marine waters.

Williams Formation—The Williams Formation (Kw series) consists mainly of sandstone and conglomeratic sandstone. Popenoe (1937, 1942) retained the name proposed by Packard (1916, 1922) for exposures near the mouth of Williams Canyon in the northwestern Santa Ana Mountains. Popenoe recognized two members within the Williams Formation, the Schulz Member (Kwsr) and the Pleasants Sandstone Member (Kwps). Woodring and Popenoe (1945) renamed the Schulz Member the Schulz Ranch Sandstone Member; the name was later shortened to Schulz Ranch Member by Morton and others (1979).

The Schulz Ranch Member was named for exposures near the mouth of Williams Canyon adjacent to the Schulz Ranch (Popenoe, 1942). It consists mainly of well cemented, coarse-grained, yellowish-white to yellowish-tan, sandstone that is composed of quartz, feldspar, and variable amounts of biotite. The rocks include pebbly and cobbly beds. Bedding in most of the unit is massive, but locally contains thinner crossbedded intervals. The member is about 60 m thick, is characterized by its cliff-forming character, and contains *Turritella chicoensis* of the Campanian Stage (Schoellhamer and others, 1981). It grades upward into the overlying Pleasant Sandstone Member.

Popenoe (1942) named the Pleasant Sandstone Member for exposures on the Pleasant Ranch at the mouth of Williams Canyon. Most of the Pleasant Sandstone Member consists of massive sandstone beds containing biotite and carbonaceous fragments interbedded with less abundant thin bedded sandstone containing bioitite and some muscovite (Schoellhamer and others, 1981). Abundant mollusks are found in the unit (Schoellhamer, and others, 1981) along with the ammonite *Metaplacenticeras pacificum* indicating the upper part of the Campanian Stage (Matsumoto, 1959 and 1960). The Pleasant Sandstone Member ranges in thickness from zero to over 150 m; the thickest section is exposed on the Santiago Truck Trail (Schoellhamer and others, 1981). There, the member consists of a basal section of pinkish-brown feldspathic sandstone and siltstone containing black carbonaceous fragments. This color constrasts with the cream colored sandstone of the underlying Schulz Ranch Sandstone Member.

Paleogene

Sedimentary rocks

Silverado Formation—The Silverado Formation (Tsi), named by Woodring and Popenoe (1945) for a composite section one kilometer northeast of Irvine Park (fig. 1), consists of marine and nonmarine Paleocene rocks (photo 204) deposited on deeply eroded and very deeply weathered pre-Paleocene basement rocks (photos 208 and 205). Weathering of the basement rocks was post Upper Cretaceous marine sedimentation and pre-deposition of the Paleocene sediments. The Silverado Formation is widespread in and on the flanks of the Santa Ana Mountains, Temescal Valley, and the western fringes of the Perris block.

In the Santa Ana Mountains the Silverado Formation ranges in thickness from about 200 to 450 m, and consists of four units. A basal conglomerate unit is overlain by a sequence of sandstone and siltstone that in turn is overlain by a prominent clay bed, informally referred to as the Claymont Clay Bed for exposures at a clay mine on the west side of Coal Canyon (Schoellhamer and others, 1981) (fig. 1). The Claymont Clay Bed is overlain by about 75 m of conglomerate, sandstone, and siltstone, which includes a second clay, the Serrano Clay Bed informally named for the Serrano Clay pits near the divide between Santiago and Aliso Creeks (Schoellhamer and others, 1981) (fig. 1). Both clay beds have been mined as a source of clay (photos 206 and 207).

On the west side of the Santa Ana Mountains the Silverado Formation extends southward a few kilometers into the Oceanside 30’ x 60’ quadrangle (Kennedy and Tan, 2005). Further south, in the vicinity of San Diego, Paleocene rocks apparently do not occur and Eocene rocks rest directly on Cretaceous rocks (Kennedy, 1975).

At Elsinore Peak (fig. 1) a thin sequence of white to gray, indurated, thoroughly decomposed bedded sandstone overlies massive decomposed arkosic sandstone (photo 209) that in turn lies on decomposed granitic basement. The sandstone is overlain by Miocene basalt (Tvep) (photos 210, 211, and 212). This sandstone is here considered to be an isolated occurrence, an erosional remnant, of Silverado

Formation. At Redonda Mesa, 0.2 km south of the Santa Ana quadrangle, sedimentary rocks lying between the Santa Rosa Plateau surface and Miocene volcanics are much less decomposed than the sedimentary rocks at Elsinore Peak, and are considered to be probably part of the Santiago Formation rather than Silverado Formation.

Santiago Formation—The 750-m-thick Eocene Santiago Formation (Tsa) is chiefly marine conglomerate and sandstone (photos 213 and 214). The lower part of the section is largely conglomeraitc, and contains an assemblage of distinctive silicic welded tuff clasts, in part piemontite bearing, which appear to be exotic to southern California (Woodford and others, 1968, 1973). These silicic volcanic clasts are extremely durable and reappear as reworked clasts in younger sedimentary units. The upper part of the Santiago Formation is mostly pale gray to pale tan, micaceous, feldspathic sandstone interbedded with subordinate siltstone (Schoellhamer and others, 1981).

Woodring and Popenoe (1945) named the Santiago Formation for exposures about one kilometer northeast of Irvine Park (fig. 1). Rocks confidently identified as Santiago Formation are restricted to the northern Santa Ana Mountains and San Joaquin Hills, however, several small, isolated occurrences of conglomerate containing the distinctive silicic welded tuff clasts occur along the western edge of the Perris block, and tenatively are correlated here with the Santiago Formation. Southward in the Oceanside quadrangle, at the latitude of Leucadia, the lower part of the Santiago Formation interfingers with the Del Mar Formation and Torrey Sandstone of the La Jolla Group (Kennedy and Tan, 2005). South of the Leucadia area, the Santiago Formation is replaced by sedimentary units of the widespread La Jolla and Poway Groups that collectively constitute the Eocene San Diego embayment (Kennedy, 1975; Kennedy and Moore, 1971).

Mollusks and foraminfers in the Santiago Formation have been correlated with middle Eocene units elsewhere in southern California (Schoellhamer, and others, 1981). Based on the presence of benthic foraminfers in the lower part of the unit it is assigned to the Ulatisian Stage of Mallory (1959).

Sespe and Vaqueros Formations—Remnants of the extensive nonmarine Sespe and marine Vaqueros Formations of Eocene to early Miocene age are widespread on the west side of the Santa Ana Mountains and in the San Joaquin Hills; limited exposures are also found along the Elsinore Fault Zone (Gray, 1961). In many places the Sespe and Vaqueros formations have not been differentiated and are mapped as an undivided unit (Tvs) (photo 215). The marine rocks contain a *Turritella inezana* fauna. Where the two formations are mapped together as undivided, nonmarine and shallow marine rocks generally dominate in the eastern part and deeper water rocks in the western part.

Sespe Formation—The Sespe Formation(Ts) is a widespread continental conglomeratic unit extending from the San Joaquin Hills (fig. 1), northward throughout much of the western Transverse Ranges. It is characterized by varicolored sandstone and pebbly sandstone, red beds, and conglomeratic intervals. Watts (1897) originally described the unit as Sespe brownstone formation for exposures along Sespe Creek in the western Transverse Ranges, about 150 km northwest of the Santa Ana Mountains. It was later described by Eldridge and Arnold (1907) and redefined by Kew (1924), who restricted the name to nonmarine conglomeratic deposits exposed in Sespe Creek area, where the Sespe Formation conformably underlies the marine Vaqueros Formation. Continental vertebrate fossil collections range in age from Eocene to early Miocene (Bailey and Jahns, 1954; Woodburne, 1987).

Although characterized by conglomerate (photos 216 and 217) and conglomeratic sandstone, much of the Sespe Formation is sandstone and silty sandstone. Rocks of the Sespe range from highly pigmented, mainly red and maroon, to gray and pale brown (photo 214). Typically, the Sespe is massive to thick bedded, and has poorly developed to well developed bedforms. Some conglomerate in the unit contain distinctive Poway-type silicious metatuff clasts (photo 20). Most of these clasts range from a few centimeters to about 20 cm in length, but in a quarry near Gypsum Canyon, a tributary to Santa Ana Canyon, they are nearly two meters across (Woodford, and others, 1973). This occurrence is interpreted as a river channel deposit, and includes a distinctive suite of potassic granitic rock clasts that are unlike granitic rocks in the adjacent Peninsular Ranges Batholith. This suite of clasts also includes vein quartz boulders about two meters across that were derived from a greenschist terrain.

In the San Joaquin Hills, conformably overlying the Santiago Formation, the Sespe attains a thickness of about 2,100 m. The intertonguing and overlying Vaqueros Formation in the Santa Ana Mountains consists of marine sandstone, pebbly sandstone, and clayey siltstone, and in the San Joaquin Hills, fine-to coarse-grained sandstone and sandy siltstone.

Vaqueros Formation—The Vaqueros Formation (Tv) is predominantly marine sandstone. It was originally described as the Vaqueros sandstone by Hamlin (1904) for marine deposits in Los Vaqueros

Valley along the east slope of the Santa Lucia Range in central California. Correlation with southern California deposits is based upon the *Turritella inezana* fauna. In the San Joaquin Hills (fig. 1) the Vaqueros Formation consists of brownish-gray, massive- to thick-bedded sandstone and sandy siltstone containing interbeds of siltstone and shale, mudstone, and minor conglomerate. Shale and siltstone are thin bedded. The Vaqueros is as much as 1,160 m thick in the San Joaquin Hills (Vedder, 1975) and contains an early Miocene shallow-water marine megafossil assemblage. In many places the Sespe and Vaqueros formations are mapped as undifferentiated (photo 215), and consist of interbedded marine and nonmarine sandstone and conglomerate. In the Puente Hills, Santa Ana Mountains, and San Joaquin Hills, marine fossil-bearing strata of the Vaqueros Formation are bed-by-bed interlayered with nonmarine rocks of the Sespe Formation to a degree that the formations cannot be mapped as separate units at a scale of 1:24,000.

Neogene

Neogene volcanic rocks

Miocene volcanism occurring between 6.7 to about 15 Ma, was widespread and sporadic in the northern Peninsular Ranges, and extended into the southern part of the San Gabriel Mountains. In the Azusa and Glendora area, older volcanic rocks, including basalt and more silicic varieties, are interlayered within the part of the Topanga Group that represents Kleinpell's Lusian Stage, and are considered to be about 15 Ma.

Glendora Volcanics—The Glendora Volcanics (Shelton, 1955) are a heterogeneous group of Miocene volcanic and volcaniclastic rocks located in both the San Gabriel assemblage and the northern part of the Peninsular Ranges assemblage. The unit crops out in the southern foothills of the San Gabriel Mountains and in the San Jose and Puente Hills to the south. These rocks range in composition from rhyolite to basalt, and include flow rocks, volcanic breccia, and tuff (photos 218, 219, and 220). The upper part of the unit appears to interfinger with the lower part of the overlying Miocene Topanga Group rocks in the Azusa area.

El Modeno Volcanics—A series of andesite, tuff, tuff-breccia, and basalt was named the El Modeno Volcanics (photos 574, 575, and 576) by Schoellhamer and others (1954) for exposures five kilometers east of the settlement of El Modeno on the northwest side of the Santa Ana Mountains (not to be confused with the nearby town of El Modena). Typically the volcanic section includes a lower part made up of basalt flows, that is successively overlain by palagonite tuff and tuff breccia, followed by andesite flows and flow breccia (Schoellhamer and others, 1981). Maximum thickness of the unit is 230 m (Schoellhamer and others, 1981). Yerkes (1957) gives a thorough petrographic description of the major rock types of the unit. In the San Joaquin Hills-Laguna Beach area, numerous volcanic- and diabasic-texured intrusives are included within this unit.. Conventional potassium-argon ages for the upper part of the volcanics are 14.1 ±1.1 Ma (Weigand, 1994), and $^{40}Ar/^{39}Ar$ ages of basalt are 11.2 ±0.2 and 10.7 ±0.2 (Luyendyk and others, 1998). The El Modeno Volcanics are the local representative of widespread middle Miocene volcanism in the greater Los Angles basin area (e.g., Blackerby, 1965; Eaton, 1958; Shelton, 1955).

Temecula area volcanic rocks—Miocene basalt volcanism occurred in the Elsinore Peak - Temecula area between 6.7 and 11.6 Ma (Hawkins, 1970; Morton and Morton, 1979; R. Fleck, written commun., 1998). On the Santa Rosa Plateau a number of mesas are capped by basalt (Tvsr) (photos 221 and 222) lying on deeply weathered basement and in some localities on Paleogene sedimentary rocks. Large shallow vernal ponds (photo 584) are in closed depressions on the basalt surface. At Elsinore Peak, basalt (Tvep) rests on well-indurated Silverado Formation (Tsi) (photo 211) underlained by saprolitic arkose and granitic rock (photo 212). A basaltic (Tvep?) vent in granitic rock (Khg) is located a short distance south of Elsinore Peak (photos 223, ~~224,~~ and 225). On the east side of the Elsinore Fault Zone, basalt that caps the Hogbacks (Tvh) has whole rock convential potassium-argon ages of 10.4 and 10.8 Ma (Morton and Morton, 1979).

The basalt of Hogbacks (Tvh) rests on stream gravels and appears to have been deposited in a channel. Its current topographically high position is interpreted to be a result of inverted relief (photo 226). A very restricted occurrence of basalt of the Temecula area (Tvtb) occurs in the very southeast corner of the Santa Ana quadrangle. On the west side of the Elsinore Fault Zone, basalt capping Elsinore Peak (Tvsr), has a whole rock convential potassium-argon age of 11.6 Ma and $^{40}Ar/^{39}Ar$ age of 11.2 Ma (R. Fleck, written commun., 1998). Santa Rosa basalt has a reported whole rock conventional potassium-argon ages of 8.7 Ma (Hawkins, 1970), and 6.7 and 7.4 Ma (Morton and Morton, 1979).

Sedimentary rocks, Los Angeles Basin

Neogene sedimentary deposits are dominated by thick sections of marine Miocene and Pliocene strata of the Los Angeles Basin (fig.3) (e.g., Woodford and others, 1946; Schoellhamer and others, 1981; Yerkes and others, 1965; Durham and Yerkes, 1964; Yerkes, 1972) and the San Joaquin Hills (Morton and Miller, 1981; Vedder, 1972). Marine strata extended into the northern end of the Elsinore Fault Zone south of Corona (Gray, 1961) and east onto Cretaceous granitic rocks in the Norco area (Morton and Matti, 1989).

Following the usage of Woodford and others (1954) and Yerkes and others (1965) we define the Los Angeles Basin as the extent of middle and upper Miocene marine deposition, and include rocks found in the Santa Monica Mountains, San Fernando Valley, south edge of the San Gabriel Mountains, San Jose Hills, Puente-Chino Hills, Chino basin, northern Santa Ana Mountains, San Joaquin Hills, and Palos Verdes Hills. The part of the basin in the Santa Ana and San Bernardino quadrangles includes part of the south edge of the San Gabriel Mountains, San Jose Hills, part of the Puente-Chino Hills, Chino basin, northern Santa Ana Mountains, and the San Joaquin Hills.

Initial subsidence of the Los Angeles Basin occurred in the middle Miocene, and was followed closely by the main phase of subsidence during the later Miocene and early Pliocene; basin closing occurred primarily during the Pleistocene (Yerkes and others, 1965). Work by McCulloh and others (2000) determined that the geometry of Oligocene and early Miocene pre-basin sedimentation in the eastern part of the basin was similar to that of the middle Miocene. Most of the oil from this prolific basin (over 6 billion barrels estimated ultimate recovery) is from late Miocene and early Pliocene strata (Yerkes and others, 1965). The southern part of the central block and the southeastern part of the northeastern block of the Los Angeles Neogene basin are included within the Santa Ana quadrangle (Yerkes and others, 1965).

At the south end of the central block, in the San Joaquin Hills area (fig. 1), widespread middle Miocene Topanga Formation is overlain by the San Onofre Breccia, which is in turn overlain by the Miocene and early Pliocene Capistrano Formation. The San Onofre Breccia (photos 4, 5, 6, 7, 8, 9, and 10) was derived from blueschist metamorphic rocks, which Woodford (1925) demonstrated had an offshore provenance. Further north, in the Puente Hills area, the Topanga Formation has a thickness in excess of 480 m (Yerkes, 1972), but is dwarfed by the more-than-4,000 m aggregate thickness of the overlying Miocene and early Pliocene Puente Formation. The Puente Formation is succeeded by as much as 1,825 m of marine Pliocene Fernando Formation (Yerkes, 1972); a total of over 6,300 m of sedimentary rock deposited in a time period spanning only parts of the Miocene and Pliocene.

Topanga Group—The Topanga Formation, predecessor of the Topanga Group, was established in the Los Angeles Basin area (Kew, 1923 and 1924) for middle Miocene rocks above the early Miocene Vaqueros Sandstone (Formation) and below the late Miocene Modelo Formation. As such, it was not defined on the basis of lithostratigraphy, but on the basis of biostratigraphic and temporal constraints. A wide variety of lithologies were included within the originally defined Topanga Formation. Of those lithologies, only coeval blueschist-bearing strata, the San Onofre Breccia (Woodford, 1925, Woodford and Bailey, 1928) and the Trancas Formation (Yerkes and Campbell, 1979), were given formational names separate from the Topanga Formation. Potassium-argon ages and fossils collected by Turner and Campbell, *in* Yerkes and Campbell (1979), indicate a middle Miocene age for the Topanga Formation, spanning the time of the Relizian, Luisian, and including the lower part of the Mohnian stages of Kleinpell (1938).

Yerkes and Campbell (1979) elevated the Topanga Formation to group rank, basing their stratigraphic revision on type-strata of the original Topanga Formation in the Santa Monica Mountains. Their Topanga Canyon Formation apparently corresponds to the Topanga Formation of Kew (1924), and they included the Conejo Volcanics as the middle part of the Topanga Group. They did not, however, extend their newly established group-level nomenclature outside of the central Santa Monica Mountains area, so it is not clear how rocks previously included within the Topanga Formation in other areas relate to the newly established formal units of Yerkes and Campbell (1979). Some of these rocks outside of the central Santa Monica Mountains are formally named members of the original Topanga Formation. All Topanga rocks in the map area, some formally named members, some not, fall outside the newly established stratigraphy of the central Santa Monica Mountains. Therefore, in this report, to conform as closely as possible to stratigraphic protocols, for rocks outside of the central Santa Monica Mountains, we follow the revision of Yerkes and Campbell (1979) and treat the original Topanga Formation as being of group rank, and treat described members as formations.

Vedder and others (1957) recognized three members within the originally defined Topanga Formation in the San Joaquin Hills (fig. 1), the Paulerino Member, Los Trancos Member, and Bommer Member. We follow the usage of Blake (1991) and treat these members at formation rank, retaining all type area and type section definitions of Vedder and others (1957).

Athough the Topanga Group rocks occur in both the San Gabriel Mountains assemblage and the Peninsular Ranges assemblage, the units are discussed only here under the Peninsular Ranges assemblage. In the Description of Map Units, Topanga Group rocks are shown and described as they occur in each assemblage.

In the Azusa area (fig. 1) of the San Gabriel Valley, the Topanga Group (Tt) consists of mostly marine sandstone and conglomerate that locally includes volcanic rocks. The section in the Azusa area is about 760 m thick (Shelton, 1955), and includes conglomeratic beds having clasts up to about one meter (photos 502 and 503). Most of the clasts resemble rocks in the adjacent San Gabriel Mountains, and some volcanic rock clasts resemble the Glendora Volcanics. Most of the exposed rocks are coarse-grained sandstone, some of which is cross-bedded, fine-grained, thin-bedded sandstone and siltstone, and diatomaceous, fissile, and partly silicified shale. Fine-grained rocks contain foraminifers indicative of Kleinpell's Lusian Stage and the highest beds contain fish scales that probably are uppermost Lusian or lowermost Mohnian (Shelton, 1955). The section also includes a mappable basalt layer about 30 m thick (Shelton, 1955), and where well exposed consists of pillow basalt (photo 219) indicating a submarine origin. This basalt appears similar to pillow basalts included within the Topanga Group (Conejo Volcanics of Yerkes and Campbell, 1979) in the Santa Monica Mountains (Blackerby, 1965).

In the South Hills, just south of Glendora (fig. 1), most of the Topanga Group (Tt) is massive and well bedded sandstone that commonly contains conglomerate lenses. It is about 600 m thick, about 35 to 40 percent of which consists of interbedded Glendora Volcanics.

Four Topanga Group units previously designated as members are here considered to be of formational rank. They occur variously on the north and west sides of the Santa Ana Mountains, in the San Jose Hills, and in the San Joaquin Hills.

Buzzard Peak Conglomerate—Woodford and others (1946) named a thick section of largely conglomeratic rocks in the San Jose Hills (fig. 1), the Buzzard Peak Member of the Topanga Formation after Buzzard Peak near the west end of the exposures. We here elevate this unit to formation rank, retaining all type area and type section definitions of Woodford and others (1946). The Buzzard Peak Conglomerate is the lowest unit of the Topanga Group in this area and is exposed along an anticline developed in predominatly sandstone of undifferentiated Topanga Group that overlies the conglomerate. In places, a thin layer of Glendora Volcanics (Shelton, 1955) separates Topanga Group rocks from the overlying Puente Formation. Surface exposures of the Buzzard Peak Conglomerate have a maximum thickness of 600 m, but the base is not exposed. Combined surface and subsurface thickness reaches 900 m. Most of the unit is well indurated sandy conglomerate (photo 227) and coarse-grained pebbly sandstone containing rare silty beds. Many of the clasts are 60 to 75 cm in length, and most appear to be derived from the eastern San Gabriel Mountains. Clasts of mylonitic rocks derived from bedrock along the southern edge of the San Gabriel Mountains are particulariy distinctive. A limited faunal assemblage suggests the Buzzard Peak Conglomerate falls in the Luisian and Relizian stages of Kleinpell (1938). Except for the differences in clast composition, the Buzzard Peak Conglomerate is similar to the Topanga Canyon Formation in the Santa Monica Mountains (R.H. Campbell, written commun., 2005)

Undivided Topanga Group, Santa Ana Mountains area—On the north and west flanks of the Santa Ana Mountains, conglomerate forms the basal part of the undifferentiated Topanga Group (Tt), but is not mapped as a separate unit. There it consists of a well cemented conglomerate bed two to nine meters in thickness that contrasts with the less resistant Sespe-Vaqueros rocks below it. Above the conglomerate are rocks consisting mainly of medium-to coarse-grained sandstone. The thickest part of the unit in this area is 689 m. Between Weir and Gypsum Canyons (fig. 1), Black Star Canyon 7.5' quadrangle, the lower and middle part of the section consists of soft sandstone and siltstone (Schoellhamer, 1981). Locally, east of El Modeno, Orange 7.5' quadrangle (fig. 1), there are a few tuff beds 1.5 to 3 meters thick.

The unit contains a fauna including *Turritella ocoyana*, *Turritella*. cf. *T. ocoyana topangensis*, *T. temblorensis*, *Leptopecten andersoni*, *Chione temblorensis*, *Crassostrea* cf. *titan subtitan*, and *Vertipecten nevadanus*. Limited foraminifers are questionably assigned to the Relizian Stage of Kleinpell (1938).

San Joaquin Hills-Laguna Beach area—In the San Joaquin Hills-Laguna Beach area the Topanga Group includes three formations, from youngest to oldest, the Paulerino, Los Trancos, and Bommer (members of Vedder, and others, 1957). Blake (1991) considers the Paulerino Formation as

Middle to early Miocene (Kleinpell's lower Luisian to upper Relizian Stages), Los Trancos Formation (Early Mioccene (Kleinpell's Relizian Stage), and the Bommer Formation Early Miocene (Kleinpell's Relizian Stage). The Bommer and Paulerino Formations appear to be the age equivalent of the Topanga Canyon Formation in the Santa Monica Mountains (R.H. Campbell, personal communication, 2005).

Bommer Formation—The Bommer Formation (Ttb) consists of gray to brownish gray, thick bedded, medium to coarse grained sandstone and interbedded fine grained sandstone and siltstone. All of the rocks are locally conglomeratic. The unit was named the Bommer Member of the Topanga Formation by Vedder (1957) for Bommer Canyon in the northern part of the San Joaquin Hills (fig. 1). The type area is from upper Moro Canyon to the mouth of Bommer Canyon. In that area, the Bommer conformably overlies the Vaqueros Formation, and contains middle Miocene *Turritella oyacana* thoughout the unit.

Los Trancos Formation—The Los Trancos Formation (Ttlt) is mostly pale gray to brownish-gray, thin- to medium-bedded siltstone and fine-grained sandstone. It includes some interbedded medium- to coarse-grained sandstone and shale beds. The unit was originally named the Los Trancos Member of the Topanga Formation by Vedder (1957) after Los Trancos Canyon in the San Joaquin Hills. Typical exposures are located between Los Trancos Canyon and Bonita Canyon, northern San Joaquin Hills (fig. 1). Clasts of blueschist and related rocks occur thoughout the Los Trancos Formation, and indicate a western offshore source for at least part of the unit (Woodford and others, 1946). The unit conformably overlies the Bommer Formation and is overlain disconformably by the Paulerino Formation. Foraminifera indicate the Los Trancos Formation belongs to the middle Miocene Relizian Stage of Kleinpell (1938). The Los Trancos Formation is up to 945 m thick.

Paulerino Formation—The Paulerino Formation (Ttp) consists mainly of a poorly exposed sequence of interbedded sandstone, siltstone and breccia; some of the sandstone includes tuffaceous beds. Breccia in the unit is restricted to discrete beds, and is mainly composed of andesitic clasts. Originally named the Paulerino Member of the Topanga Formation by Vedder (1957) for exposures in the area of Paulerino Avenue in the San Joaquin Hills, the type area is just north of Bonita Reservoir on Bonita Creek at the north edge of the San Joaquin Hills (fig. 1). Maximum thickness is about 380 m. Fossils suggest that the Paulerino corretlates with the lower part of the Luisian or the Relizian Stage of Kleinpell (1938). A whole-rock potassium-argon age on andesite at the base of the Paulerino Formation is 15.8 ±1.3 Ma. (Weigand, 1994). The unit is unconformably overlain by the Capistrano Formation (Tc) of late Miocene and early Pliocene age.

San Onofre Breccia—The San Onofre Breccia (Tsob) was named by Ellis and Lee (1919) for exposures in the San Onofre Hills or San Onofre Mountain (It is not clear from Ellis and Lee (1919) if the exposures were in the San Onofre Hills or San Onofre Mountain.). They considered the breccia to be early Miocene and interpreted it to have been derived from a western source area. The distinctive glaucophane schist clasts (photos 4, 6, and 7), which were recognized much earlier by Fairbanks (1892), formed part of the basis for their proposed source direction. Vander Leck (1921) used the term conglomerate in describing the unit. Woodford (1925) thoroughly studied the deposits, and termed them the San Onofre facies of the Temblor and the San Onofre facies of the Temblor formation (Woodford, 1925), based on the presence of the *Turritella ocoyana* zone of the Monterey Series.

The marine San Onofre Breccia is mainly green, greenish gray, gray, brown, and white sedimentary breccia, conglomerate, and lithic sandstone, and lesser siltstone, and mudstone (photos 4, 6, 7, and 8). It is well-indurated, and massive to well bedded; finer-grained parts are generally well-bedded, and massive coarse-grained parts are poorly bedded. Locally it contains diatomaceous shale and tuff beds. Breccia consists of large angular and subrounded clasts characterized by blueschist and related rocks derived from the Catalina Schist (Woodford, 1924). The unit is up to 900 m thick.

Monterey Formation—The name Monterey Formation (Tm) was first used by Blake (1856b) for siliceous and diatomaceous shale and siltstone at Monterey in northern California (Blake, 1856b). The name has been extended south through the Coast Ranges through the Los Angeles basin and into the San Joaquin Hills. The Monterey has been referred to as 'formation', 'shale', and 'series'. Strata in the Los Angeles Basin area have been termed the Monterey Shale (Woodring and others, 1946), and in the San Joaquin Hills the term Monterey Formation is used (Vedder and others, 1957). We follow Blake's (1856) and Vedder and others (1957) usage of the term formation.

The Monterey Formation consists of interbedded platy siltstone and sandstone. In the San Joaquin Hills, the thinly bedded siltstone ranges in color from white to brown, and contains biotite flakes, abundant fish remains and foraminifers and locally, diatoms. The sandstone is tan, fine to medium grained and feldspathic. The unit there is up to about 75 m thick, and is very landslide prone. In the San Juan Capistrano area (fig. 1), the Monterey Formation grades locally into the lower part of the Puente Formation.

Based on foraminifers the Monterey Formation in the San Joaquin Hills-San Juan Capistrano area belongs to the Luisian and lower Mohnian Stages of Kleinpell (1938). Elswhere, the Monterey Formation is Relizian, Luisian, and Mohian (Santa Monica Mountains), and in places Delmontian (Monterey Bay area) (written commun., R.H. Campbell, 2005).

Puente Formation—The marine Puente Formation (Tp) consists of a very thick section of early Pliocene to late Miocene sandstone, siltstone, and shale that underlies most of the Puente Hills (fig. 1), and extends into adjacent areas. In the Puente Hills area where the unit reaches a maximum thickness of nearly 4,000 m, it is divisible into four subunits. Westward, toward the central part of the Los Angles basin, distinguishing characteristics of the members merge; overall the formation becomes more uniform, and is generally not divisible into members on the basis of lithology.

The Puente Formation was named by Eldrige and Arnold (1907) for exposures in the Puente Hills. English (1926) extended distribution of the Puente Formation to areas south of the Puente Hills and subdivided the Puente into three units based on lithology, from youngest to oldest, (1) shale, sandstone, and conglomerate, (2) sandstone, and (3) shale. Daviess and Woodford (1949) further subdivided the Puente Formation in the Puente Hills into four members, from youngest to oldest, (1) Sycamore Canyon Member, (2) upper siltstone member, (3) sandstone member, and (4) lower siltstone member. Schoellhamer and others (1954) formalized Daviess and Woodford's (1949) subdivisions and added member names; (1) Sycamore Canyon Member, (2) Yorba Member, (3) Soquel Member, and (4) La Vida Member. In most places the contacts between all of the members are gradational.

The Puente Formation is generally considered to be coeval with the late Miocene part of the Monterey Shale. Dibblee (e.g., 2001a, 2001b) considers the Yorba, Soquel, and La Vida Members to be subdivisions of the Monterey Formation and named them the Yorba Shale Member, Soquel Sandstone Member and the La Vida Shale Member of the Monterey Formation. He elevated the Sycamore Canyon Member to the Sycamore Canyon Formation. Because the Monterey is a consistent and distinct lithologic unit over its extent from the Monterey area into the San Joaquin Hills, and is particularly distinct lithologically from the Puente Formation, we here retain the usage of Schoellhamer and others (1954) for the Puente Formation nomenclature and do not include any part of the Puente Formation in the Monterey Formation.

The age of Puente Formation is early Pliocene to late Miocene; the unit contains foraminifera of the Mohnian and Delmontian stages of Kleinpell (1938).

La Vida Member—The La Vida Member (Tplv) is primarily siltstone and subordinate sandstone, and locally includes porcellaneous siltstone or shale and a few beds of vitric tuff. It was named for exposures near La Vida Mineral Springs in the eastern Puente Hills (fig. 1) (Schoellhamer and others, 1954). Siltstone in the unit is light gray to black, massive to well bedded, and generally friable. Weathered surfaces are typically white or pale gray. Rocks in this member contain widespread fish remains, abundant foraminifera, local phosphate nodules, and sparse limy siltstone. Interbedded sandstone ranges from two centimeters to over one meter in thickness. Reflecting its incompetent nature, the La Vida Member is commonly tightly folded in contrast to the other Puente members. The La Vida Member contains forminifera of Kleinpell's Mohian Stage. At the limited places the contact is exposed, the La Vida unconformably overlies the Topanga Formation.

Soquel Member—The Soquel Member (Tpsq) is made up of sandstone and siltstone, although sandstone is the predominant lithology (photo 228). It was named by Schoellhamer and others (1954) for exposures in Soquel Canyon in the eastern Puente Hills (fig. 1), and consists mainly of gray to yellowish gray, massive to well bedded, medium to coarse grained, poorly sorted sandstone interbedded with matrix-supported pebbly sandstone. Many sandstone beds are graded, and locally the unit is conglomeratic. The lower part of section commonly contains ellipsoidal calcite-cemented concretions 30 cm to 1.5 m in diameter.

Yorba Member—The Yorba Member (Tpy) consists primarily of siltstone and sandstone, and is named for exposures at Yorba Bridge east of Atwood (fig. 1). The unit is a sucession of white to gray, thin bedded, micaceous and siliceous siltstone and sandy siltstone (Schoellhamer and others, 1954), which includes beds of fine-grained sandstone and white- to pale-gray limy concretions and concretionary beds (photo 229). In the eastern Puente Hills, the upper part of the Yorba Member contains large matrix-supported boulders in relatively fine-grained rocks and was interpreted to be a turbidity current deposit (Durham and Yerkes, 1959). Based on the description of Durham and Yerkes, this boulder deposit is probably a submarine landslide deposit. Locally the unit contains mappable (at 1:24,000 scale) conglomeratic intervals.

Sycamore Canyon Member—The Sycamore Canyon Member (Tpsc) is early Pliocene to late Miocene and consists predominantly of sandstone and pebble conglomerate (photo 230). The name comes from a stratigraphic section exposed at Sycamore Canyon just west of the map area (San Dimas 7.5' quadrangle) in the northwestern Puente Hills (Daviess and Woodford, 1949). The Sycamone Canyon Member is lithologically variable laterally and is composed of pale gray, thick-bedded to massive, medium to coarse grained, friable sandstone; pale gray, thin-bedded, siliceous siltstone; pale gray, poorly bedded siltstone; and brownish-gray, massive conglomerate. It contains a bathyal depth foraminiferal fauna (Yerkes, 1972), and locally has mappable (1:24,000 scale) conglomeratic zones. In the southeast part of the Puente Hills, a section of sandstone and conglomerate (see description of sandstone and conglomerate in southeastern Chino Hills (photo 569)) (Tch) is included by some workers as part of the Sycamore Canyon Member, but here is considered to be a separate unit.

Capistrano Formation—The marine late Miocene and early Pliocene Capistrano Formation (Tc) was named by Woodford (1925) for exposures in the San Juan Capistrano area (fig. 1) where it consists mainly of friable siltstone and sandy siltstone. Northward from San Juan Capistrano to Arroyo Trabuco, the grain size increases to form a white- to light-gray, massive, medium- to coarse-grained, friable sandstone facies. In the area of San Juan Capistrano to Dana Point (just south of the Santa Ana quadrangle), the Capistrano Formation contains late Miocene and early Pliocene foraminifera, shark teeth, echinoids, and whalebones (White, 1956, 1971; Ingle, 1971, 1972; Vedder, 1972). The Capistrano Formation includes one formal and one informal member.

Oso Member—A sandstone facies was recognized by Vedder and others (1957) as a formal member of the Capistrano Formation and termed the Oso Member (Tco). The name comes from Oso Creek located between Aliso Creek and Arroyo Trabuco (fig. 1). The type locality is about 4 km east of El Toro between Agua Chinon Wash and Oso Creek. Most of the Oso Member consists of white friable, crudely bedded or massive, coarse grained feldspathic sandstone (Vedder and others, 1957) that weathers to soil covered slopes having few exposures. At places, it contains scattered matrix-supported pebbles and cobbles.

The Oso Member is probably equivalent to the lower part of the undivided Capistrano Formation (Vedder, 1972). In some areas the Oso Member rests conformably on the Soquel Member of the Puente Formation, and thus is probably correlative with part of the Yorba Member and possibly part of the Sycamore Canyon Member of the Puente Formation (Schoellhamer and others, 1981). In other areas the Oso Member rests unconformably on Monterey Formation and interfingers with the undivided Capistrano Formation. The Oso Member is unconformably overlain by the Niguel Formation. Maximum thickness is about 450 m. The upper part of the Oso Member contains foraminifers of Kleinpell's upper Mohnian or Delmontian Stage (Vedder and others, 1957).

Siltstone facies—Morton and Miller (1981) defined an informal siltstone facies (Tcs) within the Capistrano Formation in southern Orange County. This siltstone facies consists of white to pale gray, massive to crudely bedded, friable, siltstone and mudstone. It contains sandstone and calcareous mudstone beds, and sparse diatomaceous and tuffaceous beds. The unit is up to 730 m thick.

Sandstone and conglomerate in southeastern Chino Hills—Poorly exposed marine and nonmarine sandstone and conglomerate (photo 569) (Tch) rests on the Sycamore Canyon Member of the Puente Formation in the Arena Blanca syncline area in the southeastern Chino Hills (fig. 1), Prado Dam 7.5' quadrangle. This is probably the section that earlier had been described as 'rocks commonly called Repetto Formation' (Woodford and others, 1954). Stewart and Stewart (1930) and Woodford and others (1944) reported Pliocene foraminifera from these rocks. Similar appearing rocks southeast of Wardlow Wash, Bedford Canyon, and Brown Canyon along the west side of the Santa Ana Mountains are included in this unit (Gray, 1961). Smith (1960) described Pliocene foraminifera from these rocks. A meager megafauna was collected on the northwest side of Bedford Canyon that included a fragment of *Cantharus sp*. of Pliocene age (Gray, 1961).

In the Chino Hills, this unit was differentiated from the underlying Puente Formation by Daviess and Woodford (1949), Woodford and others (1954), and Gray (1961) but was included within the Puente Formation by Durham and Yerkes (1964). Fossils obtained from sand and gravel quarrying included marine invertebrate and nonmarine flora (R.E. Reynolds, oral commun., 1998). J.G. Vedder (oral commun. to T. H. McCulloh, 1997) identified a relatively large molluscan taxa from material collected by R.E. Reynolds. Vedder considered the best correlation of the molluscan taxa is to the lower part of the Pliocene

Fernando Formation and the upper part of the Capistrano Formation. Forminifera collected about 1996 by T.H. McCulloh were identified as Delmontian (T.H. McCulloh, oral commun., 1997), which indicates this unit is in part coeval with the Sycamore Canyon Member of the Puente Formation.

Fernando Formation—The Fernando Formation (Tf) was named by Eldridge and Arnold (1907) for Pliocene marine strata in the Los Angeles and Ventura basins. The type area is on the north side of the San Fernando Valley. English (1926) informally elevated the Fernando Formation to group rank and later Kew (1924) formalized the elevated rank for deposits in the Ventura basin. Kew's (1924) Fernando group included the Pliocene 'Pico' Formation and the Pliocene and Pleistocene Saugus Formation. English (1926) in the Puente Hills area used Fernando Formation for Pliocene strata and for what is now the upper part of the underlying Sycamore Canyon Member of the Puente Formation. Later for the Los Angeles Basin the upper Pliocene strata was termed the Pico Formation and the lower Pliocene termed the Repetto Formation (Reed, 1932). A lithologic boundary for the Repetto could not be determined at the type section in the Repetto Hills (Durham and Yerkes, 1964) so the Pico Formation is a biostratigraphic unit, not a lithologic unit. For these reasons Durham and Yerkes (1964) reduced the Fernando back to formation status for the Pliocene strata in the Puente Hills.

For most of the eastern Los Angeles basin, the Fernando Formation can be divided into an informal upper (Tfu) and lower member (Tfl). The lower member corresponds approximately to the Repetto Formation of previous workers and consists primarily of massive to crudely bedded, micaceous, brownish siltstone that contains some thin interbeds of pebbly conglomerate (Yerkes and Durham, 1964). South of Olinda, on the south side of the Puente Hills, the lower member attains a thickness of over 350 m (Yerkes and Durham, 1964). The upper member corresponds approximately to the Pico Formation of earlier workers. This member unconformably overlies the lower member and consists primarily of sandstone, pebbly sandstone, and conglomerate. The lower conglomeratic part of the upper member is mostly cliff-forming well-cemented conglomerate and pebbly sandstone. The thickest part of the section is north of Yorba Linda where it is over 420 m thick (Durham and Yerkes, 1964). The lower member is of early Pliocene age and probably correlates with the upper part of the Capistrano Formation in the San Joaquin Hills area (Schoellhamer and others, 1981). The upper member apparently corresponds to the Etchegoin and San Joaquin megafaunal stages (Durham and Yerkes, 1964).

Niguel Formation—The Pliocene marine Niguel Formation (Tn) was named by Vedder and others (1957) from the Niguel land grant in the San Juan Capistrano 7.5' quadrangle. The type area is just west of the Galivan Overpass on U.S. 101, about seven kilometers north of San Juan Capistrano (fig. 1). Most of the Niguel Formation consists of slightly consolidated, gray to white, micaecous, feldspathic, fine- to coarse-grained sandstone interbedded with sandy siltstone. It locally contains conglomerate and breccia in the lowest part of the formation. The lower part of the section contains late Pliocene marine fossils and the upper part lacks fossils and may be nonmarine (Schoellhamer and others, 1981). The formation unconformably overlies the Capistrano Formation (Tc) and the Monterey Formation (Tm). Deposits that were mapped and named the San Mateo Formation by Woodford (1925) along Cañada Salada north of Dana Point (San Juan Capistrano Point), are now included within the Niguel Formation. The San Mateo Formation is retained for the deposits Woodford (1925) mapped south of the Santa Ana quadrangle between Arroyo San Mateo and Arroyo San Onofre. The Niguel Formation has a maximum thickness of about 100 m.

Sandstone of Norco area—In the Norco-Home Gardens area (fig. 1), scattered occurrences of marine sands (Tns), are here referred to as the sandstone of Norco area. This unit may be an eastern, shallow-water extension of the upper part of the Fernando Formation, and is rarely seen outside of artifical exposures; a number of occurrances have been completely removed or covered during building construction. Most deposits consist of greenish-yellow to pale-tan unconsolidated sandstone containing a few conglomerate lenses, which contains clasts of well rounded welded tuff. Occurrences of the conglomerate include deposits on the basement surface of low relief around Norco and deposits buttressed against steep basement rock faces (photo 231). Sandstone recovered from a shallow excavation near the intersection of Parkridge and Lincoln in the southern part of Norco contained a shallow marine fauna including *Anadara* cf. *A. trilineata* (Conrad), *Chione* sp., *Lucinoma* cf. *L. annulata* (Reeve), and *Diodora* sp. (J.D. Mount, written commun., 1973).

An occurrence of sand buttressed against granitic rock formed a low hill, now removed by construction, at Porphyry siding on the Atchison Topeka and Santa Fe Railway between Corona and Home Garden. The top of the granitic rock contained what appeared to be paleo tidepools. A few barnacles and echinoid spines were found in the sand near the granitic rock. Volcanic ash that was deposited in and across the tidepools is the ash of Blind Springs Valley, dated as 2.14 to 2.22 Ma (Sarna-Wojcicki, and others, in press). The tuff was overlain by continental deposits of cobbly sediments that contained the remains of *mammut* sp. that has an age range of four million to about 10,000 yrs bp (M.O. Woodburne, written commun., 2004). The sandstone of Norco area apparently is the eastern extent of the marine deposits of the Pliocene Los Angeles Basin.

Neogene to Pleistocene sedimentary rocks and deposits of interior basins

Inland from the Los Angeles Basin, Miocene, Pliocene, and Pleistocene nonmarine sedimentary rocks are found in the San Timoteo Badlands (photos 12 and 13), Pliocene strata in the Temecula area, and remnants of fluvial and lacustrine Miocene strata in the vicinity of Lake Mathews.

Temecula basin

The Temecula basin is an east-trending continental basin extending from the Elsinore Fault Zone in the Temecula area (Murrieta and Bachelor Mountain 7.5' quadrangles) eastward into the adjacent Palm Springs 30'x60' quadrangle.

Temecula Arkose—The oldest sedimentary rocks in the basin are termed the Temecula Arkose (Tta), named by Mann (1955) for exposures of nonmarine fluvial sandstone exposed southeast of Temecula (fig. 1). The Temecula Arkose is mainly pale greenish-yellow, medium- to coarse-grained indurated sandstone that includes thin discontinuous beds of tuffaceous sandstone, siltstone, and claystone, and some pebble and conglomerate beds having locally derived clasts. Kennedy (1977) assigned the unit a late Pliocene Blancan IV-V mammal age (2.2 to 2.8 Ma) based on vertebrate assemblages collected east of the quadrangle. Assemblages include *Nannippus, Hypolagus, Tetrameryx, Equus,* and *Odocoileus* (Golz and others, 1977). Later work establishes the first occurrence of *Tetrameryx* as Irvingtonian I rather than late Blancan (Woodburne, 1987), placing the Temecula Arkose age nearer 1.9 Ma (late Pliocene) than 2.2 Ma. A microtine fauna from the unit in the Radec area, about eight kilometers east of the quadrangle, is considered to have an age of 4.6 Ma (Blancan I) (Repenning, 1987). The thickness of the Temecula Arkose ranges from 90 to over 550 m (Kennedy, 1977).

Sandstone and conglomerate of Wildomar area—The informal name, sandstone and conglomerate of Wildomar area, is here used for a previously unnamed sequence of coarse-grained sandstone, pebbly sandstone, and conglomerate (Kennedy, 1977) exposed in the vicinity of Wildomar in the Murrieta 7.5' quadrangle (photo 232). Most of the unit is friable to relatively well consolidated, pale gray to greenish gray, crudely and discontinuously bedded (QTws). Feldspars are commonly decomposed. The lower part of the sequence (QTwc) is primarily conglomeratic, and the subrounded clasts appear to be locally derived. This part of the unit consists primarily of cobble and boulder conglomerate composed of locally derived rocks. The upper part consists primarily of medium-grained sandstone that commonly includes caliche.

The lower part of the sequence contains a vertebrate fauna of middle to late Blancan age (2 to 3 Ma) (Bell and others, 2004) and the upper part an Ivingtonian age (Bell and others, 2004) of less than 0.85 Ma (Reynolds and Reynolds, 1990a, 1990b; Reynolds and others, 1990). In the Murrieta area, at Chaney Hill (fig. 1), this unit contains the 0.7 Ma Bishop ash (Merriam and Bishoff, 1975). Deposits spanning the early Quaternary and late Tertiary include widespread sandstone and conglomerate that underlies the Pauba Formation in the Wildomar area. Also mapped as part of this unit are a few small, isolated remnants of conglomerate and gravely sand in the Riverside-Norco areas (Morton and Cox, 2001a, 2001b).

Pauba Formation—The Pauba Formation lies unconformably above the sandstone and conglomerate of Wildomar area. It was named by Mann (1955) for exposures in the Rancho Pauba area about 3.2 km southeast of Temecula, and consists of siltstone, sandstone, and conglomerate (photo 233). A vertebrate fauna from the Pauba Formation is of late Irvingtonian and early Rancholabrean ages (Reynolds and Reynolds, 1990a; 1990b). The Pauba Formation includes two informal members. An upper sandstone member (Qps) consists of brown, moderately well-indurated, cross-bedded sandstone containing sparse cobble to boulder conglomerate beds. A lower fanglomerate member (Qpf) consists of grayish brown, well indurated, poorly sorted fanglomerate and mudstone.

San Timoteo basin

A thick sequence of Miocene to Pleistocene continental deposits underlies the San Timoteo Badlands at the north end of the San Jacinto block. Two major units are represented, the Mount Eden Formation, and the San Timoteo Beds.

Mount Eden Formation—The Mount Eden Formation (Tme), is early Pliocene and Miocene, and consists of sandstone, mudrock, conglomeratic sandstone, and sedimentary breccia. These rocks were first described by Frick (1921) who termed them the Eden beds. As this name was preempted, Fraser (1931) replaced it with the Mount Eden Formation for exposures in the vicinity of Mount Eden. Five informal members are currently recognized.

A basal conglomeratic sandstone member (Tmec) consists of reddish brown, massive to indistinctly bedded, coarse grained sandstone, pebbly sandstone, and conglomerate (photo 234). The lower part is dominated by conglomerate and the upper part by sandstone. The conglomerate consists of moderately decomposed clasts locally derived from Peninsular Ranges Province basement rocks.

Conformably above, and partly interfingering with, the basal member, is an arkosic sandstone member (Tmea) that consists of mostly coarse grained arkosic sandstone, pebbly sandstone, and conglomerate. This unit is thick and indistinctly bedded, moderately to well-indurated, pale tan, gray, greenish gray, and reddish brown. It includes some interbeds of fine-grained sandstone, siltstone, and rare shale, in addition to sparse limey concretions, which are common in the overlying lower sandstone member. Because they locally interfinger, the arkosic sandstone member is possibly coeval or in part coeval with the underlying conglomeratic sandstone.

Within the arkosic sandstone member there are lenses of monolithologic boulder breccia (Tmeb) that are apparently debris flow deposits. Giant clasts in the breccia are up to six meters in diameter (photos 235 and 236). These breccia tongues occur at several different horizons mostly in the Lamb Canyon and Laborde Canyon areas (fig. 1). Clasts are Cretaceous tonalite of Lamb Canyon (Klct), a massive sphene-bearing biotite-hornblende tonalite, which crops out in the northeastern part of the El Casco 7.5' quadrangle. Sparse, large lag boulders of a somewhat similar tonalite occur on metamorphic rocks high on the east side of Lamb Canyon. A few of these boulders have tumbled down to the lower part of the canyon. Although these boulders superficially resemble the tonalite of Lamb Canyon boulders, they are derived from a different tonalite unit and their source appears to be to the north in the vicinity of the eastern Box Springs Mountains (fig. 1).

Overlying the the arkosic sandstone member is a heterogeneous member (Tmeh) of green, olive green, and gray sandstone, pebbly sandstone, and minor limestone; it locally contains abundant limey concretions (photo 424). Mudrock is distinctly subordinate in this member. Southeastward, rock of this member is progressively more indurated, and in southeastern exposures is ledge-forming sandstone and pebbly sandstone. On the north side of Mount Eden, well indurated rock contains a middle Miocene Mount Eden local fauna. Overlying is a mostly hackly fracturing to locally fissile, dark gray-green mudrock. This member weathers to form smooth rounded slopes.

The uppermost rocks of the Mount Eden Formation **c**onsist principally of interbedded sandstone and mudrock. The dominant lithology is moderately well indurated, ledge forming, thin to medium bedded, well sorted pale-brown sandstone, which is characterized by climbing ripple laminations, convoluted bedding, and locally cross-laminations. This sandstolne is interbedded with subordinate thin to medium bedded intervals of fissile to hackly-fracturing mudrock.

Frick (1921) quarried extensively for fossils on the north side of Mount Eden and described a rather large vertebrate fauna (Frick, 1921, 1933, and 1937). Later, May and Repenning (1982), Harrison (1985), Repenning (1987), and Albright (1997, 1999a, 199b) expanded the vertebrate fauna list from the unit. Based on the vertebrate fossils that constitute the Mount Eden local fauna, the unit is late Hemphillian to early Blancan and ranges in age from about 4.5 to 6 Ma (Tedford and others, 2004). Axelrod (1937, 1950) described the flora from the Mount Eden Formation.

San Timoteo Beds—The San Timoteo Beds, which consists of lithologically diverse sandstone, conglomeratic sandstone, and conglomerate, overlies the Mount Eden Formation. It was named by Frick (1921) for Pleistocene, vertebrate-bearing, nonmarine strata in San Timoteo Canyon; the unit ranges from Pliocene to mid-Pleistocene, about 4.3 to 0.7 Ma. Nearly all the sandstone is arkosic and much is lithic. Clasts within the San Timoteo Beds appear to be entirely derived from Transverse Ranges source rocks and are similar in composition to rocks presently exposed in the eastern San Gabriel Mountains, central San Bernardino Mountains, and in the San Bernardino-Yucaipa area (Matti and Morton, 1993).

In the past, the contact between San Timoteo Beds and the underlying Mount Eden Formation has been inconsistently placed at differing stratigraphic positions. Although still somewhat in dispute, in this report the contact is placed at the boundary between older fluvial-lacustrine deposits and younger fluvial-alluvial fan deposits. Age of this boundary is about 4.3 Ma (L. B. Albright, written commun., 1998). Currently the San Timoteo Beds include five informal members, and four subdivisions within the members.

Hackly fracturing to locally fissile, dark gray-green mudrock makes up the informally named fine-grained member (Tstf), the lowest unit of the San Timoteo Beds. The unit weathers to form smooth rounded slopes (photo 423). Overlying the fine-grained member is the informally named ripple-laminated member (Tstrl), which consists principally of interbedded sandstone and mudrock. The sandstone is characterized by climbing ripple laminations, convoluted bedding, and locally cross-laminations (photo 422), and is interbedded with subordinate thin-to medium-bedded intervals of fissile to hackly-fracturing mudrock.

The Pliocene lower member (Tstl) consists mostly of gray, moderately well indurated, well sorted fine-grained sandstone containing subordinate pebble lenses, and sparse medium-grained sandstone beds. These beds probably represent distal flood plain deposits. The lower member erodes to form slightly more rounded badland topography than younger parts of the San Timoteo Beds. Included within and at the base of the lower member is an interval of pale tan to reddish brown, thin to thick bedded, coarse grained arkosic sandstone ($Tstl_1$). Above these basal beds is a section of mostly greenish-gray claystone and siltstone and thick, poorly bedded coarse grained sandstone ($Tstl_1$). Highly deformed sandstone, pebbly sandstone, and conglomerate located along the western part of the San Timoteo badlands adjacent to the San Jacinto Fault Zone, is placed within this latter unit, but the stratigraphic position of these highly deformed rocks within the lower member is not known.

The middle member (Tstm), also Pliocene, is dominatly light-gray, pebbly to cobbley, moderately to well indurated, medium to coarse grained sandstone containing conglomerate beds up to nine meters in thickness (photos 237, 51, and 53). Pale- brown to light-gray fine-grained sandstone to pebbly sandstone is subordinate. Overall, the middle member consists of about 70 percent sandstone and 30 percent conglomerate, the conglomerate more abundant in the upper part. Included are common reddish-brown stratigraphic intervals consisting of oxidized sandstone, that are not paleosols, and reddish-brown clay-rich intervals, which may be paleosols (photo 238). The middle member erodes to form sharp-ridged badlands topography distinct from the lower member; these hogbacks are developed extensively on the north side of San Timoteo Canyon.

The upper member (Qstu), of Pleistocene age, is mostly gray coarse-grained, moderately-indurated sandstone and conglomerate. It contains early Pleistocene Irvingtonian I, Shutt Ranch and El Casco local faunas, that are about 1.8 Ma (Repenning, 1987). This unit erodes to form sharp-ridged badlands topography. Included within the upper member is a sequence of distinctive quartzite bearing conglomerate beds located next to the San Jacinto Fault Zone at the north end of the San Timoteo Badlands. This well-indurated conglomerate (Qstcq) consists largely of clasts derived from the central part of the San Bernardino Mountains. It is characterized by quartzite clasts derived from a Precambrian terrain and by megaporphyry clasts (Matti and Morton, 1993; Morton and others, 1986). The unit contains an early Pleistocene Irvingtonian I, Olive Dell local fauna (Repenning, 1987) that is about 1.3 Ma.

Also included within the upper member is an unconsolidated section of conglomeratic sand (Qsts) that appears to be derived from adjacent sedimentary beds. It is localized, forming a small lens-shaped body along the crest of an anticline in the the western part of the San Timoteo Badlands.

The upper part of San Timoteo beds contain three vertebrate faunas, the Olive Dell, El Casco, and Shutt Ranch local faunas of earliest Pleistocene Irvingtonian I age (Repenning, 1987). Eckis had earlier suggested a Pleistocene age for the upper part of section in 1934. Albright (1997) collected vertebrate fossils throughout most of the upper part of the unit. All parts of San Timoteo Beds below the upper member are late Pliocene, Hemphillian age.

Pleistocene

Sedimentary deposits

San Pedro Formation—The Pleistocene San Pedro Formation (Qsp) was first described as the San Pedro sand by Dall in 1898 and was named for exposures at Harbor Hill, near the head of San Pedro Harbor. Kew (1923) formally changed the name to San Pedro Formation. Most of the unit lies along the Newport-Inglewood Fault Zone, and at Newport Bay, Palos Verdes Hills, and in the San Pedro Harbor area. Maximum exposed thickness in the Puente Hills area is 100 m, but in subsurface it is about 535 m (Yerkes, 1972). In the La Habra area (fig 1) the San Pedro Formation rests conformably upon the Pliocene Fernando Formation (Tf), and consists mostly of barely consolidated massive sandstone, minor pebbly sandstone, and sandy conglomeratic beds. A basal conglomerate, consisting of mostly one centimeter size clasts, is well indurated. Tan (1988) divided the San Pedro Formation in the southern La Habra 7.5' quadrangle into four mappable units, including a lower sequence of siltstone and claystone overlain by sandstone. The sandstone is in turn overlain by additional siltstone and claystone, which is overlain by more sandstone. The San Pedro Formation contains a shallow water marine molluscan fauna.

Coyote Hills Formation—The Coyote Hills Formation (Qch) was named by Yerkes (1972) for exposures of nonmarine pebbly sandstone and mudstone in the Coyote Hills (fig 1). East of the Coyote

Hills, this unit was previously referred to as unnamed strata of Pleistocene age by Durham and Yerkes (1964). The type section is on the south flank of the East Coyote oil field structure (Yerkes, 1972), where the upper part of the unit consists of 150 m of 60 percent mudstone and 40 percent sandstone and pebbly sandstone, and the lower part, 66 m of pebbly sandstone. The mudstone is massive, includes some sandstone interbeds, and contains nonmarine mollusks, ostracodes, and plant remains. The pebbly sandstone is massively bedded and locally has interbeds of coarse-grained arkosic sandstone. Most of pebbles are less than one centimeter in length, but some are up to 1.5 cm. The formation rests unconformably on the San Pedro Formation. Based on its stratigraphically unconformable relationship with the underlying lower Pleistocene San Pedro Formation, the Coyote Hills Formation is considered to be of early late Pleistocene age (Yerkes, 1972).

La Habra Formation—Along the south side of the Puente Hills, a sequence of late Pleistocene nonmarine sandstone and silty conglomerate was originally included in the Fernando Formation by English (1926). These beds were subsequently termed the La Habra conglomerate by Eckis (1934), and later redefined as the La Habra Formation (Qlh) by Durham and Yerkes (1959). The type area is in the west-central part of the Yorba Linda 7.5' quadrangle (Durham and Yerkes, 1959).

The La Habra Formation consists of mudstone, sandstone, and conglomerate. The mudstone is friable, gray to brown, and sandy to pebbly. It locally contains fresh water snails and ostracodes. Sandstone is grayish to reddish brown, massive or crudely bedded, and not well cemented. A basal conglomerate and pebbly-sandstone about 12 m thick, is gray to brown, and massive to crudely bedded. Most of the clasts in the La Habra Formation were derived from the adjacent Puente Hills, and some were probably transported by the Santa Ana River (Durham and Yerkes, 1964). In the Yorba Linda 7.5' quadrangle, the upper part of the the La Habra Formation consists of a relatively uniform silty sandstone and siltstone, apparently derived entirely from the Puente Formation (Yerkes, 1972).

The formation ranges in thickness from about 150 to 300 m, thickest north of La Habra. Just west of the West Coyote Hills oil field, fragments of a tusk of *Elephas imperator* (?) were collected from the base of the unit (Yerkes, 1972). The La Habra Formation is probably correlative with the San Dimas Formation of Eckis (1934).

Unnamed deposits—Pleistocene deposits are dominated by nonmarine fluvial deposits in the Santa Ana basin except in the coastal area where narrow strips of paralic deposits occur. Lesser, young alluvial fans border the west side of the Santa Ana Mountains south of the Santa Ana River fan. Aspects of these Quarternary deposits are noted in the geomorphology section.

Extensive late Pleistocene and Holocene alluvial fans (Qf series) extend south from the San Gabriel Mountains. These deposits range from large boulderly deposits in the proximal part of the fans to sandy alluvium in the distal parts, and in the Fontana-Rialto-Colton areas include extensive eolian deposits. Widespread, valley-filling, dissected, mid to late Pleistocene alluvial-fan deposits occur south of the Santa Ana River. Most of these deposits consist of red brown, well indurated sandy alluvium, that commonly include lithified calcrete and less commonly silcrete intervals. In the Menifee Valley area and around Sun City (fig. 1), Pleistocene alluvial deposits adjacent to hills consist of well indurated, cemented cobbly alluvium.

Two separate occurrences of lithologically diverse, moderately-indurated, gray to brown, coarse-grained sandstone, pebbly sandstone, and conglomerate interpreted to be of Pleistocene age are located in the Riverside area (photo 239). In the Riverside West 7.5' quadrangle, most clasts in this unit (QTc) were derived from the San Bernardino Mountains. Southeast of Riverside, in the area near the interchange between California State Highway 60 (a freeway) and Interstate 215, is a poorly exposed unit of thick poorly bedded sandstone (QTs), pebbly sandstone, and conglomerate (photos 240 and 241). Clasts in the unit are locally derived from Peninsular Ranges sources.

Along the southern California coast in the map area and to the south, a large number of elevated Pleistocene and late Pliocene marine terrace deposits (Qp series) result from progressive and (or) episodic tectonic uplift of coastal southern California. Building on earlier work, published and unpublished mapping by Kern and coworkers has led to the recognition of 28 marine terraces that range in age from less than 80,000 to 3,090,000 years and range in elevation from 5 to 6 m to 408 to 413 m (Kern, 1996, Kern and others, 1996, and unpublished mapping). In the Santa Ana quadrangle Kern has mapped six of the youngest eight terraces that range in age from 80,000 to 450,000 years, in addition to undifferentiated older terrace(s). These terraces, labeled Qop_1, Qop_2, Qop_3, Qop_4, Qop_6, Qop_7 and Qvop on the map, are thin marine deposits on abrasion platforms produced in the intertidal and shallow subtidal zones. Generally the marine deposits are overlain by non-marine sediments.

Quaternary basins
San Jacinto basin

As used here, the San Jacinto basin refers to the Quaternary age structural basin located within the San Jacinto Fault Zone and not the San Jacinto River drainage basin as was used by Waring (1919). The San Jacinto basin is formed at a right-step between the Casa Loma and Claremont Faults of the San Jacinto Fault Zone. The maximum depth of the basin is about 3,000 m and is estimated to be no older than 1.5 Ma. Within the San Jacinto basin are very young Holocene deposits that include sizable areas subject to historic flooding and deposition. Apparently much of the young sedimentary fill is of low density and is subject to hydroconsolidation. Much of the alluvium in the Mystic Lake area (photo 242) contains large amounts of silt and clay

Elsinore basin

The Quaternary age Elsinore basin is a structural basin located within the Elsinore Fault Zone between the constituent Glen Ivy (photo 37) and North Fault on the northeast and the Wildomar and Willard Faults on the southwest. Like the San Jacinto basin the Elsinore basin is filled with young Quaternary sediments. Most of the basin is a closed basin, referred to as 'La Laguna', and the central part filled by Lake Elsinore. Prior to the intervention of man, Lake Elsinore was ephemeral, similar to Mystic Lake in the San Jacinto basin. The lower part of the basin is underlain by saline-alkali silty clay. The basin is flanked on the west by short, relatively steep alluvial fans at the base of canyons along the east side of the Santa Ana Mountains. Similar young fluvial deposits occur along the Elsinore Fault Zone in the Murrieta and Temecula area and include very fine grained alluvium in the area of Lake Elsinore.

San Gabriel Mountains assemblage

Introduction

The San Gabriel Mountains basement rock assemblage includes two discrete segments west of the San Andreas Fault, the high standing San Gabriel Mountains (photo 298) and the relatively low San Bernardino basin that lies between the San Andreas and San Jacinto Faults. The basement rock assemblage is characterized by a unique suite of rocks that includes rare Proterozoic anorthosite (Ꝑa), Proterozoic and Paleozoic gneiss and schist, the Triassic Mount Lowe Intrusive Suite, extensive deformed and undeformed Cretaceous granitic rocks, the Cretaceous Pelona Schist, and Oligocene granitic rocks. Internal structure of the assemblage includes the Vincent Thrust (photo 243, 565, and 566), at least two old, abandoned faults of the San Andreas Fault system, and extensive areas of pervasively mylonitized rocks.

The main body of the San Gabriel Mountains (fig. 1) is bounded on the north by the San Andreas Fault and on the south by the Sierra Madre-Cucamonga Fault Zones (Matti and Morton, 1993). The San Bernardino basin, an asymmetric pull-apart basin, bounded by the San Andreas Fault on the east and the San Jacinto Fault on the west, is underlain by the same rock units that characterize the San Gabriel Mountains (Morton and Matti, 1993).

Cretaceous and older rocks of the San Gabriel Mountains basement rock assemblage are divided into two structurally and lithologically distinct groups by the Vincent Thrust (photo 243 and 566), a regional, low-angle thrust fault that predates intrusion of Oligocene granitic rocks. The thrust, named for exposures in the Vincent Gap area west of the San Bernardino quadrangle, was first recognized by Levi Noble (unpublished mapping, 1928; published, 1954b), and later, investigated by Ehlig (1958), who first described the fault in detail and realized its regional tectonic importance. The Vincent Thrust (fig 1) separates the Mesozoic Pelona Schist in the lower plate from highly deformed Proterozoic, Palezoic, and Mesozoic gneiss and schist, and Mesozoic granitic rocks in the upper plate. The fault, along with its far-offset, dismembered analogs in the Orocopia and Chocolate mountains east of the Salton Sea, may underlie much of southern California (Haxel and Dillon, 1978; Ehlig, 1982; Grove and others, 2003). Oligocene granodiorite of Telegraph Peak (Tgtp) intrudes both the Vincent Thrust and upper and lower plate rocks in the eastern San Gabriel Mountains (photo 244), and a similar Oligocene granitic rock (Tgry) intrudes the Pelona Schist in the Crafton Hills, Yucaipa 7.5' quadrangle (fig. 1), in the low lying southern part of the San Bernardino basin (fig. 1).

The varied basement rocks of the San Gabriel Mountains have been described in terms of suspect terranes by a number of workers (e.g., Coney and others, 1980). Blake and others (1982), recognized two suspect terranes, the Tujunga and Baldy. Powell (1982a, 1982b) subdivided basement rock units in the southeastern Transverse Ranges into terranes and designated a distinctive suite of Proterozoic rocks in the San Gabriel Mountains as the San Gabriel terrane. Powell, however, used the term terrane in a more restricted sense, and not to designate a far traveled, exotic accreted block. Dibblee (1982) divided the

Tujunga terrane of Blake and others (1982) in the San Gabriel Mountains into two additional terranes, the San Sevaine terrane and San Antonio terrane. He retained the San Gabriel terrane of Powell (1982) although he used it in a different context than Powell defined it. Dibblee additionally referred to the Pelona Schist as a separate terrane. May and Walker (1989) interpreted the basement rocks in the southeastern San Gabriel Mountains in terms of an amalgamation of terranes, and renamed Dibblee's San Sevaine terrane the Cucamonga terrane, after exposures in Cucamonga Canyon. They interpreted the amalgamation of the Cucamonga, San Antonio, and San Gabriel terranes to have occurred in the Late Cretaceous, and subsequently, following Late Cretaceous magmatism, the terranes were amalgamated with the Baldy terrane; the Vincent Thrust is considered to be the terrane boundary. In this report the 'amalgamated' Cucamonga, San Antonio, and San Gabriel terranes are referred to as the upper plate rocks of the Vincent Thrust, and the tectonic entity below the Vincent Thrust, the Baldy terrane of Blake and others (1982), is referred to simply as the Pelona Schist.

Proterozoic rocks

Rocks of probable Proterozoic age extend along the southern range front of the San Gabriel Mountains from San Antonio Canyon to Lytle Creek (fig. 1) (Hsu, 1955; Morton, 1975 and 1976; May, 1986; Morton and Matti, 1987; May and Walker, 1989). They are considered by Dibblee (1982) to be Paleozoic. These rocks (Ꮲm) are garnet-pyroxene-bearing quartzofeldspathic gneiss (photo 245) and minor marble and calc-silicate rocks of lower granulite metamorphic grade (Ꮲm). During metamorphism premetamorphic layering (bedding?) was transposed to form gneissic layering (photo 246). Most of the unit was subsequently metamorphosed to amphibolite and greenschist grade during a period of mylonitization, and was intruded by tonalite and charnockite. The gneissic layering was transposed during the retrograde metamorphism (photos 247 and 248). Mylonitization, in part contemporaneous with plutonism, produced a pronounced planar mylonitic fabric (photo 249) that is primarily east striking and dips at low to moderate angles to the north (photo 604). East trending lineations and minor fold axes are subhorizontal or plunge at low angles.

Vergence of minor folds suggests movement of the San Gabriel Mountains westward relative to rocks to the south. At the mountain front, post-mylonitization deformation produced complex folds including non-homoaxial flow-flexural slip folds (photos 250 and 251). Morton and Matti (1987), May (1986 and 1989), and May and Walker (1989) present structural analyses of these and nearby basement rocks of the southeastern San Gabriel Mountains.

The age of the pre-granulite protolith is uncertain. It is considered Proterozoic, but could be Paleozoic. May and Walker (1989) found Proterozoic zircons with inheritance ages of 1,686, +148/-124 Ma and 1,666 +178/-170 Ma in the granulitic rocks. Age of of granulite metamorphism was as late as 108 Ma (May and Walker, 1989). Mylonitic tonalite associated with the granulitic rocks yield Uranium-lead ages of about 88 Ma (May and Walker, 1989). Most of this unit underwent retrograde metamorphism sometime before the close of the Cretaceous.

Other rocks of probable Proterozoic age, many of them closely intermixed with Mesozoic granitic rocks, are widespread in the core of the eastern San Gabriel Mountains. These rocks, especially the mixed metamorphic and granitic rocks of the Big Dalton Canyon unit (fig 1) (MzᏢb), are extremely heterogeneous, consisting of layered and augen gneiss, and gneissic amphibolite cut by Triassic, Cretaceous, and probably Jurassic granitic rocks. In the western part of the unit, mafic diorite makes up about one-third of the rocks, and various gneisses the remainder. Eastward in the unit, the rocks appear to be progressively more heterogeneous and mixed on a finer scale. Variably developed mylonitic fabric is common throughout the unit, but is more pervasively developed eastward and southward. This fabric is also developed in the Cretaceous granitic rocks that are intermixed with the older rocks.

Smaller, more localized units of probable Proterozoic age include variably layered gneisses, mafic diorite and amphibolite, and finely layered gneiss containing garnet, sillimanite, and rarely staurolite. A small body of highly mylonitic anorthosite (Ꮲa) in the hanging wall of the Vincent Thrust, probably related to or a part of a large gabbro-anorthosite complex west of the San Bernardino quadrangle, occurs on the southern flank of Copter Ridge (fig. 1). Contacts between relatively homogeneous Proterozoic units and the highly mixed Mesozoic-Proterozoic units are gradational.

Paleozoic rocks

All Paleozoic and Paleozoic(?) rocks in the San Gabriel Mountains are high metamorphic grade or have undergone multiple metamorphic events and contain no fossils or primary bedding features. Schist and gneiss of probable Paleozoic age (Pzsg) are extensively exposed from Potato Mountain, Mount Baldy 7.5' quadrangle (fig. 1) to Icehouse Canyon and eastward to Cucamonga Peak. Equivalent rocks are also found on both sides of lower Lytle Creek, where they are highly fragmented and intruded by tonalite. In the Lytle Creek area, composition of the schist and gneiss is variable, but most is biotite-bearing and derived almost exclusively from a pelitic sedimentary protolith. Representative lithologies include biotite gneiss, garnet-biotite quartzofeldspathic gneiss, biotite quartzofeldspathic schist, and phyllite. In the Potato Mountain and Ontario Ridge areas (fig. 1), the unit consists of highly recrystallized quartzite (Pzqg), marble (Pzmg), biotite-sillimanite schist, and graphitic schist, all intruded by Cretaceous tonalite. Flexural-slip folds are common within the marble sections (photos 252 and 253).

These rocks are considered to be part of the regionally extensive Placerita suite of Powell (1993). Degree of metamorphism and deformation in all parts of the unit preclude stratigraphic subdivision or correlation with any unmetamorphosed Paleozoic sections. Detailed descriptions of the metasedimentary rocks in the San Antonio Canyon area are given by Baird (1956) and Ehlig (1958).

Pre-Cretaceous granitic rocks

Triassic rocks are widespread and well dated in the eastern San Gabriel Mountains, especially just west of the San Bernardino quadrangle. They fall into two groups, an early, highly mafic set of relatively small intrusions (photo 38), and the much more voluminous, and relatively leucocratic, Mount Lowe Intrusive Suite. The Jurassic intrusive history of the range is less well known, chiefly due to a paucity of reliable isotopic age dates. Jurassic age assignments in this report have been made largely on the basis of chemical and mineralogic similarity to dated Jurassic rocks in other parts of the region.

Mount Lowe Intrusive Suite

This unit was originally designated the Mount Lowe Granodiorite in an abstract by Miller (1926), but in later publications he used the name Lowe Granodiorite (Miller, 1934, 1946). Barth and Ehlig (1988) much later informally renamed the unit 'Mount Lowe intrusion'. Because of confusion and shortcomings in all of these names, we here refer to the unit as the Mount Lowe Intrusive Suite to reflect its wide compositional range. The original name by Miller (1926 and 1946) is not used here, because (1) the unit is not primarily granodiorite, (2) the name does not reflect the wide compositional range of the unit, and (3) the name(s) has been used inconsistantly. The name, Mount Lowe Intrusive Suite is preferred over Mount Lowe intrusion, because the unit appears to be made up of multiple, genetically related intrusions, and the term, intrusive suite, more closely follows the guidelines of the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). The original type locality at the Mount Lowe area, west of the San Bernardino quadrangle, remains useful; representative parts of the unit are well exposed there in road cuts and in natural exposures.

A Triassic age for the Mount Lowe Intrusive Suite was first established by Silver (1971). Later a refined Late Triassic age of 218 ±2 Ma was reported by Barth and others (1990).

The Mount Lowe Intrusive Suite (TRlu, TRlq, TRll, TRlh, and TRlb) includes a wide variety of genetically related intrusions ranging in composition from diorite to monzogranite (photos 254 and 255); average composition is probably quartz monzonite, but alkalic, quartz-deficient elements range from monzonite to syenite.

A major part of the unit appears to consist of a single zoned intrusion. Overall, the intrusive suite covers about 300 km^2 in the central San Gabriel Mountains (Ehlig, 1981); the central, and areally greatest part of the unit lies west of the San Bernardino quadrangle. In addition to its wide range in composition, the unit is characterized by highly varied appearance and highly varied grain size. Pronounced grain-size reduction is characteristic of much of the unit; primary minerals, most obviously hornblende, are noticeably disaggregated. Almost all intrusive types constituting the Mount Lowe Intrusive Suite contain very abundant sphene.

Many of the mixed rock units in the upper plate of the Vincent Thrust contain tectonically mixed lenses, pods, and small bodies of the Mount Lowe Intrusive Suite. Typically, these bodies range from 10 cm to five meters thick and from a few meters to several hundred meters long. Athough these bodies have been tectonically elongated, along with the granitic or metamorphic rocks they are intermixed with, they are thoroughly recrystallized and commonly do not exhibit an internal fabric commensurate with the degree of elongation. In places, these tectonically incorporated bodies make up more than ten percent by volume of the mixed unit.

Jurassic rocks

Rocks of inferred Jurassic age are limited in the San Gabriel Mountains, consisting of the quartz monzodiorite of Hutak Canyon (Jhc), the granodiorite and quartz monzonite of Fern Canyon (Jgf), and limited, very small occurrances of gabbro and pyroxenite (JTRgb) that could be Jurassic or Triassic. The quartz monzodiorite of Hutak Canyon is typically heterogeneous with respect to composition, grain size, and texture, but locally is homogeneous. Much of the unit is highly porphyritic, having phenocrysts up to four centimeters long. Hornblende is more abundant than biotite. Feldspars are typically much darker gray than those in Cretaceous granitic rocks, and potassium feldspar commonly has a distinct lavender hue. Phenocryst concentration and size, mafic ratio, feldspar color, and relatively low quartz content are characteristic features of very extensive, well dated Jurassic plutons found in the western and central parts of the Mojave Desert. The granodiorite and quartz monzonite of Fern Canyon shares many of the characteristics of Jurassic rocks in the region, but also contains very abundant pods of younger granitic rocks and included masses of older granitic and metamorphic rocks.

Cretaceous granitic rocks

Cretaceous granitic rocks are widespread in the eastern San Gabriel Mountains, even more so than suggested by the geologic map, because many of the mixed granitic-metamorphic units contain abundant granitic rocks of Cretaceous age. Composition ranges from tonalite to monzogranite, but tonalite is by far the most voluminous. Cretaceous granitic rocks in the San Gabriel Mountains differ from those in the San Bernardino Mountains and Mojave Desert by being more mafic, containing more hornblende and much less potassium feldspar, and commonly having a well developed planar fabric.

Much of the Cretaceous tonalite in the San Gabriel Mountains is gneissic or foliated, and mylonitic fabrics and zones of well-developed mylonite are common (photos 256, 257, and 258). The degree of mylonitic deformation in the range increases southward toward the mountain front where, in places, tonalite has been uniformly converted to zones of mylonite and mylonitic rock more than 300 m thick. Dikes and small masses of essentially undeformed biotite granodiorite and monzogranite (Kmg) that are late Cretaceous in age, about 78 Ma (May and Walker, 1989) intrude the deformed tonalite. In Cascade Canyon, on the east side of San Antonio Canyon, a granitic dike intrudes marble. Reaction between the dike rock and marble produced a contaminated dike rock characterized by abundant small, euhedral pink corundum crystals (photo 259, and 260). Lenticular bodies of Cretaceous hornblende diorite, the Deer Diorite of Alf (1948) (Kdd) (photo 261 and 262), occur along the southern part of the mylonitized tonalitic rock.

South of the San Gabriel Fault (fig. 1), and in the easternmost San Gabriel Mountains, the tonalite of San Sevaine Lookout (Kss) (photo 263), the quartz diorite of Mt. San Antonio (Ksa), the tonalite of San Gabriel Reservoir (Ksgr), and their mylonitic variants (photos 256, 257, and 258) account for most of the Cretaceous granitic rocks. These units are all roughly tonalitic in composition, and all have mylonitic fabrics ranging from barely perceptible to extreme.

North of the San Gabriel Fault (fig. 1), most Cretaceous granitic rocks are combined into a single unit, the monzogranite of Cloudburst Summit (Kcs). The western part of this unit is typically relatively massive, structureless biotite monzogranite. Eastward toward the Vincent Thrust, rocks of the unit are progressively more foliated, and irregularly more mylonitic. In addition to development of deformational fabrics eastward, the rocks are generally more mafic, more heterogeneous, and may include one or more intrusive bodies that may or may not be related to the main body of the monzogranite of Cloudburst Summit to the west.

Rocks in lower plate of Vincent Thrust: Pelona Schist

Beneath the Vincent Thrust, the Pelona Schist (Kpu) is a thick sequence of well layered schist (photo 264) metamorphosed to greenschist and lower amphibolite grade. The Pelona Schist is a component of a widespread group of similar rocks that include the Rand and Orocopia Schists. From the Vincent Thrust area in the San Bernardino quadrangle, schist bodies of the Pelona-Rand-Orocopia-type beyond the quadrangle extend from western exposures in the area of Frazier Park northeastward to the Randsburg area and westward to the type locality at Sierra Pelona in the western San Gabriel Mountains. Major areas of schist of this type are also found in the eastern San Gabriel Mountains, the San Bernardino basin, southeastern San Bernardino Mountains, Orocopia Mountains, Chocolate Mountains-Gavilan Hills in southeastern California and east into the Trigo Mountains, Castle Dome Mountains, and Neversweat Ridge in southwestern Arizona (Haxel and others, 2002); a distance of about 550 km between the two most distant occurrances. Although initially considered to be Precambrian, recent data indicate a Cretaceous age and possible an early Tertiary age for some of the assemblage (Haxel, and others, 2002). Metamorphic age of hornblende from the Orocopia Schist in the Gavilan Hills ranges from 52 to 57 Ma (Jacobson and others, 2002).

The Pelona Schist is named for exposures in the Sierra Pelona area west of the map area (Hershey, 1902). Exposed thickness (the base is not exposed) is about 4,000 m consisting of about 3,700 m of schist and 300 m of greenstone, derived from a protolith of Mesozoic marine sedimentary and volcanic rocks.

Most of the sedimentary rocks probably were carbonaceous mudrocks (graywacke) containing thick intercalated zones of basalt, thin zones of siliceous-carbonate sediments, and thin, localized zones of barite-bearing chert and manganese-bearing siliceous sediments. Scattered pods of actinolite-talc rock were probably derived from serpentine. Fuchsite, a chrome-bearing muscovite, commonly occurs in association with actinolite-talc rock. Small masses of rhodonite and minor occurrences of piemontite are rare.

In the San Bernardino quadrangle, Pelona Schist occurs in two blocks that are distinguished by contrasting metamorphic grade separated by the Punchbowl Fault (photo 566) (fig 1), an abandonded segment of the San Andreas Fault system. North of the Punchbowl Fault, the Pelona Schist is characterized by gray, medium to coarse grained plagioclase, white-mica schist of lower amphibolite grade (Kpa). The gray color is caused by disseminated, very fine-grained graphite. Greenstone (metabasalt) layers, largely hornblende, plagioclase and garnet, are common (photo 265 and 266); metachert and metacarbonate-quartzite layers are rare, and commonly include trains of complexly folded spessartite garnet. Locally, metachert contains small amounts of barite and rare blue amphibole. Most layers of metacarbonate-quartzite are slip-folded (photo 267).

South of the Punchbowl Fault the Pelona Schist is mostly gray, well layered, greenschist-grade spotted albite-muscovite schist (Kps) (photos 268 and 269). As in the higher grade schist, the gray color is due to disseminated very fine-grained graphite. Biotite is rare, but stilpnomelane is widespread (photos 270, 271, 272, and 273). Thick zones of greenstone (Kpg) and thin zones of metachert and metacarbonate-quartzite are interlayered with the schist. Most greenstone consists of an assemblage of albite-epidote-chlorite, and is most abundant in the structurally upper part of the section close to the Vincent Thrust. Metachert layers are typically associated with the greenstone layers, and generally are found beneath greenstone layers, suggesting overturned sections (photo 274).

In the northeast corner of the Crafton Hills, a small fault bounded block of biotite bearing schist (Kpb) is here tentatively correlated with the Pelona Schist. Unlike the Pelona Schist at other localities, biotite is abundant, and the rocks appear to have relict bedding (photos 275 and 276).

Internal structure of the Pelona Schist

Lithologic layering in nearly all of the Pelona Schist appears to be the result of extreme transposition produced by slip folding (photo 277). Hand sample-sized specimens commonly show various stages of transposition at a variety of scales (photos 278 and 279). Transposition of bedding throughout the Pelona Schist precludes establishment of a stratigraphic succession; the position of one predominant rock type relative to another denotes a structural and not a stratigraphic relationship. Additionally, the exposed 4,000 m thickness of the Pelona may bear little relationship to the original stratigraphic thickness of the same rocks.

Slip folds are best seen where rocks are made up of thin, contrasting lithologic layers; this is most apparent in metacarbonate-quartzite and metachert sections (photos 267 and 277). Though much of the schist contains minor homoaxial slip folds (photos 280, 281, and 285), refolded folds are common (photo 282) and some outcrops contain 3 to 4 non-homoaxial fold axes. Single and double sets of crenulations post dating slip folding are common (photos 283 and 284). A comprehensive structural analysis of the Pelona Schist is given by Jacobson (1983).

Tertiary granitic rocks

Both the Pelona Schist and the overlying mylonitic and gneissic complex are intruded by the Oligocene granodiorite of Telegraph Peak (Tgtp), Telegraph Peak 7.5' quadrangle (photo 244) (Hsu and others, 1963; McCulloh and others, 2001; Miller and Morton, 1977; Nourse and others, 1998). It consists of massive light colored hypidiomorphic-granular granodiorite, except in the marginal parts of the pluton, where the rock has a hypabyssal texture reflecting a shallow intrusion depth. The granodiorite contains localized, poorly developed primary flow foliation in the fine-grained marginal parts, but does not contain any secondary fabric like the rocks it intrudes. Some hypabyssal-textured marginal parts of the pluton contain large quantities of stoped wall rock, especially Pelona Schist (photo 244). The granodiorite of Telegraph Peak is intruded by diabase dikes and a small body of texturally-zoned olivine diabase-gabbro (Tdg) (photos 578 and 579) exposed along Interstate 15 between Sycamore Flats and Cajon Creek (fig. 1).

Uranium-lead zircon age for the pluton was determined by May and Walker (1989) to be 25.6 ±1 Ma; these zircons had a Proterozoic inheritance. McCulloh and others (2001) consider the best isotopic age determination for the granodiorite to be 26.3 Ma. An uranium-lead ion probe age of 26 ±2 Ma on zircon was determined by Wayne Premo (written commun., 2004). In the northeastern Crafton Hills, a hypabyssal textured dike interpreted as related to the granodiorite of Telegraph Peak intrudes biotite-bearing schist

(Kpb) tentatively correlated with the Pelona Schist. The dike rock has a uranium-lead age of 27.2 +/- 0.6 Ma on zircon (Wayne Premo, written commun., 2006). Hornblende from a diabase dike (Tdg) cutting the Telegraph Peak pluton near Telegraph Peak yielded a potassium-argon age of 9.3 Ma.

Tertiary volcanic and sedimentary rocks

Tertiary volcanic and sedimentary rocks are widespread and highly varied in the San Gabriel Mountains assemblage. Almost all are highly disrupted by faults related to the San Andreas Fault system or the thrust and reverse faults along the southern margin of the San Gabriel Mountains. Several units occur only as small areas of outcrop that are not large enough to show on the 1:100,000 scale map plot, but can be located in the digital map coverage, or by making enlarged plots of specific parts of the coverage.

The Glendora Volcanics (Tg) (Shelton, 1955) are a heterogeneous, highly faulted and redistributed group of Miocene volcanic and volcaniclastic rocks located in both the San Gabriel assemblage and the northern part of the Peninsular Ranges assemblage; the unit crops out in the southern foothills of the San Gabriel Mountains and in the San Jose and Puente Hills south of the mountains. These rocks range in composition from rhyolite to basalt, and from flow rock to volcanic breccia and tuff (photos 218, 219, and 220). The upper part of the unit appears to interfinger with the lower part of the overlying Miocene Topanga Group rocks in the Azusa area (fig. 1). North of Glendora and in the Johnston Peak area, a thin, unconsolidated conglomerate zone separates the volcanics from the underlying basement. Clasts in this conglomerate include a distinctive augen gneiss that is exotic to at least the eastern San Gabriel Mountains. Some augen gneiss clasts are greater than one meter in length. Other than a variety of hypabyssal dike rocks, the Glendora Volcanics are the only Tertiary volcanic rocks in the San Gabriel Mountains assemblage on the south side of the mountains.

The Topanga Group rocks overlying the Glendora Volcanics in the Azusa area form a highly faulted sequence of marine sandstone, siltstone, shale, and conglomerate, which is discussed in detail under the Peninsular Ranges assemblage. Rocks of the Topanga Group are overlain by the Miocene Puente Formation, also discussed in detail under the Peninsular Ranges assemblage, that thickens to the south and west. The Puente Formation is chiefly marine sandstone, siltstone, and shale, and was one of the most important oil producing units in the Los Angeles Basin. Rocks of the Puente Formation(?) were described at the base of the mountains north of San Dimas (Proctor and others, 1970).

Devil's Punchbowl area

Units in this area include early, middle, and late Tertiary rocks restricted to the south side of the San Andreas Fault, and the late Tertiary to Pleistocene Juniper Hills Formation that spans the fault.

Paleocene

The Paleocene in the Devil's Punchbowl area is represented by a single unit, the San Francisquito Formation.

San Francisquito Formation—On the north side of the San Gabriel Mountains, the marine, Paleocene San Francisquito Formation (Tsf) is located between the San Andreas and Punchbowl Faults in the area of the Devil's Punchbowl (fig. 1). It consists mainly of sandstone, conglomeratic sandstone, conglomerate, and shale, and rests nonconformably on Mesozoic granitic rocks (Koozer, 1980, 1982). The lower part of the San Francisquito Formation includes well stratified, regularly bedded sandstone and conglomerate (photos 286 and 287). The upper part of the section is fine grained and includes sheared and deformed shale containing sandstone beds (photo 288) that are typically disrupted (photos 289 and 290). The San Francisquito Formation contains *Turritela pachecoences* (Koozer, 1980, 1982), a Paleocene guide fossil. The Punchbowl Fault truncates the southern extent of the San Francisquito Formation (photo 291).

Miocene-Pliocene

The Miocene-Pliocene in the Devil's Punchbowl area is represented by a single unit, the Punchbowl Formation. Only the upper part of the upper member is Pliocene.

Punchbowl Formation—Unconformably overlying the San Francisquito Formation is the late Miocene to early Pliocene Punchbowl Formation(Tpb series) (photo 292). The Punchbowl Formation consists of nonmarine arkosic sandstone, conglomeratic arkosic sandstone, conglomerate, and minor sandstone and freshwater limestone.

The coarse-grained sandstone (Tpbv) (photo 293) superficially resembles the lower sandstone units of the Cajon Valley Formation (Tcv_2) (photo 294) 40 km to the east and on the north side of the San Andreas Fault. The similar appearance of these two sandstone units led to their specious correlation, and to the incorrect interpretation that offset on this segment of the San Andreas Fault was limited to 40 km. Woodburne and Golz (1972) determined the oldest part of the Punchbowl Formation is younger than the youngest part of the Cajon Valley Formation.

South of the Punchbowl Fault, and not in contact with either the San Francisquito Formation or the Punchbowl Formation, are several noncontiguous areas of Oligocene to Miocene Vasquez Formation. The Vasquez at other places is mostly conglomerate, conglomeratic sandstone, and sandstone, but in the San Bernardino quadrangle consists of andesite, ranging to basalt, and containing minor tuffaceous rocks.

Pliocene-Pleistocene

The Pliocene-Pleistocene in the Devils Punchbowl area is represented by a single unit, the Juniper Hills Formation.

Juniper Hills Formation—The Quaternary-Tertiary Juniper Hills Formation (QTjh) (Barrows, 1987) is found on both sides of the San Andreas and Punchbowl Faults. The unit represents interstratified and interfingering fluvial, lucustrine, and playa deposits (Barrows, 1980, 1987; Barrows and others, 1985), and was named by Barrows (1987) for exposures in the Juniper Hills area in the northwestern part of the San Bernardino quadrangle. It is a nonmarine unit, whose lithology and physical characteristics vary widely, and at any given locality reflect localized source materials being shed into specific areas of sediment accumulation. Sediment sources, transport processes, and depositional sites all contribute to the highly variable appearance of this unit from one place to another. Various informal units are subdivided mainly on the basis of lithology or clast composition.

In general, the Juniper Hills Formation consists of arkosic sandstone, silty sandstone, and lesser conglomerate and thin bedded shale. Ten localized, informal subunits are differentiated and grouped by their positions relative to the San Andreas, Punchbowl, and northern and southern Nadeau Faults. Between the northern and southern Nadeau Faults, informal Juniper Hills subunits include: red arkose unit (QTjhr), clay-shale unit (QTjhc), siltstone unit (QTjhs), and arkosic breccia unit (QTjhb). Between the San Andreas and northern Nadeau Faults, informal Juniper Hills subunits include: fine-grained unit (QTjhf) and sedimentary breccia unit (QTjhsb), but between these two faults, much of the Juniper Hills Formation is undifferentiated. South of the Punchbowl Fault, informal Juniper Hills subunits include: playa deposit unit (QTjhp), volcanic clast unit (QTjhv), arkosic sandstone unit (QTjha), and conglomeratic sandstone unit (QTjhcs). No Juniper Hills Formation is found between the Punchbowl and southern Nadeau faults.

Rocks of the Juniper Hills Formation are generally coarse grained, poorly sorted, and commonly contain pebbles and cobbles. Rarer lithologies, such as siltstone, gypsiferous shale, and coarse sedimentary breccia, are present in only one member or a few members. Most of the rocks in the unit are pinkish gray, pale tan, and reddish brown, and are poorly to moderately well indurated; bedding ranges from poor to distinct. Many clasts are probably recycled from the Pliocene and Miocene Punchbowl Formation (Tpb).

Quaternary geology

The Quaternary sedimentary history associated with the San Gabriel Mountains assemblage is largely recorded in the area surrounding the bedrock and structural elements that define the assemblage, and not within the area encompassed by the bedrock and structural elements; landslides are a major exception to this statement. Uplift and dissection of the eastern San Gabriel Mountains is reflected in the complex array of alluvial deposits emanating from the range, so even though many of these fans lie mostly on basement of other assemblages, they are also included here. Within the San Gabriel Mountains, Quaternary deposits are largely restricted to alluvial valley, small alluvial-fan, alluvial wash, landslide, and creep deposits. Of these, the landslide deposits are volumetrically, numerically, and societally the most important.

The informally named and loosely defined Victorville fan (fig. 3) on the north side of the San Gabriel Mountains (photos 295, 296, and 297) extends from the Hesperia-Victorville area westward at least to the fan emanating from Sheep Creek (fig. 1). Although most of the sediments that make up the fan were derived from the San Gabriel Mountains, nearly all of the fan lies on basement of the San Bernardino Mountains assemblage, so it is discussed more fully in that part of this report.

Alluvial fan complexes (Qf, Qyf, Qof, and Qvof series) emanating from the south flanks of the San Gabriel and San Bernardino Mountains cover the northern part of the Peninsular Ranges (photo 298). An extremely complex series of large and small fans extend from Lytle Creek to the west edge of the San Bernardino quadrangle. The large and symmetrical Lytle Creek fan is made up of a single Quaternary unit (Qyf_5), in contrast to fans emanating from most of the other major canyons, which are built from multiple pulses spanning longer intervals of the Quaternary. Eckis (1928) described these fans, and later (Eckis, 1934) gave physical properties of the fan deposits. East of the Lytle Creek Fault, at the west side of the mouth of Lytle Creek (fig. 1), old channel deposits of one of these fans were hydraulicly mined for placer gold (photos 299, and 601).

A complex array of alluvial fans (Qf, Qyf, Qof, and Qvof series) rings most of the San Bernardino basin (fig. 1). Drainages in the basin extend from the southeast flowing Lytle and Cajon creeks, southwest flowing Waterman and City Creeks, and the west flowing Santa Ana River and Mill Creek. These drainages converge with drainages from the Peninsular Ranges at the southwestern edge of the basin to form the trunk of the Santa Ana River that exits the San Bernardino quadrangle between the Jurupa Mountains and the La Loma Hills.

Creep and Landslides

Evidence of creep is apparent on many of the steep slopes underlained by fractured rock. Most evident are 'bowed' trees (photo 300). Creeping lobes, resembling soliflution lobes, of surficial loose rocks occur on the south slopes near the summit of Mount San Antonio (photo 301).

The combination of steep, rugged topography, highly fractured rock, and susceptible rock types are the underlying causes of the numerous, widespread, and in many cases, large landslides developed in the rocks of the San Gabriel assemblage. Major landslides occurred throughout the Quaternary and continue to occur thoughout the range (Morton and Streitz, 1969). Most of the larger landslides appear to be rock avalanches, and based on their dissected nature, many appear to be early and middle Quaternary in age (Morton and others, 1989). In the eastern San Gabriel Mountains, rock avalanche deposits appear to be localized in terrains of older plutonic rocks, gneiss, and mylonitic gneiss, exclusive of the Pelona Schist (Morton and others, 1989).

The Crystal Lake landslide (fig. 1) (photos 302, 303, and 304) in the upper reaches of the San Gabriel River drainage, is nearly five kilometers long and 1.5 km wide, and is probably the largest landslide in the range (Morton and others, 1989). Its size and canyon-modifying topography caused Miller (1926a) to misinterpret it as a glacial deposit. Adjacent to the Crystal Lake landslide, the Alpine Canyon landslide is of similar length but half the width. Both landslides are well dissected, cut by moderate sized canyons, and probably occurred in early Quaternary.

Landslides appear to be responsible for alterations of major drainage patterns in the San Gabriel Mountains. For example, that part of San Antonio Canyon, more than nine kilometers from its mouth, probably was once the headward part of Cow Canyon (fig. 1) to the west (fig. 1) (Morton and others, 1989). The distal part of a landslide originating high on the east side of San Antonio Canyon near the crest of Ontario Ridge blocked the paleo-Cow Canyon, forming the low divide between Cow Canyon and present day San Antonio Canyon (photo 305). Headward erosion of lower San Antonio Canyon captured the drainage that formerly flowed west down Cow Canyon (Morton and others, 1989). Above this landside is another large landslide deposit that originated near the summit of Mount San Antonio, descending south to the mouth of Icehouse Canyon. Attesting to ongoing major landsliding is a prominent scarp that forms a large side-hill trench (photo 306) on the north side of the ridge between Mount Harwood and Mount San Antonio.

Another large dissected avalanche deposit is located in the upper part of North Fork Lytle Creek (fig. 1). This avalanche originated near Telegraph Peak, and traveled at high speed to the north and northeast down Coldwater Canyon onto the floor of North Fork Lytle Creek (photo 307).

In contrast to rock avalanches, slow-moving landslides are abundant in areas underlain by the Cretaceous Pelona Schist. Many of these landslides are foliation-plane failures that commonly lack classic landslide topography (Morton and Sadler, 1989a). Sackungen and sackungen-like features are common, resulting in numerous side-hill (photo 308) and ridge-top trenches (photos 309, 310, and 589). Ridge-top trenches are widespread but less common in other basement lithologies (photo 311).

Spring melting of snow on slowly moving landslides can give rise to debris flows. Best known of these debris flows occurs at and around the community of Wrightwood in Swarthout Valley (photo 45) (Sharp and Nobles, 1953; Morton and Campbell, 1974; Morton and Kennedy, 1979), where debris flows have caused damage to structures. Most of Wrightwood is built on a debris flow-dominated fan. Originating on Wright Mountain (photos 41, 40, and 588), the larger debris flows are deposited on Sheep Creek fan.

In this region, most debris flows originating in the past 60 years have been from Heath Creek Canyon (photos 42, 43, and 44). The debris flows are common in the spring, but many times are small and confined to the mountain side. These small flows are merely scaled-down versions of the larger destructive debris flows (photo 312). The debris flows typically consist of discrete masses of rocky debris, commonly referred to as 'slugs', that decend debris flow channels. At times a debris slug comes to rest in the channel, completely filling the channel (photo 313). Episodes of debris flows, best described as a debris flow cycle, emanating from Heath Creek can occur over periods of weeks. A debris flow cycle occurs during periods of extensive debris flow activity. In the initial part of a cycle, debris flows reach only the proximal part of the fan (photo 314). If debris flow activity increases, the deposition on the proximal part of the fan is followed by debris flows that erodes a narrow channel in the proximal part of the fan (photo 315) through earlier deposited debris flows. As debris flow activity decreases there is once again deposition on the proximal part of the fan, backfilling the earlier eroded channel (photo 316). Other extensive debris flow deposits are located on the east side of Dawson Peak and Pine Mountain (photos 317, 318, and 319).

San Bernardino basin

The San Bernardino basin is an asymmetical pull-apart basin located between the San Andreas Fault and the San Jacinto Fault (fig. 1) (Morton and Matti, 1993), which narrows to the north in the vicinity of Devore and Cajon Creek. The broad southern terminous is bounded by the northeast striking Crafton Hills Fault complex consisting of a series of normal faults. These faults form the Crafton Hills horst and small grabens such as at Dunlap Acres. The basin is filled by Quaternary sediments deposited on a surface of moderate relief developed in Pelona Schist. Prior to the origin of the San Jacinto Fault and the development of the basin, the area was high standing and shed debris southward to form the sedimentary rocks of the San Timoteo Badlands. Along the northwest side of the basin is a narrow, elongate sub-basin (Anderson and others, 2004) bounded on the west by the Rialto-Colton groundwater barrier (fault) of Dutcher and Garret (1963).

Rocks bounded by the Mill Creek Fault and the San Andreas Fault

Crystalline basement rocks and overlying Tertiary sedimentary rocks between the Mill Creek Fault and the main trace of the San Andreas Fault Zone are here treated as a separate basement entity, because: (1) the bounding faults, which are both segments of the San Andreas Fault system, appear to have controlled the site, configuration, and sediment sources for the depositional basin of the sedimentary rocks, (2) the crystalline rocks are gneissic to foliated granodiorite and massive diorite to monzogranite granitic rocks (Matti and others, 1983, 1992) that are unique in the quadrangle, and (3) the structural block contains a third fault, the Wilson Creek Fault, that is considered to be an older strand of the San Andreas Fault system.

Crystalline rocks of this basement assemblage are similar to rocks in the Little San Bernardino Mountains southeast of the map area, and appear to have been displaced about 50 km by the Wilson Creek and Mill Creek Faults of the San Andreas Fault system (Matti and Morton, 1993). These rocks range from highly deformed gneiss (gg) (photo 320) of unknown age to relatively undeformed Mesozoic biotite-hornblende diorite (Mzc).

In the lower part of Mill Creek (fig. 1) a thick section of sedimentary rocks lies between the San Andreas Fault and the Wilson Creek Fault. These and similar rocks between the Wilson Creek Fault and the Mill Creek Fault were first described by Vaughan (1922), who named them the Potato Sandstone. This name was also used by Smith (1959) and was extended by Dibblee (1964b, 1970, 1973) to include a variety of sedimentary rocks adjacent to the San Andreas Fault Zone from Mill Creek northwestward to Waterman Canyon. The sedimentary rocks south of the Wilson Creek Fault (Yucaipa Ridge Fault of Sadler and others, 1993) and north of the San Andreas Fault were termed Mill Creek Formation by Owens (1959) and were more fully described by Gibson (1964 and 1971). Usage of the name Mill Creek Formation has been relatively consistent since Gibson (1971) (e.g., Dibblee, 1982; Sadler and others, 1993), and the unit is here referred to as the Mill Creek Formation of Gibson (1971).

The Mill Creek Formation of Gibson (1971) (Tm series) apparently was deposited in a late Miocene pull-apart basin, into which the bulk of, but not all of, the sediments entered from the northwest (Sadler and others, 1993). Stratigraphy within this basin is characterized by extreme sedimentary facies changes over short distances. Sadler and others (1993) recognized at least five mappable facies which, with slight modifications, are included in the geologic map of the San Bernardino quadrangle. A thick sandstone unit (Tms) (photos 321 and 322) that contains turbidite structures (photo 323) is well exposed along State Route 38 which follows Mill Creek Canyon. The formation also includes a distinctive, local basal conglomerate (Tmcp) (photo 324) at the entrance to Mill Creek Canyon that is characterized by a large proportion of Pelona Schist clasts (photo 325), and had a south-southwest sediment source. Rocks of the northeastern part of the basin appear to have had a source from the north or northeast, and a distinctive unit (Tmcv) with volcanic clasts apparently had a southeast source (Sadler and others, 1993).

Between the Wilson Creek Fault and the Mill Creek Fault, a thin sliver of sedimentary rocks is preserved, which originally was included in the Mill Creek unit by some workers (e.g., Dibblee 1964b, 1970, 1973), or termed the Potato Sandstone by others (Sadler and others, 1993). Based on lithology, two Tertiary units are recognized within this fault bounded sliver. The formation of Warm Springs Canyon

(Tw) is restricted to the north side of the Wilson Creek Fault and the south side of the Mill Creek Fault, and is nowhere in depositional contact with the Mill Creek Formation of Gibson (1971). The formation of Warm Springs Canyon is similar to part of the second, currently unnamed, Tertiary unit in this structural block. This unnamed unit consists of a section of conglomerate, sandstone, and arkose (Tsg), that is also bounded by the Wilson Creek and Mill Creek Faults, and is found strung out between the Mill Creek and Wilson Creek Faults from the vicinity of Plunge Creek northwestward to about Devil Canyon (fig. 1). It also is not in contact with the Mill Creek Formation of Gibson (1971), nor is it in contact with the formation of Warm Springs Canyon.

Based on lithologic variation, the conglomerate, sandstone, and arkose (Tsg) may contain components from a variety of sedimentary units, and for this reason is distinguished from the formation of Warm Springs Canyon (Tw). It differs from the formation of Warm Springs Canyon because it appears to contain rocks that resemble part of the Paleocene San Francisquito Formation (Tsf) or more probably the Cretaceous sedimentary rocks of Cosy Dell area (Kcd) (photos 326 and 327). In the Devore area part of the Tsg unit is a massive light-colored lithic arkose that resembles leucocratic granite.

San Bernardino Mountains Assemblage

Introduction

The San Bernardino Mountains extend approximately 95 km eastward from Cajon Pass, ending where the boundaries of the Transverse Ranges Province constrict (see fig. 2). Only the western part of the range, slightly less than half, is within the San Bernardino quadrangle. The range is bounded on the south by the San Andreas Fault Zone and on the north by a discontinuous series of south-dipping thrust faults commonly termed the north-frontal fault system (e.g., Meisling, 1984; Miller, 1987). The interior of the range is cut by the east-striking, north-dipping Santa Ana reverse fault, the left lateral Cleghorn Fault, and the Devil Canyon Fault of unknown slip sense (fig. 1).

About 75 percent of the San Bernardino Mountains is underlain by Mesozoic granitic and volcanic rocks and about 25 percent by metamorphic rocks ranging in age from Middle Proterozoic to Pennsylvanian. Within the San Bernardino quadrangle, about 80 to 85 percent of the San Bernardino Mountains bedrock is Mesozoic granitic rocks, and the rest, highly metamorphosed and deformed Late Proterozoic and Paleozoic metasedimentary rocks. Except for rocks of questionable affinity having limited extent in the Little Shay Mountain area (fig. 1), all Middle Proterozoic rocks in the San Bernardino Mountains lie east of the quadrangle. All Mesozoic volcanic rocks and most of the Late Proterozoic and Paleozoic metasedimentary rocks also lie east of the quadrangle. Granitic rocks of the San Bernardino Mountains are similar to those in the Mojave Desert province to the north; both include a broad range of compositions spanning the Mesozoic, many having been deformed by a variety of geologic structures.

There is a pronounced gradient that increases from east to west, and to a slightly lesser degree from south to north, in the magnitude of both deformation and metamorphism of the Late Proterozoic and Paleozoic metasedimentary rocks of the San Bernardino Mountains. About 15 to 30 km east of the quadrangle, these units are moderately to highly deformed and recrystallized, but in most places, primary sedimentary structures are preserved, and stratigraphic continuity involving more than one formation is fairly common. From about 10 km east of the quadrangle, extending to the White Mountain area within the quadrangle, deformation and recrystallization have destroyed, or made questionable, most primary bedding features in carbonate units, and thicknesses of units are alternately highly attenuated or highly thickened. Stratigraphic continuity is minimal due to faulting, folding, and ductile deformation. In the Shay Mountain area (fig. 1), deformation and recrystallization precludes formational assignment, and even though the rocks are probably parts of mapped Late Proterozoic (and possibly Paleozoic) units to the east, all are identified only by lithology and assigned to the Proterozoic Shay Mountain complex of MacColl (1964).

In addition to the east-west metamorphic and deformational gradient, east of the quadrangle there appears to be a sharp break between relatively deformed and relatively undeformed Late Proterozoic, Paleozoic, and Triassic rocks. The boundary between the relatively deformed and relatively undeformed rocks, probably a fault or fault zone, predates the Middle to Late Cretaceous monzogranite of Keller Peak (Kk), but appears to postdate or be contemporaneous with emplacement of several large Middle Cretaceous monzogranite plutons 16 km due east of Little Pine Flat (fig. 1). Because Late Cretaceous granitic rocks have destroyed it, there is no control on the position of this structure within the San Bernardino quadrangle, except that it would have to pass south of the Shay Mountain complex of MacColl (1964).

The westernmost metasedimentary rocks in the range occur in the Ord Mountains (fig. 1), a promontory in the western San Bernardino Mountains, and consist of coarsely crystalline schist, quartzite, marble, and calc-silicate rocks. All layering in these rocks is probably the result of multiply transposed bedding (photos 328, 329, 571, 572 and 573). Slip folding is pronounced in rocks throughout the Ord Mountains (photo 571).

Late Cretaceous granitic rocks in the Ord Mountains predictably do not reflect the intense deformation recorded in the metasedimentary rocks, but unlike plutons in the eastern part of the quadrangle, neither do granitic rocks of well established Jurassic age (photo 330). The Jurassic rocks do not contain internal structures or deformational fabrics, nor are they faulted or have the deformed contacts seen in Middle Cretaceous granitic rocks just east of the San Bernardino quadrangle. These relationships suggest that the pre-Late Cretaceous deformation seen in plutonic rocks east of the quadrangle may be localized or bounded by pre-Late Cretaceous structures, and that the deformation affecting the metasedimentary rocks in the Ord Mountains is Early Jurassic or pre-Jurassic. Conversely, the lack of deformation in Jurassic and Triassic granitic rocks may be more apparent than real, because these rocks are syenites and monzonites, and contain very little quartz that accomodates strain in the Middle Cretaceous monzogranites.

Proterozoic rocks

Proterozoic rocks in the San Bernardino Mountains assemblage comprise two groups based on age, lithology, and metamorphic history. The older rocks are Middle Proterozoic North American continental crust (Silver, 1971), and the younger rocks are metamorphosed Late Proterozoic marine sedimentary rocks that were deposited on the Proterozoic continental crust. The Middle Proterozoic and older rocks are collectively called the Baldwin Gneiss (Guillou, 1953), and are exposed extensively east of the quadrangle. There, the unit consists of three major rock types, (1) well foliated muscovite-biotite granitic gneiss containing abundant, large, potassium feldspar augen, (2) massive to foliated equigranular to porphyritic gneiss, and (3) foliated, layered muscovite-biotite gneiss that may have had a sedimentary protolith. Silver (1971) reported a uranium-lead zircon age of 1,750 Ma from the granitic augen gneiss that apparently intrudes older parts of the gneiss.

In the Little Shay Mountain area, Butler Peak 7.5' quadrangle, micaceous, muscovite-biotite quartzofeldspathic gneiss and schist (Ꮲgsq) are tightly interfolded with massive quartzite of probable Late Proterozoic age. The gneiss contains far more quartz than found in normal granitic rocks, and probably had a sedimentary protolith. This unit, which strongly resembles parts of the Baldwin Gneiss, is the only San Bernardino Mountains unit in the quadrangle that may be of Middle Proterozoic age.

Quartzite and very limited marble and calc-silicate rocks in the Shay Mountain complex of MacColl (1964) are probably highly deformed and recrystallized Late Proterozoic and possibly Early Cambrian units. The quartzite units in the Shay Mountain area are probably derived from the Late Proterozoic quartzite of Wildhorse Meadows, which does not occur in this area, the Late Proterozoic Stirling Quartzite, and possibly from the lower part of the Cambrian Wood Canyon Formation. All of these units crop out fairly extensively just east of the quadrangle, and within the quadrangle, all are tightly interfolded with each other and with the quartzofeldspathic gneiss (Ꮲgsq).

The westernmost group of rocks in the range that include probable Proterozoic metamorphic rocks are in the Ord Mountains. Most of the rocks that are grouped as mixed metamorphic rocks of Ord Mountains area are probably derived from a Paleozoic protolith, but some are possibly derived from the upper part of the Late Proterozoic Stirling Quartzite (Ꮲsu). All are highly deformed and coarsely crystalline, some containing sillimanite porphyroblasts three centimeters long. The age and protolith of these highly deformed and metamorphosed rocks are uncertain enough that they are listed as age unknown on the geologic map and in the database.

The very widespread gneiss of Devil Canyon (MzᏢd) is made up of an extremely heterogeneous mixture of schist, layered gneiss, calc-silicate rocks, and marble, all of which are complexly intruded by granitic rocks ranging in composition from monzogranite to quartz diorite. The granitic part of the unit is probably Mesozoic, but the age of the metamorphic component is uncertain. Carbonate-bearing parts of the unit are most likely Paleozoic or Late Proterozoic. The lack of a significant quartzite component in the unit suggests that the gneiss and schist may be derived not from a Paleozoic or Late Proterozoic protolith, but from Middle Proterozoic gneiss and schist, or that they are highly deformed, heterogeneous Mesozoic rocks.

North of Lone Pine Canyon and Wrightwood, localized, but large, areas are underlain by comminuted and pervasively sheared mixtures of marble, gneiss, and granitic rock (fz) (photo 368). The relationship of these deformed rocks to known structures is unclear, but they are in relatively close proximity to the San Andreas Fault. Although these rocks are in the northeastern part of the San Gabriel

Mountains, they are northeast of the San Andreas Fault and are considered part of the San Bernardino Mountains assemblage.

Paleozoic rocks

Paleozoic rocks in the San Bernardino Mountains show the same east to west progressive increase in deformation and metamorphism as in the Late Proterozoic units. The Paleozoic units comprise a thick sequence of metasedimentary rocks generally consisting of a lower quartzitic sequence and an upper carbonate rock sequence. The entire lower quartzitic part is Early Cambrian, and includes the Wood Canyon Formation and Zabriskie Quartzite; the Wood Canyon Formation appears to conformably overlie the Late Proterozoic Stirling Quartzite (Stewart and Poole, 1975).

Carbonate rocks overlying the quartzite sequence range in age from Early Cambrian through Pennsylvanian, and comprise, in ascending order, the Cambrian Carrara and Bonanza King Formations, the Devonian Sultan Limestone, the Mississippian Monte Cristo Limestone, and the Pennsylvanian Bird Springs Formation. The Carrara Formation is a mixture of carbonate, siliceous, and argillaceous rocks and appears to represent a transition between dominantly clastic to dominantly carbonate deposition. Although highly deformed, complete, or nearly complete, sections of each of these units exists a few kilometers east of the San Bernardino quadrangle (Brown, 1991). In the San Bernardino quadrangle, all of the units are highly disrupted and consist only of faulted and folded partial sections. The carbonate rocks have been multiply folded in two or more generations to form mesoscopic to megascopic-scale open-to isoclinal-folds cut by numerous low-angle faults that have both older-over-younger and younger-over-older geometries (Cameron, 1981; Sadler, 1981; Brown, 1991). Many of the folds and low-angle faults are refolded (Brown, 1991).

Along the eastern edge of the San Bernardino quadrangle, in the White Mountain area, Butler Peak 7.5' quadrangle, highly deformed Paleozoic units are complexly faulted, tightly folded, and recrystallized to the degree that formational assignments of many units are poorly established. In the Ord Mountains area, probable Paleozoic formations, mapped as age-unknown, are tightly to isoclinally folded (photo 329), and many of the fold axes faulted to produce pods of one formation completely surrounded by another (photo 332). Intense slip folding on a variety of scales effects most of these rocks. Elements of the Wood Canyon (photo 333, see also photos 332 and 572), Carrara (photo 334, see also photos 328, 571, and 573), and Bonanza King (photo 330) Formations and the Zabriskie Quartzite (photo 335) are probably present in the area, but in each unit all layering consists of multiply transposed bedding, and no stratigraphic continuity has been established. In addition, all rocks are intricately intruded by dikes, sills, and pods of Jurassic, leucocratic, hornblende- and arfvedsonite-bearing syenite, and Cretaceous or Jurassic biotite quartz monzonite.

Cambrian

Wood Canyon Formation

In the map area, the Wood Canyon Formation (Ꞓwc) is quartzite, quartzose phyllite, biotite schist, and minor calc-silicate rock. In the Big Bear City 7.5' quadrangle, just east of the map area, the formation consists of five subunits. Parts of these five subunits are recognized in the map area, but due to the degree of metamorphism, they could not be differentiated and mapped separately. Although some parts of these subunits may not be present, and their relative stratigraphic positions may not be preserved in map area, brief descriptions are given here for reference. (1) The lower 15 to 20 m of the formation is black, biotite-rich, quartz-bearing phyllite containing sparse but ubiquitous metamorphic tourmaline and locally abundant *Scolithus* and flaser-laminated zones. (2) The phyllite grades upward into 20 to 25 m of interbedded coarse-grained, cross-bedded, feldspathic quartzite, pebbly quartzite, and quartzose phyllite. (3) Overlying the pebbly unit is relatively uniform lavender-gray, fine- to coarse-grained, trough-cross-bedded quartzite. The thickness and extent of this unit is unknown, because, although very distinctive, it is either not recognized or poorly developed in other nearby Wood Canyon sections. (4) Black, quartzose phyllite of uncertain thickness overlies the cross-bedded unit. (5) The upper part of the formation consists of about 20 m of medium-gray and brownish-gray, finely interbedded quartzite, phyllite and siltite. In the San Bernardino quadrangle, color and nearly all sedimentary structures in all of the formation are destroyed by metamorphism, and faulting and folding obscure the internal stratigraphy.

Zabriskie Quartzite

Extremely uniform, tough, quartz-cemented, thoroughly recrystallized quartzite characterizes the Zabriskie Quartzite (Ꞓz). The quartzite is uniformly white, but some fracture surfaces are stained yellow, orange or hematite-red by iron oxides. Quartz is almost the only mineral in the rock, which is medium to fine grained, but contains scattered grains up to five millimeters across. These coarser grains are not aligned to define bedding. Within the San Bernardino quadrangle, no original grain shapes have survived recrystallization. Bedding is thick to massive east of the quadrangle, but is not recognizable in the quadrangle. Locally, the unit contains partings of phyllitic argillaceous rock, which may or may not reflect bedding, and may or may not be restricted to any particular part of the formation. The Zabriskie Quartzite is distinguished from quartzites of the Wood Canyon Formation (Ꞓw) and Late Proterozoic Stirling Quartzite (Ꝑsu) by purity, lack of feldspar grains, whiteness, and massive structure. The unit in the San Bernardino Mountains was correlated with the Zabriskie Quartzite of the southern Great Basin by Stewart and Poole (1975). In the Fawnskin 7.5' quadrangle to the east, the average thickness as calculated from outcrop width is 400 m (Miller, and others, 1998). Variation in thickness in the quadrangle is probably due to folding and faulting and does not represent changes in stratigraphic thickness.

Carrara Formation

The Carrara Formation (Ꞓc) is a heterogeneous mixture of interlayered calcite marble, phyllite, calc-silicate rock, schist, and minor quartzite. In general, the upper part is dominated by carbonate rock, and the lower part is dominated by phyllite, calc-silicate rock and quartzite. Due to metamorphism and deformation in the map area, it is not certain if even gross lithologic layering in the unit reflects primary bedding (photo 334). The Carrara Formation is equivalent to the lower part of the Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960), and is correlated with the Carrara Formation of the southern Great Basin by Stewart and Poole (1975) and by Tyler (1975). In the Marble and Providence Mountains (Hazzard and Mason, 1936), the Latham Shale, Chambless Limestone, and Cadiz Formation occupy the same approximate stratigraphic interval as the Carrara, but it is not possible to map these three distinct formations in the map area.

Bonanza King Formation

In the map area, the Bonanza King Formation (Ꞓbk) was originally designated as the as lower part of the Furnace Limestone by Vaughan (1922) as mapped by Richmond (1960). The Bonanza King Formation was originally named by Hazzard and Mason (1936) for exposures in the Providence Mountains, where they recognized five informal subdivisions of the unit. In the San Bernardino quadrangle, where it consists mainly of dolomite and limestone marble, the Bonanza King is metamorphosed, and unlike in the adjacent Fawnskin quadrangle (Miller and others, 1998) it is not divisible into even informal members. It exhibits thin to thick layering, which at most places in the quadrangle is probably secondary and does not reflect bedding. The marble is white to medium gray, commonly striped, texturally massive to mottled, and fine to coarse grained. As mapped, the unit probably includes some or all of the Cambrian Nopah Formation in some sequences. It contains intervals, meters to tens of meters thick, consisting of greenish-brown and grayish-brown metasiltstone, argillite, and hornfels.

Devonian

Sultan Limestone

The Sultan Limestone (Ds) was mapped as the middle part of the Furnace Limestone by Vaughan (1922) as mapped by Richmond (1960). Brown (1991) correlated the rocks in this interval with members of the Sultan Limestone as designated by Hewett (1931) in the southern Great Basin. Brown (1991) recognized that in the map area rocks in the upper part of this interval include thin- to thick-layered, white calcite marble containing sparse, thin layers of dark-gray calcite and dolomite marble, and that they are characteristic of the Crystal Pass Member of the Sultan Limestone. These rocks are, in part, irregularly dolomitized. Below these relatively calcite-rich rocks, the unit consists of laminated to massive, light-gray, brown, and white, finely crystalline, locally chert-bearing metadolomite characteristic of the Valentine Limestone Member of the Sultan Limestone.

Mississippian

Monte Cristo Limestone

The Monte Cristo Limestone (Mm) is the upper part of the Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960). Cameron (1981) correlated this interval of the Furnace Limestone with the Monte Cristo Limestone of the southern Great Basin where it was originally recognized by Hewett (1931) and subdivided into several formal stratigraphic members. Brown (1991) recognized several of Hewett's members in the map area and in the quadrangle to the east, but the degree of recrystallization precludes recognition of detailed subdivisions. Typically, the unit here includes heterogeneous, interlayered, light- and dark-gray calcite and dolomite marble characteristic of Hewett's Yellowpine Member, and thick-layered, light-gray to white, texturally massive, very pure calcite marble characteristic of his Bullion Member (Brown, 1991).

Pennsylvanian

Bird Springs Formation

Cameron (1981) and Brown (1991) correlated the upper part of Furnace Limestone of Vaughan (1922), as mapped by Guillou (1953) and Richmond (1960), with the Bird Spring Formation (ℙbs) of the southern Great Basin. In the map area, the unit generally consists of light-colored, medium to thick layered, medium to coarsely crystalline calcite marble. Here, the degree of recrystallization precludes confident subdivision of the formation, but in the Fawnskin 7.5' quadrangle just to the east of the map area, five lithologic members are recognized (Brown 1984, 1987, and 1991). Typical lithologies include white, gray, or mottled marble and cherty, silicified marble. Some chert-bearing calcite marble contains lenses and thin layers of quartz silt and fine sand. Intermittent layers of minor brown-weathering dolomite marble, siliceous marble, and dark-gray calcite marble are also present. The unit locally includes yellowish to brownish gray phyllite (or schist), white quartzite, schistose metasiltstone, and interlayered chert and marble. Due to recrystallization and deformation, layering in much of formation here may or may not represent primary bedding.

Pre-Cretaceous granitic rocks

In addition to the voluminous Cretaceous granitic rocks, Mesozoic intrusive rocks in the San Bernardino Mountains and southern Mojave Desert include numerous Triassic and Jurassic plutons. The Triassic rocks, with one exception, are relatively alkalic, quartz deficient, and heavily sphene-bearing, averaging monzonite in composition. Many have well developed, but highly irregular, swirled, primary flow foliations or lineations. In the western San Bernardino Mountains, they occur as scattered bodies, typically intruded or engulfed by Cretaceous granitic rocks.

Near the eastern edge of the San Bernardino quadrangle, Bulter Peak 7.5' quadrangle, several bodies of the monzonite of Fawnskin (TRf) intrude Late Proterozoic and Paleozoic metasedimentary rocks, and are intruded by Cretaceous granitic rocks. This unit is much more extensive east of the quadrangle. The monzonite of Fawnskin is typically a fairly mafic hornblende monzonite, but includes several subdivided bodies of leucocratic monzonite. Barth and others (1997) report a zircon uranium-lead age of 231 Ma for the Fawnskin monzonite.

South of Silverwood Lake, the monzonite of Cedarpines Park (TRcp) forms a single pluton that intrudes the older rocks of the gneiss of Devil Canyon (MzPd) and is intruded by younger granitic rocks associated with that unit. The monzonite of Cedarpines Park is very similar to, and may be the same as, the monzonite of Fawnskin, but it is generally coarser grained and less mafic.

The monzogranite of Manzanita Springs (TRm, type locality, Manzanita Springs, is east of the San Bernardino quadrangle) (photos 336 and 337) forms three, noncontiguous, variously fault-bounded bodies in the southeastern part of the quadrangle, north of the Mill Creek Fault segment of the San Andreas Fault. A fourth body occurs at the north end of the Ord Mountains, 7.5' quadrangle. This unit differs compositionally from all other Triassic rocks in the San Bernardino Mountains, in that most of it is monzogranite, rather that monzonite. Quartz and especially potassium feldspar vary greatly in abundance, resulting in rocks ranging from quartz diorite to quartz monzonite. Much of the unit contains moderately abundant primary biotite, which is rare in the more alkalic Triassic rocks. The unit also differs from other Triassic units by containing a large proportion of angular, mafic, included rocks and a large proportion of pegmatitic and fine-grained leucocratic dike rocks. Frizell and others (1986) report a zircon uranium-lead age of 215 Ma for this rock.

In the northeastern corner of the San Bernardino quadrangle, in the Fifteenmile Valley 7.5' quadrangle, most of the Granite Mountains are underlain by several discrete Triassic intrusive bodies that are probably closely related to one another (Miller, 1977a, 1977b, 1978; Miller and Matti, 2001a). Most of these rocks are moderately mafic, coarse-grained hornblende and pyroxene-hornblende monzonite that contain widespread, but not very well developed flow foliation. In the northeastern half of the range, the rocks have been noticably altered, but the mode and timing of the alteration are not well understood. From approximately the center of the range, progressively northeastward, the rocks loose hornblende and pyroxene, which is replaced by much smaller quantities of yellow-orange garnet and pale-green epidote, and trace fluorite. The alteration does not appear to affect nearby Cretaceous granitic rocks, suggesting that it may be a late-stage emplacement process. Barth and others (1997) report a zircon uranium-lead age of 235 Ma for the monzonite of Hill 4001 (TRh), 7.5' Fifteenmile Valley Quadrangle,,which appears to be outside the area of alteration.

Probable Jurassic rocks are widespread, but not voluminous in the San Bernardino Mountains assemblage. Most are not well dated, but are identified by mineralogic and compositional similarities to nearby dated Jurassic rocks. At the east edge of the quadrangle near White Mountain (fig. 1), Butler Peak 7.5' quadrangle,a small area of the leucocratic quartz monzonite of Crystal Creek (Jc) represents the westernmost part of a large, well dated pluton exposed extensively east of the quadrangle. J.L. Wooden (written commun., 1997) obtained a sphene uranium-lead age of 151 Ma for the quartz monzonite.

Leucocratic, hornblende- and arfvedsonite-bearing syenite in the Ord Mountains (Js), Apple Valley South 7.5' quadrangle, is an alkalic rock made up of about 90 percent potassium feldspar, and containing very little quartz. This rock forms small dikes, sills, and pods intruding metasedimentary rocks of unknown age (photo 330), and is not found in any other association. J.L. Wooden (written commun., 1997) obtained a zircon uranium-lead age of 148 Ma for the syenite. The granodiorite of Arrowhead Peak (Ja), San Bernardino North 7.5' quadrangle, a moderate sized, faulted pluton of probable Jurassic age is found south of Lake Gregory (fig. 1). This rock is a highly mafic, porphyritic biotite-hornblende granodiorite ranging to quartz monzonite that is very similar to Jurassic granodiorite and quartz monzonite bodies in the Mojave Desert northeast of the quadrangle (Miller and Morton, 1980).

Cretaceous granitic rocks

Cretaceous granitic rocks make up the largest part of the San Bernardino Mountains assemblage in the San Bernardino quadrangle. They range in composition from leucocratic monzogranite to fairly mafic granodiorite. The voluminous tonalitic rocks in the San Gabriel Mountains and Peninsular Ranges assemblages are essentially absent in the western San Bernardino Mountains. Some rocks mapped as the mixed diorite and gabbro unit (KJdg), may be of Cretaceous age, but most are probably Jurassic. Unlike many of the Cretaceous granitic rocks in the eastern half of the San Bernardino Mountains, almost none in the western part of the range are appreciably deformed or have obvious secondary fabrics or grain-size reduction.

Granitic rocks mapped as Mesozoic are probably predominantly Cretaceous rocks, including the mixed granitic rocks of Silverwood Lake (Mzsl), Silverwood Lake 7.5' quadrangle, the monzogranite and granodiorite of Holcomb Ridge (Mzh), Butler Peak 7.5' quadrangle, and the biotite monzogranite of Big John Peak (Mzgr), Butler Peak 7.5' quadrangle. All of these units are mapped as Mesozoic rather than Cretaceous, because they are slightly to very heterogeneous, containing some components that are either quartz deficient or alkalic, more characteristic of Jurassic and Triassic rocks than Cretaceous rocks.

Most of the Cretaceous rocks fall into three groups, (1) moderately mafic granodiorite and monzogranite, (2) relatively uniform composition biotite and hornblende-biotite monzogranite, and (3) very heterogeneous granitic rock units. The granodiorite of Angeles Oaks (Kao) (photo 338), Keller Peak 7.5' quadrangle, granodiorite of Hook Creek (Khc), Lake Arrowhead 7.5' quadrangle, and granodiorite of Willow Creek (Kwc), Lake Arrowhead 7.5' quadrangle, are examples of the first group. All of these units are granodiorite, but contain minor amounts of rocks that range to monzogranite. All have color indexes of 15 or greater, and even though biotite is the dominant mafic mineral, hornblende is abundant. Sphene is abundant and megascopically obvious in all three units.

The second group is represented by the Rattlesnake Mountain pluton of MacColl (1964) (Kr and Krp) Butler Peak 7.5' quadrangle, the granodiorite of Hanna Flat (Kh), Butler Peak 7.5' quadrangle, the monzogranite of Butler Peak (Kbp), Butler Peak 7.5' quadrangle, the monzogranite of Keller Peak (Kk), Keller Peak 7.5' quadrangle, the monzogranite of Kinley Creek (Kkc) (photo 339), Lake Arrowhead 7.5' quadrangle, and the monzogranite of Muddy Spring (Kms), Lake Arrowhead 7.5' quadrangle. Of these, the monzogranite of Butler Peak, monzogranite of Kinley Creek, and monzogranite of Muddy Spring all contain primary muscovite ranging from trace amounts to several percent. The granodiorite of Hanna Flat is a hornblende-biotite-bearing unit, and the monzogranite of Keller Peak and Rattlesnake Mountain pluton of MacColl (1964) are biotite-bearing units that locally contain trace to minor amounts of hornblende. None of the muscovite-bearing units contain sphene, but rocks of the other three units do. All or much of the monzogranite of Keller Peak and Rattlesnake Mountain pluton of MacColl (1964) is porphyritic, but the other units are essentially even grained. Only the Rattlesnake Mountain pluton of MacColl (1964) contains widespread evidence of primary flow fabric.

The third group is represented by the very extensive monzogranite of City Creek (Kcc), Harrison Mountain 7.5' quadrangle, and the mixed granitic rocks of Heaps Peak (Kmx), Lake Arrowhead 7.5' quadrangle. The monzogranite of City Creek is largely biotite and muscovite-biotite monzogranite, but contains large amounts of pegmatitic and alaskitic rocks in dikes and small bodies ranging to 0.5 km long. It also includes abundant granodiorite, diorite, gabbro, and other monzogranite that differs texturally and compositionally from the typical monzogranite in the unit. Bodies of these included rocks range in length from centimeters to hundreds of meters and are very irregularly distributed. Disregarding all of the included rocks, the monzogranite of City Creek, as mapped, could represent more than one Cretaceous pluton. The mixed granitic rocks of Heaps Peak unit is similar to the monzogranite of City Creek, but contains much less of the basic biotite monzogranite that characterizes the larger unit.

Cenozoic sedimentary rocks

Late Cenozoic nonmarine sedimentary rocks occur at a number of noncontiguous localities in the San Bernardino Mountains, several in partially fault-bounded blocks. With one exception, ages of these units are poorly constrained, and because all are probably derived from local sources in a geologically varied terrane, they are notably different from one another in appearance. The most extensive occurrances are in Santa Ana Canyon, at Fredalba (fig. 1), Harrison Mountain 7.5' quadrangle, south of Lake Arrowhead, Lake Arrowhead 7.5' quadrangle, west of Lake Gregory, San Bernardino North 7.5' quadrangle, and west of Silverwood Lake, Silverwood Lake 7.5' quadrangle.

The Pliocene and Miocene Santa Ana Sandstone (Tsa) in Santa Ana Canyon, Keller Peak 7.5' quadrangle, consists of over 300 m of arkosic sandstone and conglomeratic arkosic sandstone (photo 340) (Vaughan, 1922; Sadler, 1982, 1993; Jacobs, 1982; Sadler and Demirer, 1986). It extends almost 20 km east of the map area, and is bounded on the north by the Santa Ana Fault, a major, seismically active, north dipping reverse fault. It is moderately well lithified, forming large, near-vertical cliff faces in places (photo 341). Most of the sediment and clasts appear to have been derived from the nearby monzogranite of City Creek (Kcc) and monzogranite of Keller Peak (Kk). The unit contains a basalt flow that has a 6.2 Ma whole-rock potassium-argon age (Woodburne, 1975).

A conglomerate (Tcf) containing lesser interbedded arkosic conglomerate (photo 342) is restricted mainly to the area around Fredalba and Running Springs, Lake Arrowhead 7.5' quadrangle. It is derived from local rocks, is much more conglomeratic than the Santa Ana Sandstone, and is only moderately well consolidated. The Pliocene age is based only on general lithologic comparison with other nearby late Cenozoic sedimentary units. This unit may be bounded on the north by a fault.

In the Crestline area (fig. 1), San Bernardino North 7.5' quadrangle, conglomerate and conglomeratic arkose (Tcc) is very poorly exposed in roadcuts only. From its distribution, it must be mostly fault bounded. Unlike most of the other late Cenozoic sedimentary units, it is gray and greenish-gray. Bedding is indistinct, except where arkose lenses are abundant, and the larger clasts are typically matrix supported. Most clasts are from recognized local sources.

In Cleghorn Canyon, west of Silverwood Lake, Silverwood Lake 7.5' quadrangle, highly faulted, pale tan and pale pinkish-tan, conglomeratic arkose nonconformably rests on Mesozoic granitic rocks. These conglomeratic rocks are mapped as noncontiguous fault slices of Crowder Formation (Tcr), which is extensively exposed to the west in the Cajon Pass area (Meisling and Weldon, 1989).

<u>Rocks of the Cajon Valley area</u>

North of the San Andreas Fault, in the Cajon Valley area, Tertiary and Quaternary sedimentary rocks were widely deposited on basement rocks of the San Bernardino Mountains basement assemblage. The two oldest of these units are marine; the rest are nonmarine.

<u>Sedimentary rocks of Cosy Dell area</u>

The oldest unit in the Cajon Valley area is the Cretaceous marine sedimentary rocks of Cosy Dell area (Kcd), Cajon 7.5' quadrangle, that occurs in a number of fault blocks in the southern part of the Cajon Valley area (Weldon, 1986). It consists of a basal conglomerate deposited on gneissic granitic basement; the conglomerate is overlain by sandstone and siltstone (photos 343, 344, 345, and 346). All contacts between the sedimentary rocks of Cosy Dell area and younger sedimentary units are faulted (photo 347).

Based on lithologic similarity, Noble (1954b), Dibblee (1967), and Kooser (l980, 1982) correlated these rocks with the Paleocene San Francisquito Formation (Noble termed them the Martinez Formation) on the south side of the San Andreas Fault in the Devils Punchbowl area 40 km west of the Cajon Valley area (fig. 1). Subsequently two separate remains of a Cretaceous *elasmosaurid* plesiosaur have been recovered from the sedimentary rocks of Cosy Dell area, including about 40 incomplete vertebrae, ten of which were articulated (Kooser, 1985; Lucas and Reynolds, 1991). Based on the plesiosaur fossils, the rocks are now considered Late Cretaceous age rather than Paleocene.

<u>Vaqueros Formation</u>

Several small fault blocks of coarse-grained arkosic sandstone and minor siltstone resting depositionally on granitic basement or faulted against the sedimentary rocks of Cosy Dell area are assigned to the marine early Miocene Vaqueros Formation (Tv) (Woodburne and Golz, 1972), Cajon 7.5' quadrangle. Fossils from this unit were described by Woodring (1942). These rocks are unconformably overlain by nonmarine Miocene sedimentary rocks of the Cajon Valley Formation.

Cajon Valley Formation

The Cajon Valley Formation (Tcv units) is a fault-isolated 2,400-m-thick sequence of nonmarine clastic rocks (photos 348, 294, and 349), Cajon and Telegraph Peak 7.5' quadrangles, that at one time had been correlated with the similar-appearing Punchbowl Formation (Noble, 1953, 1954a) 40 km to the west. Biostratigraphic studies by Woodburne and Golz (1972) demonstrated that the unit is not coeval with, nor lithologically the same as, the Punchbowl Formation, and that the youngest rocks in Cajon Valley Formation are older than the oldest rocks of the Punchbowl Formation.

The Cajon Valley Formation contains a vertebrate fauna of middle to late Miocene age (Woodburne and Golz, 1972). The unit consists of a lower sequence of tan conglomerate and conglomeratic sandstone and an upper sequence of finer-grained conglomeratic sandstone and reddish to grayish sandstone that locally includes gray siltstone. Within part of the unit are fine-grained, gray to black beds, some of which contain lignite and common snail remains (photo 350). Along the western boundary of the Cajon Valley Formation, the late Miocene Cajon Valley Fault juxtaposes the unit against Cretaceous tonalite (Woodburne and Golz, 1972). The eastern boundary of the unit is the Squaw Peak Thrust that juxtaposes it beneath the Miocene Crowder Formation.

Crowder Formation

The Crowder Formation (Tcr), Cajon 7.5' quadrangle, is a thick section of tan and light-gray conglomerate and conglomeratic sandstone (photos 351, 352, 353, and 354) that is not as well lithified as the Cajon Valley Formation. Dibblee (1967) considered the Crowder Formation to be Pliocene and interpreted it to have been unconformably deposited on the Cajon Valley Formation. Weldon (1984, 1986), Meisling and Weldon (1989), and Reynolds (1984) determined that the Crowder Formation is approximately the same age as the Cajon Valley Formation and that the Cajon Valley and the Crowder Formations were structurally juxtaposed by the Squaw Peak thrust fault (Meisling and Weldon, 1989). Ehlig (1988b) provides an alternative view of these structural relations.

Phelan Peak deposits of Weldon (1984)

Sedimentary rocks on the north side of Cajon Valley, Cajon and Telegraph Peak 7.5' quadrangles, were included with the Crowder Formation by Dibblee (1967). Foster (1980), noting litholithic differences with the type Crowder Formation, termed these rocks the western facies of the Crowder Formation. These deposits were subsequently determined to be younger than the Crowder Formation and are now called the Phelan Peak deposits of Weldon (1984) (QTpp) (Meisling, 1984; Weldon, 1984, 1986). These fluvial rocks are unconsolidated to moderately indurated, light brown to orange coarse sandstone, conglomeratic sandstone, and conglomerate (photos 355, 356, and 357). Time of deposition ranges from 4.1 Ma to 1.4 Ma (Weldon, 1984, 1986). As now defined, the Phelan Peak deposits of Weldon (1984) unconformably overlie the Cajon Valley Formation and the Crowder Formation, as well as the tectonic structures that separate these two older units.

Harold Formation and Shoemaker Gravel

Quaternary deposits in the Cajon Valley region, Cajon and Telegraph Peak 7.5' quadrangles, include the upper sediments of the informally named Inface Bluffs (photos 358 and 359) on the north side of Cajon Valley (Noble, 1954b). Three Pleistocene sedimentary units are exposed in these bluffs, and record the tectonic history of the informally named Victorville fan, a beheaded, dissected Quaternary alluvial fan complex extending northward from the Inface Bluffs (Meisling and Weldon, 1989; Weldon and others, 1993). The lowest unit in this sequence is the Harold Formation, which is overlain by the Shoemaker Gravel, which in turn is overlain by a sequence of dissected sand and gravel alluvial fans that form the uppermost part of the Victorville fan (Foster, 1980; 1982; Meisling, 1984; Weldon, 1986) (photo 360, also see 351). Where best developed, the Harold Formation (Noble, 1953) is 35 m of poorly consolidated, fluvial sandstone and pebbly sandstone (Foster, 1980, 1982), which grades upward into the Shoemaker Gravel (Noble,1954b), a poorly consolidated, thick, and indistinctly bedded, coarse sand, conglomeratic sand, and conglomerate (photo 361). North of Cajon Valley the Shoemaker Gravel is about 60 m thick.

Generic Quaternary deposits

As in the San Gabriel Mountains, the Quaternary sedimentary history associated with the San Bernardino Mountains bedrock assemblage is largely recorded in the area surrounding the assemblage, and to a much lesser degree, within the mountains. Within the mountains, Quaternary deposits are largely restricted to alluvial valley, small alluvial-fan, alluvial wash, and landslide deposits, but in a few places there are moderately large older alluvial-fan deposits (photos 362 and 363).

Alluvial fans emanate from canyons along the south margin of the mountains, especially the canyons of Waterman Creek, City Creek, Plunge Creek, the Santa Ana River, and Mill Creek (photos 596 and 595), and coalesce and cross-cut to form an extremely complex alluvial-fan array. Although these fans on the south side of the mountains largely lie on basement of the San Gabriel assemblage, they are included here, because they emanate from the San Bernardino Mountains and reflect the uplift and erosional history of that range. Within the San Bernardino quadrangle, alluvial sediments from the Santa Ana River and Mill Creek systems dominate the alluvial deposits from the San Bernardino Mountains, truncating all but the most recent deposits coming from canyons to the northwest. Just north of the Box Springs Mountains (fig. 1), the Santa Ana River and Mill Creek systems merge with the Cajon Wash and Lytle Creek systems (photo 183), the latter furnishing sediments from not only the western San Bernardino Mountains, but also the eastern San Gabriel Mountains.

Along the north side of the San Bernardino Mountains, similar alluvial-fan units extend northward onto Apple Valley, aggraded to Rabbit Dry Lake (photo 366), Fifteen Mile Valley 7.5' quadrangle. Although deposited on basement characteristic of the San Bernardino Mountains assemblage, including Mojave Desert basement, most of the informally named Victorville fan (photo 367, see also photos 295, and 359) is built from sediments originating from the San Gabriel Mountains assemblage. Within the San Bernardino quadrangle, almost all of the alluvial deposits on the north side of the San Bernardino Mountains are much finer grained than their counterparts surrounding the San Gabriel Mountains. This grain-size difference reflects a period of extremely deep weathering of the granitic rocks that underlie the western San Bernardino Mountains. The protracted Tertiary weathering produced vast amounts of grus for developing alluvial deposits as the western part of the range was uplifted.

Within the mountains, large, perched, old fan deposits, capped by well-developed, relatively undissected surfaces, are present in the West Fork of City Creek drainage and north of the Santa Ana River in the area south of Keller Peak. Perched, very old alluvial-fan deposits (Qvof), capped by well-developed, relatively undissected surfaces and well developed soil horizons are found in the Little Pine Flats area, Butler Peak 7.5' quadrangle. Although derived from local bedrock types, these latter fan deposits do not have an obvious source area drainage of a size expected for deposits this thick and extensive.

Landslides are common in the western San Bernardino Mountains, but are not nearly as numerous or large as they are in the eastern part of the range or in the San Gabriel Mountains. Several moderate sized landslide areas occur locally along the steep south margin of the range in the upper reaches of Bear Canyon, on the east side of City Creek, and in canyons between Silverwood Lake and Lake Arrowhead. In the lower part of Mill Creek numerous old landslides are developed in the Mill Creek Formation of Gibson (1971).

POST-BATHOLITHIC STRUCTURES

Post-batholithic geologic structures in the San Bernardino and Santa Ana quadrangles are dominated by the seismically active, right-lateral strike-slip San Andreas Fault System. The major fault zone of the system is the San Andreas Fault Zone, which, in this area, forms the northern boundary of the San Gabriel Mountains and the southern boundary of the San Bernardino Mountains. Related seismically active strike slip faults in the Peninsular Ranges assemblage include the San Jacinto, Elsinore, and Whittier Fault Zones. Other strike-slip faults in the quadrangles include the Glen Helen, Cleghorn, and Chino Faults, and the mostly off-shore part of the Newport-Inglewood Fault Zone. Two older faults within the eastern San Gabriel Mountains are considered to be abandoned strands of the San Andreas Fault, the Punchbowl Fault and the San Gabriel Fault.

The southern margin of the San Gabriel Mountains is bounded by the seismically active Cucamonga and Sierra Madre Fault Zones. Despite different names, these fault zones comprise a continuous complex structural zone of north dipping oblique-slip reverse faults that are largely responsible for uplift of the San Gabriel Mountains. Numerous other faults related to both the Cucamonga-Sierra Madre system, the San Andreas system, and the complex interaction between the two systems occur within and surrounding the San Gabriel Mountains.

Post-batholithic geologic structures in and around the San Bernardino Mountains include late Miocene structures associated with uplift of the ancestral range, displacement on structures associated with the San Andreas Fault Zone, and Quaternary structures associated with uplift of the range.

Uplift structures are associated with late Miocene uplift of the ancestral San Bernardino Mountains (Meisling and Weldon, 1982, 1989), and include the Squaw Peak Thrust Fault in the Cajon

Valley region and east-trending north-dipping reverse faults and left-lateral faults in the central and western parts of the mountains. These latter structures include the Santa Ana Fault, which is an east-striking reverse fault (fig. 1), and possibly the Devil Canyon Fault, along which the slip sense is unknown, but is probably up on the north. The extensive, only moderately dissected plateau that forms the main mass of the San Bernardino Mountains lies north of the Santa Ana Fault. South of the fault, just east of the quadrangle, is a higher, more dissected terrain that includes the highest summits of the San Bernardino Mountains.

Several strands of the San Andreas Fault Zone both traverse the southeastern San Bernardino Mountains and flank the southwestern base of the range (Matti and others, 1992; Matti and Morton, 1993). Older strands of the fault zone include the Wilson Creek and Mill Creek Faults; the modern trace of the fault in this region is labled San Andreas Fault Zone on fig. 1 and on the accompanying fault map (Map sheet 2). The older strands are responsible for very large right-lateral displacements that over the last few million years have juxtaposed far-traveled crystalline basement rocks south of the fault against the main mass of the San Bernardino Mountains.

The modern San Andreas Fault Zone is capable of generating large earthquakes, although most of that part of the fault in the San Bernardino quadrangle apparently did not rupture during the 1857 earthquake; rupture occurred only along the segment in the northwesternmost part of the quadrangle. Part of the reason for this may be that south of the Transverse Ranges, much of the strain associated with the San Andreas Fault system has shifted to the San Jacinto Fault Zone (Morton and Matti, 1993, Kendrick and others, 2002).

Locally, complexities in the San Andreas Fault Zone have created associated reverse and thrust-fault zones and normal dip-slip fault zones (Matti and others, 1985, 1992). The fault geometry in the Yucaipa area and in the San Gorgonio Pass area east of the map area are examples of these complexities.

Uplift structures associated with Quaternary uplift of the range include the north-frontal fault zone (Meisling, 1984; Miller, 1987; Sadler, 1982) and faults along the south part of the range that facilitated uplift. Meisling and Weldon (1989) present evidence that in the early Quaternary, uplift was accomplished by north-directed upward movements of the San Bernardino Mountains block along south-dipping low-angle structures that underlie the range. This uplift created the majority of the topographic relief along the north face of the San Bernardino Mountains. Although largely complete by middle Quaternary time (Meisling and Weldon, 1989), some tectonism presumably associated with uplift of the range may have continued into the late Quaternary, giving rise to strike-slip and thrust fault scarps along the northern range front (Miller, 1987; Miller and Matti, 2001a).

Faults

Introduction

Sequential uplifts that formed the San Bernardino and San Gabriel Mountains are a result of movements and complex fault interactions on the numerous faults of the San Andreas Fault system and on various faults both closely, and only partly, related to it (Matti and others 1992; Matti and Morton, 1993). The Peninsular Ranges Province is relatively stable and coherent, but it also is cut by the seismically active Elsinore Fault, Whittier Fault; Chino Fault, and offshore, the submarine extension of the Newport-Inglewood Fault.

Major fault types in the quadrangle include right-lateral and left-lateral strike slip faults, reverse faults, and thrust faults. Numerous small, but no major normal faults have been identified. In addition to the modern San Andreas Fault Zone and the Peninsular Ranges faults just mentioned, several other faults are seismically active, including the San Jacinto Fault Zone, Glen Helen Fault, Cucamonga Fault, Sierra Madre Fault, Santa Ana Fault, and numerous smaller unnamed faults. In some places zones of intensely tectonically deformed rocks do not appear to be connected to any mapped fault (photo 368).

San Andreas Fault Zone

Within the map area, the San Andreas Fault Zone and its Neogene and Quaternary history are relatively complex compared to the central California segment of the fault zone. Through most of the Transverse Ranges, the fault zone has a west-northwest orientation and has shifted position and abandoned major segments through time. The San Gabriel (photos 369 and 370) and Punchbowl (photo 371) Faults are abandonded segments of the San Andreas Fault in the San Gabriel Mountains as is the Wilson Creek Fault in the San Bernardino Mountains. Also in the San Bernardino Mountains, the Mill Creek Fault was once the main strand of the San Andreas Fault, and although the main segment shifted southward, the Mill Creek Fault is still seismically active. Within the San Bernardino quadrangle, the present day main trace of the

San Andreas, informally termed the San Bernardino strand by Matti and others (1992), is coincident with another older segment informally termed the Mission Creek strand (Matti and others, 1992).

Modern trace

The modern, active trace of the San Andreas Fault Zone traverses the San Bernardino quadrangle almost from corner to corner. Reconstruction of the developmental history of the fault in this area (Matti and others, 1992; Matti and Morton, 1993) shows that it is not a uniformally active fault that has through time followed this present day trace, but is a complex, migrating structure, some of which is coincident with older structures, but most of which is not.

Holcomb Ridge to Cajon Pass—On the north side of the San Gabriel Mountains, the San Andreas Fault Zone forms a nearly linear, relatively simple trace that, over several tens of kilometers, is very slightly concave to the south. Along most of the fault its position is marked by linear disruption of the topography (photo 372). Where exposed, such as near Big Pines west of Wrightwood, the wide fault zone consists of finely comminuted basement rock that erodes to form smooth slopes (photo 331). In Lone Pine Canyon, the fault zone forms a linear trench-like valley that reflects erosion of comminuted rock formed through long-term displacement on the fault (photo 373). Youthfulness of ground rupture is indicated by slightly discontinuous, but numerous, close-spaced fault scarps from Wrightwood to Blue Cut (fig. 1). A major sag pond, Lost Lake, is located just north of Blue Cut (photo 593 and 375). Near Lost Lake the San Andreas Fault offsets a modern stream drainage (photo 376). This segment of the fault along the north flank of the San Gabriel Mountains has been informally termed the Mojave Desert segment of the San Andreas by Matti and others (1992), and to the southeast, passes into the informally termed San Bernardino segment, which defines the southern edge of the San Bernardino Mountains (Matti and others, 1992a) (photos 378 and 595).

Cajon Pass to east edge of San Bernardino quadrangle—The San Bernardino and Mission Creek segments are discussed together here, because in this area they are coincident, but the Mission Creek vastly predates the San Bernardino segment in terms of activity and development. Along the south side of the San Bernardino Mountains the San Andreas Fault Zone is marked by sharp, well defined scarps and offset drainages (photos 380, 598, 382, 597, and 599). East of the mouth of Santa Ana Canyon, Yucaipa 7.5' quadrangle, it juxtaposes the gneissic granitoid rocks and gneiss unit (gg), and very old alluvial fan deposits (Qvof) forming a major rent near the base of the San Bernardino Mountains (photos 383 and 384).

From approximately where the San Andreas Fault crosses Cajon Wash, Cajon 7.5' quadrangle (photo 599), to where it exits the east side of the quadrangle, the surface trace of the fault is much more complex than it is to the northwest. Part of this difference may be due to the main fault zone intersecting the Punchbowl Fault near Cajon Wash and the Mill Creek Fault southeast of there. Throughout the interval southeast of Cajon Wash, the San Andreas Fault is much more a zone than it is to the northwest, consisting of numerous long and short segments that diverge and remerge with the main trace, and numerous short segments that parallel, but do not join the main trace. Nearly all of these segments and the main trace show very youthful fault features, and many cut all but the youngest Quaternary units. Included in places are low angle faults whose relationship to the San Andreas Fault is not clear. North of the San Andreas Fault in the Devore to Waterman Canyon area, Devore and San Bernardino North 7.5' quadrangles, a major thrust fault places basment rocks over a section of varied sedimentary rocks (photo 385). Elsewhere poorly-exposed, minor low-angle faults occur.

Older faults closely related to the San Andreas Fault

Several faults in the quadrangle represent old, abandonded segments of the San Andreas Fault. Some of these no longer intersect, merge, or are coincide with the present day fault, and some are now kilometers removed from it.

Mill Creek Fault—The Mill Creek Fault, an old segment of the San Andreas Fault, intersects the main trace of the San Andreas near Devils Canyon, San Bernardino North 7.5' quadrangle. For about 13 km southeastward, it irregularly parallels the main trace, but about one-quarter to one kilometer to the north (photo 596), near City Creek, the Mill Creek Fault begins a gradual, but progressive bend northward, which opens the distance between them to about 3.5 km where they cross Santa Ana Canyon, Yucaipa 7.5' quadrangle. The trace of this fault is marked by young looking features, and along one segment, has a consistent mountain-side-down vertical component in addition to obvious right lateral offset (photo 386). Rocks similar to the gneissic granitoid rocks and gneiss unit (gg) and the diorite of Cram Peak (Mzc) are found to the southeast in the Little San Bernardino Mountains on the north side of the Mill Creek Fault. Restoration of these rocks to the Yucaipa area requires a combined right-lateral displacement on the Mill

Creek Fault and the Wilson Creek Fault, another old segment of the San Andreas, of about 50 km (Matti and Morton, 1993).

Wilson Creek Fault—Only segments of the Wilson Creek Fault are preserved in the map area, and west of Santa Ana Canyon, Yucaipa 7.5' quadrangle, the fault is deformed, shallow dipping to the south, and has a late component of reverse movement. There, it places the gneissic granitoid rocks and gneiss unit (gg) over the Miocene conglomerate, sandstone, and arkose unit (Tsg). East of Santa Ana Canyon, the fault typically is steeply dipping, and separates the Miocene formation of Warm Springs (Tw) from the Miocene Mill Creek Formation of Gibson (1971). Although well defined, the fault has no youthful fault features.

Punchbowl Fault—The Punchbowl Fault is another deformed early strand of the San Andreas Fault (photo 566). In the Blue Cut area rocks between the San Andreas Fault and the Punchbowl Fault Zone are intensely deformed (photo 389). From the west edge of the map area to the vicinity of Blue Cut (figure 1), Cajon 7.5' quadrangle, Punchbowl Fault fault roughly parallels the San Andreas 0.5 to four kilometers south of the modern day trace. The Punchbowl Fault Zone consists of two closely spaced faults separated at most places by a sliver of intensely deformed, chloritized tonalite and gneissic rock. At Blue Cut this deformed rock is about 300 m thick (photos 387 and 388). In some places recognizable gneiss and tonalite are missing and the fault zone consists of thoroughly sheared basement rock of uncertain parentage. In the western part of the area the fault zone includes deformed sedimentary rocks (photo 291). Like the Wilson Creek Fault, the Punchbowl Fault is nowhere associated with youthful fault features.

San Gabriel Fault—The San Gabriel Fault is also a deformed early strand of the San Andreas Fault (Crowell, 1952, 1954), similar to the Punchbowl Fault. In the eastern San Gabriel Mountains, it has a relatively linear east-strike orientation west of San Antonio Canyon, Mount Baldy, Glendora, and Azusa 7.5' quadrangles, roughly paralleling the San Gabriel River (photo 369). It is offset northward by a fault in San Antonio Canyon (photo 603), but continues east of the canyon, roughly following Icehouse Canyon (photo 370), Cucamonga Peak 7.5' quadrangle. From Icehouse Canyon, it extends into the Middle Fork of Lytle Creek where it veers progressively eastward and then southeastward joining the South, Middle, and North Forks of the Lytle Creek Faults (photo 602) before emerging at the mountain front in the Sycamore Flat area (fig. 1) (photo 391). The San Gabriel Fault is probably the oldest San Andreas-related fault because (1) its orientation is strongly divergent from the modern San Andreas Fault, (2) it is deformed by a number of younger structures, and (3) it lacks any youthful fault features.

Thrust fault, Devore area

On the north side of the San Andreas Fault in the Devore area, Devore 7.5' quadrangle, a north-dipping to near horizontal thrust fault places basement rocks over conglomerate and sandstone (Tsg) (photo 385). The role this thrust plays in the structurally complex history of the area is unclear.

Elsewhere low-angle faults and irregular low-angle faults are observed in basement rocks (photo 392).

San Jacinto Fault Zone

The San Jacinto Fault is a young, major element of the San Andreas Fault system, originating at the southeast margin of the San Gabriel Mountains in Cajon Creek, Devore 7.5' quadrangle, and extending southeastward with a more southerly strike than the San Andreas Fault Zone. It is seismically the most active fault zone in southern California, and has generated a large number of destructive earthquakes in historic time. In some trenches the fault is seen to extend to the surface offsetting Holocene deposits (photos 1, 2, 3, and 393). In contrast to the relatively continuous and singular trace of the San Andreas Fault, the San Jacinto Fault Zone consists of a series of relatively short en echelon faults (Sharp, l975; Sanders and Magistrale, 1997). Most of these faults have numerous surface features (e.g., scarps, sagponds, and offset drainages) indicative of recent ground rupture. In all but the youngest alluvial units, the location of the San Jacinto Fault in the San Bernardino lowland is marked by scarps and small pressure ridges (photos 394, 395, 396, 397, 398, 399, and 400).

South of the city of San Bernardino, sedimentary rocks are folded and uplifted as the rocks pass through a restraining left-bend in the San Jacinto Fault Zone, San Bernardino South and Redlands 7.5' quadrangles,. The uplifted sedimentary rocks form the San Timoteo Badlands. These sedimentary rocks are ramp-like uplifted 500 m over a distance of about eight kilometers. Deformation is most intense adjacent to the San Jacinto Fault, where the sedimentary rocks are tightly folded. Eastward, these tightly folded rocks are separated from an open anticline by the diachronous fault resulting from the compressional deformation produced at the restraining bend of the San Jacinto Fault Zone. (Kendrick and others, 2002, Morton and others, 1990). This diachronous fault enters the San Jacinto Fault Zone in the northern part of the San Jacinto Valley, Sunnymead and El Casco 7.5' quadrangles. Anticlinal deformation in the Mount Eden area (fig. 1) may reflect the southern extent of the deformation produced by the restraining bend. Displacement along foliation planes within steeply dipping schist in the Mount Eden area appears to be the result of the deformation producing the anticline in the adjacent sedimentary rocks. The contact between the basement rocks and sedimentary rocks is sheared and faulted everywhere it is exposed. This faulting appears to be produced by the anticlinal deformation. On the southwest side of Mount Eden is a linear fault-line valley. A northeast dipping fault, probably an early strand of the San Jacinto Fault, is located on the west side of the fault-line valley. This fault, with a distinctive black gouge zone, separates basement from sedimentary rocks (photo 401).

In the northern San Jacinto Valley, El Casco and Lakeview 7.5' quadrangles, a major right-step in the San Jacinto Fault Zone has produced a deep pull-apart basin, here informally termed the San Jacinto basin. The fault on the east side of this basin is generally termed the Claremont Fault, named for a peak north of the city of San Jacinto (photo 32). East of the map area, basement relief across this small basin reaches a maximum of just over 3.5 km, 650 m above the valley floor and 3,000 m below the valley floor. The fault bounding the west side of the basin is the Casa Loma Fault, named for a small compressional hill produced at an irregularity in the strike of the fault. The location of the fault is marked by a northeast-facing fault scarp, in part modified by the San Jacinto River. Holocene(?) alluvial fan sediments on the west side of the Casa Loma Fault near the east edge of the quadrangle were largely derived from the San Jacinto Mountains (San Jacinto pluton) suggesting the scarp did not exist in the early(?) Holocene.

The San Jacinto basin is about three kilometers in width, 25 km in length, contains about three kilometers of Quaternary fill, and is actively and rapidly subsiding. The subsidence is a result of long-term tectonic subsidence accelerated by recent mining of groundwater (Lofgren, 1976; Lofgren and Meyer, 1975; Proctor, 1962; Morton, 1977). The age of the basin and the bounding faults is estimated to be no older than 1.5 Ma. Wood recovered from a depth of 150 m, the deepest dated sediments, gave a ^{14}C age of 30,400 ±1,200 years. A rapidly expanding closed depression called Mystic Lake (fig. 5) (photo 242), located west of Mount Eden area, does not mark the area of maximum subsidence; the location of the lake is due to most of the sediment entering the San Jacinto basin, being deposited northwest and southeast of the closed depression.

Varied interpretations of slip rates on the San Jacinto Fault Zone have been made. Sharp (1967) determined the slip to be no less than 10 mm per year for part of the San Jacinto Fault southeast of the map area; this has been commonly misstated by some to indicate a slip rate of 10 mm per year, quite different than what Sharp stated. Later Sharp (1981) quantified his determination to a minimum slip rate of 8 to 12 mm per year. Rockwell and others (1986), also for a segment of the fault east of the Santa Ana quadrangle, determined a slip rate of 10 to 15 mm per year. Using offset soils in the northern part of the San Timoteto Badlands, Morton and Matti (1993) indicated a minimum slip rate of about eight mm per year for an older soil estimated to be about 500,000 yrs old, and a slip rate for the past 50,000 yrs of about 20 mm per year.

Glen Helen Fault

Most earlier interpretations have placed the San Jacinto Fault Zone entering the San Gabriel Mountains near Sycamore Flat (fig. 1). However, lack of recent displacement on faults (observations from trenches dug to assess fault features) just north of Sycamore Flat indicates that the faults there do not represent the northern part of the San Jacinto Fault Zone. Our interpretation is that from a point just south of the easternmost San Gabriel Mountains, slip steps to the right from the north end of the San Jacinto Fault, to form the Glen Helen Fault (Note: early spelling of Glen Helen was Glenn Helen). The Glen Helen Fault along the west side of lower Cajon Canyon (fig. 1) has a variety of more-or-less continuous youthful fault features, such as sag ponds and scarps, that characterize the San Jacinto Fault Zone throughout the Peninsular Ranges (e.g., Sharp 1967, 1972). Although not on the direct projection of the San Jacinto Fault to the south, we suggest that motion from the San Jacinto Fault has been transferred to the the Glen Helen Fault (right step), and that the latter represents the northern terminus of the San Jacinto Fault Zone (photo 600). The Glen Helen Fault loses its identity in Cajon Creek between the Applewhite area of Lytle Creek and the Blue Cut area of Cajon Creek, Devore 7.5' quadrangle. A cross fault between the Applewhite and Blue Cut areas appears to be a relatively minor structure marked by imbricated Pelona Schist clasts, however its role in the fault geometry of the area is not clear.

Relationship between the faults at Sycamore Flat-Lytle Creek, and the San Antonio Canyon-Stoddard Canyon Faults

Because the Glen Helen Fault is considered to be the stepped, northern continuation of the active San Jacinto Fault, the faults previously thought to be part of the San Jacinto Fault Zone within the San

Gabriel Mountains are now thought to be related to older faults. The fault zone at the front of the range southeast of Sycamore Flat continues northwestward along the west side of Lower Lytle Creek Ridge (fig. 1). Farther into the range, the faults constituting this zone traditionally have been depicted as either branching directly off of the San Andreas Fault on the north side of the mountains or merging with the inactive Punchbowl Fault. Geologic mapping by Morton (1975), Morton and Matti (1990a, 1990b), and Morton and others (1990), however, indicates that the surface trace of the fault zone does not connect either with the Punchbowl or San Andreas faults at the surface, but instead interacts in some fashion with east-to northeast-striking faults in the interior of the eastern San Gabriel Mountains.

At Sycamore Flat, a 300-m-wide zone is defined by three nearly vertical faults. From west to east, these three faults bound four distinct blocks consisting of biotite gneiss, mylonitic leucogranite, Pelona Schist, and granodiorite of Telegraph Peak (photo 391). The fault having the greatest width of crushed rock is overlain by apparently unfaulted alluvium interpreted to 200 to 500 Ka in age (Morton and Matti, 1987). Four kilometers into the range, the projection of these faults merge, and consists of a relatively homogeneous zone of gouge and crushed rock, 200 to 300 m thick, bordered on the east by a thrust fault. Here, also, apparently unfaulted alluvium considered to be 200 to 500 Ka (Morton and Matti, 1987) overlies the broad crush zone, but is offset along the eastern edge by the thrust fault with Oligocene Telegraph Peak pluton rock thrust over detritus derived from the pluton.

We interpret the fault zone at Sycamore Flats to be not the San Jacinto Fault, but the easternmost exposed segment of the San Gabriel Fault, and that the thrust fault is the result of compression in the eastern San Gabriel Mountains that postdates San Gabriel Fault strike-slip displacement (Morton and Matti, 1993). Noble (1954b) considered the fault in the South Fork Lytle Creek to be the south branch of the San Gabriel Fault and the fault in the Middle Fork Lytle Creek to be the north branch of the San Gabriel Fault. Within the San Gabriel Mountains this fault zone branches into three north-dipping faults, each traversing a separate fork of Lytle Creek in addition to the San Gabriel Fault (photo 602) (Morton and Matti, 1993). The South Fork Lytle Creek Fault is exposed along the road in Lytle Creek (photos 403, 404, and 582) near where the three faults coalesce and is well exposed on the north side of the canyon a short distance up the South Fork Lytle Creek. Within the mountains, a gouge zone marking the location of the fault is well exposed in several places (photos 568 and 594). West of this junction, these three faults branch and progressively change in strike counterclockwise until they are all orientated in a southwest direction (photo 405). These southwest-striking faults converge to the west near the mountain front at the mouth of San Antonio Canyon. The southwestern part of the South Fork Lytle Creek Fault is called the Stoddard Canyon Fault (see map sheet 2). Just west of San Antonio Canyon, two faults appear to coincide with the San Gabriel Fault Zone in Cow Canyon.

Based on the distribution of basement rocks, separation on the northwest-striking faults in the Lytle Creek area appears to be oblique-right-reverse, on the east-striking faults appears to be thrust, and on the southwest-striking faults is oblique-left-reverse. This is similar to the generalized sense of displacement determined by Cramer and Harrington (1987) from microearthquakes. The overall geometry and sense of displacement of the faults is an antiformal schuppen-like structure.

Lytle Creek Fault Zone

The Lytle Creek Fault Zone, located just west of the mouth of Lytle Creek, forms scarps in alluvial deposits capped by soils that are considered to be S_4 or S_5 soil stage (Morton and Matti, 1987). These are apparently the same as the ones considered to be 50 to 60 Ka by Mezger and Weldon (1983). Lateral displacement along the Lytle Creek Fault offsets the paleo-Lytle Creek channel. On the projection of the Lytle Creek Fault, tectonically imbricated clasts were observed in trenches on the Lytle Creek fan just south of the mountain front.

Elsinore, Whittier, and Chino Fault Zones

Apparent ambiguities and uncertainties associated with the Elsinore, Whittier, and Chino Faults suggests a much more complex and, in part, perhaps an older history than that of the nearby San Jacinto Fault Zone. The Elsinore, Whittier, and Chino fault zones have commonly been combined as a single, related fault complex; we interpret them as probably separate entities. Faults generally included as specifically part of the Elsinore Fault Zone extend from south of Laguna Salada in Baja California north to Corona, Corona South 7.5' quadrangle. In the map area, the N45W-striking fault zone is made up of a series of en echelon, relatively short faults. Youthful fault features such as offset drainages, scarps, fault-line scarps, and pressure ridges, occur along the length of the fault zone in this area (photo 406). Near

Wildomar, the Hot Springs Fault (named for Murrieta Hot Springs) is considered by many to be a branch of the Elsinore Fault Zone; it has a strike of about N85W and forms the northern boundary of the Temecula basin that includes sedimentary rocks as old as 4.6 Ma (Repenning, 1987). To the north in the vicinity of Corona, the N45W-striking fault zone splays to form the Whittier Fault, which has a more westerly strike (N70˚W) and the Chino Fault, which has a more northerly strike (N38W). The area of the junction or splaying of the three faults is obscured beneath young alluvium.

Estimates of the lateral displacement along the Elsinore Fault Zone vary widely. Lateral displacement based on offset Cretaceous and older basement rock units (Weber 1976 and 1977) and offset potassium-argon isopleths of biotite ages from Peninsular Ranges batholithic rocks (Morton and Miller, 1987) are in the range of nine to 15 km. Kistler and others (2003) interpreted initial Sr isopleths to be offset left-laterally across the fault zone. In the southern part of the area Kennedy (1975) estimated right-lateral offset across the zone to be greater than five kilometers, but his offset criteria did not allow him to estimate an upper limit. Detailed studies of the Elsinore Fault Zone by Hull and Nicholson (1992) led to interpretation of 10 to 15 km of right-lateral displacement, most likely less than 15 km. Right-lateral offsets of up to 40 km (Lamar, 1961, Sage, 1975; Crowell and Ramirez, 1979) appear to be to too large by nearly a factor of four. Slip rates of four to five mm/yr have been estimated for the Elsinore Fault (Gath and others, 1992; Rockwell and others, 1992).

McCulloh and others (2000) interpret the active Whittier Fault to be a westward continuation or splay of the Elsinore Fault Zone. The Whittier Fault extends some 30 km as a relatively well defined, narrow, linear feature seemingly lacking the en echelon breaks so characteristic of the Elsinore Fault Zone. A relatively early inception is interpreted for the Whittier Fault based on intrusion of a 9 Ma or older diabase dike along the hanging wall of the fault (Durham and Yerkes, 1964; Yerkes 1972). McCulloh and others (2000) interpret inception of tectonism on the Whittier-Elsinore Fault Zones to be at least 11 Ma ago, whereas Hull (1990) interpreted the age of the Elsinore Fault to be much younger.

Lateral offset of Paleogene sedimentary rocks of 8 to 9 kilometers has been determined by McCulloh and others (2000) for the eastern part of the Whittier Fault. Holocene slip rates of about two mm per year are estimated by Gath and others (1992) and by Rockwell and others (1992), which is about half the estimated slip rates for the Elsinore Fault Zone. Oblique movement on the Whittier Fault has resulted in a maximum vertical separation of about 4,265 m (northeast side relatively up) near the northwest end of the Whittier Hills, but decreases to about 610 m near the southeast end of the Puente Hills (west side of the Prado Dam 7.5' quadrangle) (McCulloh, and others, 2000).

The somewhat ill-defined Chino Fault splays from the Elsinore Fault Zone and extends northward from just south of Corona for about 20 km along the west side of the Chino basin. The fault is exposed at only a few places along the eastern part of the Puente Hills. It strikes about N50W, and apparently forms the western margin of the Chino basin, separating a strikingly different stratigraphic section of Tertiary sedimentary rocks found there from the section found in the adjacent Puente Hills. This stratigraphic difference in Tertiary units between the Chino basin and the Puente Hills also suggests a relatively old age for this fault.

It has been suggested that the Chino Fault is the offset continuation of the San Gabriel Fault from where it exits the east end of the San Gabriel Mountains (e.g., Ingersoll and Rumelhart, 1999). This interpretation also includes the Cristianitos Fault (see map sheet 2), the near north striking fault zone extending southward from the Trabuco Canyon area, as being offset from the Chino Fault by the Whittier Fault. There appears to be little, if any, data to support this interpretation.

About three kilometers east of the Chino Fault, Prado Dam 7.5' quadrangle, a fault recognized by Woodford and others (1944) on the basis of a groundwater barrier, and referred to as the Central Ave Fault, forms the eastern boundary of the Chino basin. Although the fault probably exists, we have found no recognizable surface expression of it and thus do not show it on the geologic map. Upper Cretaceous and Palgeogene sedimentary rocks of the Chino basin do not extend east of this fault (e.g., McCulloh and others, 2000).

Crafton Hills fault complex

A number of northeast striking normal faults are located on both sides of the Crafton Hills, Redlands and Yucaipa 7.5' quadrangles. These faults, the Redlands, Reservoir Canyon, Crafton Hills, Chicken Hill, and San Timoteo Canyon Faults, are the bounding faults at the south end of the San Bernardino pull-apart basin. The Redlands and Reservoir Canyon Faults produce prominent scarps in older alluvial deposits and the Crafton Hills Fault is marked by faceted spurs along the south side of the Crafton Hills (photo 11).

Tokay Hill and Peters Faults

Two faults, the Tokay Hill and Peters faults, having north-facing scarps, are located at the northwest end of the San Bernardino pull-apart basin, Devore 7.5' quadrangle. The curved northwest-striking Tokay Hill Fault (Morton, 1992b) branches from the San Andreas Fault on the north side of Tokay Hill (photos 407, and 598). The northern part of the fault is a reverse fault (photo 408) and at the southern end the morphology suggests a normal component of displacement. The east-striking Peters Fault (Noble, 1954b) forms a prominent north-facing scarp on the alluvial fan north of Devore (photos 409 and 410). The sense of slip on this fault is unknown.

Cucamonga-Sierra Madre Fault Zone

The Cucamonga Fault Zone located along the southern margin of the eastern San Gabriel Mountains, Mt Baldy, Cucamonga Peak, and Devore 7.5' quadrangles, marks the eastern end of the frontal fault system of the San Gabriel Mountains (e.g., Morton and Matti, 1987). It consists of numerous anastomosing, east-striking, north-dipping thrust and reverse faults that separate crystalline basement rocks of the eastern San Gabriel Mountains from alluvium of upper Santa Ana Valley to the south, as well as including faults entirely located within alluvium.

West of Lytle Creek, Devore 7.5' quadrangle, crystalline basement rocks are thrust over Tertiary conglomerate and sandstone (San Sevaine Canyon area unit, Tcd). The sedimentary rock is overturned, apparently forming the northern edge of an overturned syncline produced by the basement being thrust over it; this relation is similar to the structural setting along the Sierra Madre Fault Zone in the Azusa area to the west. There are numerous other localities along the mountain front where basement is thrust over older fanglomerate (photo 411). Many of the thrust faults constituting the Cucamonga Fault Zone cut the alluvium. Some are located entirely within alluvium, and are associated with prominent scarps, especially on the Day Canyon and the Cucamonga Canyon alluvial fans (photos 412, 413, 414, 415, and 592), Cucamonga Peak and Mount Baldy 7.5' quadrangles (Morton and Matti, 1987).

Exposures in trenches cut across the southern splay of the Cucamonga Fault on Day Canyon fan show a relatively thin zone, one to two meters thick, of disturbred sediments. The fault dips about 35 degrees about midway up the scarp face, and is commonly marked by tectonically imbricated clasts and an abrupt color change where the fault has overridden a dark colored colluvial wedge. Scarp angle on the highest segments of the scarp are essentially at the angle of repose. A high prominent scarp segment on the northern splay of the Cucamonga Fault on Day Canyon fan consists of basement obscured by a thin veneer of colluvium and capped by very old alluvial fan deposits. Prominant scarps are also located high on the fan on the east side of Cucamonga Canyon.

Slickensides in the basement rocks are consistently oriented down-dip, indicating the most recent displacements on faults of this zone have been pure thrust. The average dip of faults in this zone is about 35 degrees north. Ground rupturing by the faults has occurred throughout the Quaternary; individual fault events are estimated to be about magnitude 6.7 and have a recurrence of about 625 years for the past 13,000 years (Morton and Matti, 1987). The average north-south convergence across the Cucamonga Fault Zone is estimated to have been in the range of three mm per year (Weldon, 1986) to five mm per year (Matti and others, 1992; Morton and Matti, 1987). Some earthquakes with epicenters near and to the north of the surface trace of the San Andreas Fault have fault-plane solutions that project to the surface trace of the Cucamonga Fault.

West of San Antonio Canyon, Mount Baldy 7.5' quadrangle, the Sierra Madre Fault Zone bounds the south margin of the mountains. Although lacking the spectacular scarps of the Cucamonga Fault Zone, the Sierra Madre Fault Zone has numerous exposures of basement rocks thrust over young sedimentary rocks. In the Azusa area Cretaceous granitic rocks are thrust over Topanga Formation (middle Miocene) forming an overturned syncline that necessitates a vertical displacement of over 3,000 m (e.g., Morton, 1973).

Faults related to the Cucamonga-Sierra Madre Fault Zone

Two thrust faults having limited extent, the Etiwanda Ave and Powerline Faults, Cucamonga Peak 7.5' quadrangle, are located south of the main part of the Cucamonga Fault (see map sheet 2). The Poweline Fault dips 25 degrees to 30 degrees to the north, similar to the main traces of the Cucamonga Fault. The Etiwanda Ave Fault has a similar dip of 30 degrees to the north, but unlike the faults to the north has a low constructional scarp with an angle of about 15 degrees. Trenches in the western part of the Etiwanda Ave Fault encounter two separate faults whose collective displacement results in a low-angle constructional scarp. At the east end of the fault the two faults pass into a broad distributive fault zone, about 30 m thick, consisting of disranged boulderly alluvium (photo 416). The low-angle constructional scarp is produced by this broad distributive deformation.

Farther south in the valley is the Red Hill Fault, located south of the base of Red Hill. Unlike the Cucamonga, Etiwanda Ave, and Powerline faults, the Red Hill Fault appears to have no surface expression in late Pleistocene and Holocene alluvial deposits. Trenching has apparently encountered the fault south of the base of Red Hill, indicating an old degradational feature.

North of the Cucamonga Fault Zone between Lytle Creek and San Antonio Canyon, three northwest-striking right-lateral faults, the Duncan Canyon, Day Canyon, and Demens Canyon faults (Morton and Matti, 1987) appear to be terminated on the south by the Cucamonga Fault Zone and on the north by the South Fork Lytle Creek Fault. All three show right-lateral separation, the 1.5-km separation along the Duncan Canyon Fault being the greatest.

Sawpit-Clamshell fault complex

Entering the San Gabriel Mountains at the west edge of the map area is the broad fault complex of the Sawpit-Clamshell Faults. This northeast-striking fault complex consists of two parallel faults zones that dip at moderate angles to the north, and can be traced from just west of the area to the San Gabriel Fault Zone in the west fork of the San Gabriel River, Glendora 7.5' quadrangle. The northern Clamshell Fault consists of a 50- to 100-m-thick fault zone consisting of finely comminuted material that forms a groundwater barrier. Four hundred to eight hundred meters south of the Clamshell Fault zone is the roughly parallel Sawpit Fault zone, which is similar but thinner than the Clamshell, and splits into two main branches near the western edge of the map area.

Cleghorn Fault

The Cleghorn Fault is located in the western San Bernardino Mountains, Cajon and Silverwood Lake 7.5' quadrangles, passing through the southern edge of Silverwood Lake. Westward from the Silverwood Lake, it follows the base of Cleghorn Ridge emerging into Cajon Canyon near Cajon Junction. In Cajon Canyon it lies beneath Quaternary sediments, and its extent westward up the canyon is unknown. East of Silverwood Lake the fault follows Miller Canyon and appears to merge with an unnamed fault at the east end of the canyon.

The Cleghorn Fault is a complex zone of anastamosing faults that has an aggregate 3.5 to four kilometers left-lateral and about 300 m vertical (south side down) offset (Meisling and Weldon, 1989). Meisling and Weldon (1989) base cumulative strike-slip motion on offset of Cajon Valley and Crowder Formations, offset of monoclinal axes, and restoration of offset older faults. They suggest that about 0.5 km of motion took place in the last 500,000 years, and as much as 200 m since 50,000 to 100,000 years ago.

Santa Ana Fault

The Santa Ana Fault, Harrison Mountain and Keller Peak 7.5' quadrangles, is a north dipping reverse fault that places Cretaceous granitic rocks over Miocene Santa Ana Sandstone and Cretaceous and Triassic granitic rocks. It has an irregular trace north of the canyon of the Santa Ana River, and extends at least another 20 to 25 km east of the San Bernardino quadrangle (Jacobs, 1982). Most dip measurements on the fault are between 30 and 60 degrees north. A number of continuous and discontinuous, branching faults roughly parallel the Santa Ana Fault on the south, suggesting a possible relationship to the reverse fault. Dip measurements are not available for these faults, but distribution of Santa Ana Sandstone relative to the faults indicates that sense of movement on at least one may be opposite that of the Santa Ana Fault.

West of Plunge Creek, the Santa Ana Fault has monzogranite of City Creek (Kcc) in both the hanging wall and footwall, and is difficult to identify as a single through-going structure. The westward projection of the fault appears to cross City Creek near the intersection of the East and West Forks, and to continue northwestward for at least another six kilometers. Although not shown on the geologic map, the fault may continue northwestward and eventually merge with the Devil Canyon Fault.

Devil Canyon Fault

The Devil Canyon Fault, San Bernardino North and Harrison Mountain 7.5' quadrangles, is an east striking, multiply branching, high-angle fault that appears to intersect the San Andreas Fault just southeast of Cable Canyon (fig. 1). Eastward from the San Andreas Fault, it is fairly well defined to about where it crosses City Creek; east of City Creek its location and extent are not well established. The fault and its branches bound and enclose areas of a Tertiary, undifferentiated conglomerate and arkose unit (Tcu), suggesting localized graben-like structures. Limited fault dip measurements in the central and western parts are near vertical. Topographic break-in-slope associated with much of the fault suggests mountain-side (north) down sense of movement. If this is the case, it is the opposite sense of movement associated with the nearby, semi-parallel Santa Ana Fault.

Fault zone bounding the north side of San Bernardino Mountains

A prominent, discontinuous system of south dipping reverse faults bounds the north side of the San Bernardino Mountains northward and eastward from the vicinity of Deep Creek, Fifteen Mile Valley 7.5' quadrangle. Meisling (1984) and Meisling and Weldon (1989) refer to the faults as a thrust system, but except for the east central part of the zone, well east of the quadrangle, limited dip measurements are mostly greater than 40 degrees. They interpret the zone to shallow considerably in the subsurface.

Eroded fault and fault-line scarps tens of meters high are associated with late movement on parts of the fault zone. North of the Ord Mountains segment of the San Bernardino Mountains, the fault zone passes into a monoclinal flexure for several kilometers and then back into a fault (Meisling, 1984; Meisling and Weldon, 1989). Meisling (1984), Meisling and Weldon (1989), and J.C. Matti (oral commun., 2000)) consider northeast and east striking parts of this fault zone to be dominantly reverse or thrust movement, but some of the northwest striking parts to be strike slip.

Initial development of the fault zone was in early Pleistocene, but maximum movement occurred in middle Pleistocene. Middle Pleistocene fanglomerates flanking the western part of the range contain abundant, large, angular clasts derived from the San Bernardino Mountains, so elevation and drainage pattern off of the range had been established by that time. Meisling and Weldon (1989) consider this north-bounding fault system to be responsible for most of the uplift of the central San Bernardino Mountains, and that the uplift tapered off toward the western and eastern ends of the range.

Squaw Peak Fault

The Squaw Peak Fault, Cajon 7.5' quadrangle, is a deformed fault of unknown extent interpreted by Meisling and Weldon (1989) to be a late Miocene to early Pliocene thrust. It is highly disrupted by younger faults, and changes from north striking in its southern part to west-northwest striking in its northern part. Where exposed, the southern part of the fault dips steeply east, and the northwestern part, shallowly north. In the northern part, the fault places Crowder Formation over Cajon Valley Formation, and in the southern part, granitic rocks of the San Bernardino assemblage over Cajon Valley Formation.

DESCRIPTION OF MAP UNITS

SURFICIAL DEPOSITS

Qdg **Disturbed ground (late Holocene)**—Bedrock fragmented to sand- and gravel-sized pieces; commonly mixed with Quaternary sedimentary material found at site. Occurs mainly in areas where construction or excavation has obscured, mixed, redistributed, or covered naturally occurring units; thickness generally less than 3 meters. Areas shown as disturbed ground are localities where results of human activity generally preclude accurate identification or classification of natural geologic units

Qaf **Artificial fill (late Holocene)**—Sand, gravel, and bedrock from pits, quarries, and excavations related to construction, mining, or quarrying activities; mapped primarily where materials are placed for construction of highways, canals, railway grades, dams, and water catchment basins. Only large features are mapped; not shown in some places where unit obscures detailed surficial or bedrock relations. Differs from disturbed ground (Qdg) in that generally large amounts of rock and (or) sediment have been imported to site

Qw **Very young wash deposits (late Holocene)**—Unconsolidated sand and gravel deposits in active washes, ephemeral river channels of axial-valley streams, and in channels on active surfaces of alluvial fans; has fresh flood scours and channel-and-bar morphology. Essentially no soil development. Subject to localized reworking and introduction of new sediment mainly during winter months. In places, especially upper reaches of some drainages, contains clasts several meters across that were deposited by flash floods. Grain shape ranges from angular to rounded; larger clasts tend to be more rounded than smaller clasts. All sediment derived from local bedrock or reworked from local, older

Quaternary deposits. In Mojave River bed, almost all sediment is fine- to very coarse-grained sand containing lesser gravel and pebbles; clasts larger than pebbles are sparse. Gravel bars up to 100 m long fairly common. In beds of Arrastre Creek, Mescal Creek, and Big Rock Creek, clasts are mixed sand to boulders and include numerous bars dominated by one or another of larger clast sizes. Unit in Sheep Creek differs from other Qw deposits; it is dominated by debris-flow deposits originating in steep headwater area of drainage in Mesozoic Pelona Schist. Debris flows catastrophically transported during years of heavy snowfall when rapid melt occurs (Morton and Campbell, 1974; Sharp and Nobles, 1953). In Cajon Wash and beds of Lytle Creek and Santa Ana River, clasts are mixed sand to boulders, coarsening toward mountains; in lower reaches of Santa Ana River, unit consists mostly of unconsolidated sand and gravel. North of mountains and west of Mojave River, nearly all Qyw deposits are cut by medial channels of Qw too small to show at map scale. Divisions are distinguished by relative position in local terrace riser succession and by overlapping relations. In northwestern part of quadrangle, within 2 km of San Andreas Fault Zone, includes most of stream channel deposits unit of Barrows and others (1985) and Barrows (1987). Locally subdivided to include:

Qw_3 **Very young wash deposits, Unit 3**—Unconsolidated sand, gravel, and pebble deposits that form very slightly elevated terraces. Unit common in vicinity of city of Riverside. Also mapped within, or along margins of, active Mojave River channel. Grain size distribution and degree of rounding generally same as Qw deposits at similar distances from mountain front. Has slightly less prominent vegetative cover than most Qw deposits. Probably intermittently active during high water in years of peak rainfall. Range of clast size, shape, and distribution similar to that of Qw deposits

Qw_2 **Very young wash deposits, Unit 2**—Unconsolidated, mixed sand, gravel, pebble, cobble, and boulder deposits that form slightly elevated, low terraces within, or along margins of, active washes. Grain size distribution and degree of rounding generally same as Qw units at similar distances from mountain front. Clast compositions reflect bedrock and older Quaternary sources within individual drainages. Commonly has noticeably denser vegetative cover than Qw_3 deposits, especially larger, older bushes and trees. Appears to be intermittently active based on localized bar-and-swale geomorphology and channel scouring. May or may not undergo redistribution or destruction during high water in years of peak rainfall. Range of clast size, shape, and distribution similar to that of Qw deposits

Qw_1 **Very young wash deposits, Unit 1**—Unconsolidated sand-and-gravel deposits that form consistent, but low, elevated terraces in or marginal to channelized washes of streams and rivers. Grain size distribution and degree of rounding generally same as Qw units at similar distances from mountain front. Largely abandoned by modern stream flows; less likely to become occupied or destroyed by major flood events than Qw_2 deposits. Has noticeably denser vegetative cover than Qw_3 or Qw_2 deposits, may show suggestion of soil development, and has larger, older bushes and trees. Range of clast size, shape, and distribution similar to that of Qw deposits

Qf **Very young alluvial-fan deposits (late Holocene)**—Unconsolidated to slightly coherent, essentially undissected deposits of sand, gravel, and boulders that form active and recently active parts of alluvial fans (photo 587). Clasts typically angular to subrounded, rarely rounded. Deposits generally coarsen toward heads of fans. Relative abundance of clast sizes varies greatly depending on setting, size of drainage area, and sediment source. At most places, unit lacks soil development, but on south side of San Bernardino Mountains, locally is capped by weak A/AC soils. On north side of San Bernardino and San Gabriel Mountains, unit occurs chiefly as small fans emanating from limited-extent, steep canyons, mouths of channels cut in dissected scarps, or mouths of channels cut in elevated, older Quaternary deposits. Surfaces typically cut by braided streams, but deposition exceeds dissection. Where subdivision of Qf deposits is possible, subunits are distinguished from one another by relative position in local terrace riser succession, by local superposition, or by relative dissection. Includes:

Qf_2 **Very young alluvial-fan deposits, Unit 2**—Unconsolidated to loosely compacted alluvial-fan deposits. Essentially undissected, but surface typically cut by anastomosing network of channels. Size, shape, and distribution of clasts similar to that of unit Qf. Distinguished in most cases as fans built out on Qf_1 sediments, and to some degree as fans relatively less dissected than, or emanating from channels cut into, Qf_1 sediments. Appearance from place to place differs greatly; primarily dependent on sediment source, steepness of source area and fan location, and distance from mountain front

Qf_1 **Very young alluvial-fan deposits, Unit 1**—Unconsolidated to loosely compacted alluvial-fan deposits, varying in grain size from sand to boulders. Degree of compaction unreliable for distinguishing Qf_1 from other Qf units or some Qyf units. Has general physical characteristics of Qf and Qf_2 sediments. Mode of occurrence, in addition to range of clast size, clast shape, and clast distribution, similar to that of unit Qf and Qf_2. Distinguished in most cases as fans upon which Qf and Qf_2 fans have built, and to lesser degree as fans that are relatively more dissected than Qf and Qf_2 fans, or as fans that are cut by channels from which Qf and Qf_2 fans emanate. Appearance from place to place differs greatly; primarily dependent on sediment source, steepness of source area and fan location, and distance from mountain front

Qa **Very young axial-channel deposits (late Holocene)**—Unconsolidated deposits of silty, sandy and cobbly alluvium deposited by streams in through-going stream valleys; cemented only where carbonate rocks are in source area. Includes:

Qa_1 **Very young axial-channel deposits, Unit 1**—Largely unconsolidated to barely consolidated alluvial deposits in valley bottoms. Varies in grain size from sand to boulders; finer size-fractions more common. Has general physical characteristics of Qa sediments, but is relatively more dissected than Qa, and is distinguished by relative position in local terrace-riser succession. Appearance from place to place differs greatly; primarily dependent on sediment source and steepness of source area

Qv **Very young alluvial-valley deposits (late Holocene)**—Active and recently active fluvial deposits along valley floors. Consists of unconsolidated sandy, silty, or clay-bearing alluvium; coarser clasts are relatively rare

Qc **Very young colluvial deposits (late Holocene)**—Unconsolidated sediment and loose sediment, rock fragments, and soil material deposited by rain wash or slow continuous downslope creep; found mainly, but not exclusively, at base of slopes or hillsides. In western San Bernardino Mountains, much of sediment is angular, derived from extensive grus developed on Cretaceous and Jurassic granitic units. No soil development

Qt **Very young talus deposits (late Holocene)**—Unconsolidated to slightly consolidated deposits of angular pebble-, cobble-, and boulder-size material that form scree and rubble on hill slopes and at base of slopes. In places, loose and hazardous to walk on. Best developed below steep faces of highly fractured granitic and metamorphic rocks in eastern San Gabriel Mountains. In places, probably includes some colluvium. Numerous small talus cones found on steeper slopes in San Bernardino and eastern San Gabriel Mountains are too small to map

Qsw **Very young slope-wash deposits (late Holocene)**—Unconsolidated sand, cobbles, and pebbles deposited by water not confined to channels. Most deposits are angular, multi-mineralogic sand derived from in-place weathering of granitic rocks, but many include larger clasts transported by torrential storms or clasts spalled from up-slope outcrops of bedrock

Qls **Very young landslide deposits (late Holocene)**—Slope-failure deposits consisting of chaotically mixed soil and rubble and (or) displaced bedrock blocks; most are debris slides and rock slumps or earth slumps. Landslides may or may not be active. Landslide morphology well preserved. In San Bernardino Mountains in Holcomb Creek drainage northeast of Lake Arrowhead, consists of granitic rubble. On west side of Bear Canyon, near east edge of San Bernardino quadrangle, consists of granitic rubble and probably includes some talus. In eastern San Gabriel Mountains between Deer Canyon and San Sevaine Flats, consists of granitic rubble and possibly includes some talus and slope wash

Qpl **Very young playa deposits (late Holocene)**—Pale-brown to pale-gray, silty, sandy clay, and clayey silt. Relatively coherent where damp or dry. All playa deposits, including Qp_1, restricted to Rabbit Dry Lake (photo 366) and small unnamed dry lake 7 km west of Rabbit Dry Lake. New sediment is distributed and uppermost part of existing sediment redistributed by wind generated wave action during wet periods. Along margins, mixed with and includes some very young eolian deposits (Qe)

Qpl_1 **Very young playa deposits, Unit 1**—Pale-brown to pale-gray silty, sandy clay, and clayey silt. Relatively coherent where completely dry. Slightly elevated and locally shows incipient dissection compared to active playa surface of Rabbit Dry Lake (photo 366). Along margins, mixed with and includes some very young eolian deposits (Qe)

Ql **Very young lacustrine deposits (late Holocene)**—Silt, sand, and gravel associated with sag ponds along San Andreas Fault strands; also underlies floor of closed pull-apart depression in Elsinore Fault Zone that is partly filled by Lake Elsinore (Alberhill and Elsinore 7.5' quadrangles). Sediments are commonly submerged, but are exposed partly or completely during dry periods. Dominately gray, clayey, silty, and fine-grained sandy lacustrine deposits

Qlv **Very young lacustrine and fluvial deposits (late Holocene)—**Dominately gray, clayey, silty, and fine-grained sandy lacustrine deposits interbedded with fluvial deposits. Underlies floor of closed pull-apart depression in San Jacinto Fault Zone that is partly filled by ephemeral Mystic Lake (photo 242) (Lakeview and El Casco 7.5'quadrangles)

Qe **Very young eolian deposits (late Holocene)**—Fine-grained sand and silt. Along north bank of Arrastre Canyon between San Bernardino and Granite mountains, forms thin sand patches in lee of desert vegetation; mapped only where sand patches have coalesced. Unconsolidated, active or recently active sand dune deposits along coast in Newport Beach area. Shows dune morphology in coastal areas, but generally not in desert areas

Qm **Very young marine deposits (late Holocene)**—Unconsolidated, active or recently active sandy beach deposits along coast

Qes **Very young estuarine deposits (late Holocene)—**Unconsolidated, active, sandy, silty, and clayey organic-rich estuarine deposits (Newport Beach 7.5' quadrangle)

Qs **Very young surficial deposits (late Holocene)**—Silt, sand, and pebble- to small-cobble gravel. Mostly unconsolidated, but locally, slightly consolidated. Includes many small scattered deposits consisting of sediment that does not have features allowing confident assignment to any specific surficial materials unit. Some were identified on aerial photographs, and not checked at site. Probably includes wash, alluvial-fan, colluvial, and valley-filling deposits

Qs_1 **Very young surficial deposits, Unit 1**—Sand and pebble to small- cobble gravel not assigned to any specific surficial materials unit. Essentially same characteristics as very young surficial deposits unit (Qs), but distinguished either as terraces cut into Qs sediments, or parts of Qs sediments that show anomalous dissection

Qyw **Young wash deposits (Holocene and late Pleistocene)**—Unconsolidated to slightly consolidated sand and gravel deposits in marginal parts of active and recently active washes and ephemeral river channels of axial-valley streams. Differs from very young wash deposits by absence or modification of flood scours, modified channel-and-bar morphology, and immature soil horizons. Mapped mainly on north sloping fan surfaces north of Cajon Summit area, where sediment is mixed with eroded and slumped material from steep, high, stream embankments. Clast size reflects distance from mountain front to same degree as Qw deposits. All is sediment derived from local bedrock or reworked from local, older Quaternary deposits. West of Rabbit Dry Lake and west of Silverwood Lake, includes sediment in partially abandoned washes. Subunits are distinguished by relative position in local terrace riser succession. Includes:

Qyw_3 **Young wash deposits, Unit 3 (early Holocene)**—Unconsolidated silt, sand, and coarse-grained sand to cobble alluvium. Forms low, moderately well defined terrace risers along Antelope Valley wash south of Hesperia. Truncated by locally younger Qyw sediments, but shows very little surface modification

Qyw_2 **Young wash deposits, Unit 2 (early Holocene)**—Unconsolidated to slightly consolidated silt, sand, and coarse-grained sand to cobble alluvium. Forms relatively low, but well defined terrace risers along Antelope Valley wash south of Hesperia. Truncated by Qyw_3 sediments, but shows only slight surface modification

Qyw_1 **Young wash deposits, Unit 1 (early Holocene and late Pleistocene)**—Unconsolidated to slightly consolidated silt, sand, and coarse-grained sand to cobble alluvium. Forms well defined terrace risers along west side of Mojave River southeast of Hesperia. Stands above, and is truncated by younger Qyw_2 sediments; shows slight surface modification

Qyf **Young alluvial-fan deposits (Holocene and late Pleistocene)**—Unconsolidated to moderately consolidated silt, sand, pebbly cobbly sand, and bouldery alluvial-fan deposits having slightly to moderately dissected surfaces (photo 417). Young alluvial-fan deposits, including subunits, constitute most widespread, and probably greatest in terms of sediment volume, of all Quaternary units. Forms large and small fans throughout quadrangle. Covers large areas in upper part of Cajon Canyon and on north side of San Gabriel Mountains west of Sheep Creek. Close to mountains, unit typically contains large proportion of cobbles and boulders. Intermediate and distal parts of large fans west of Sheep Creek are mainly pale-brown, mixed silt to medium-grained sand, containing sparse, coarse-grained sand and pebble lenses. Except where coarser-grained lenses are present, stratification is obscure. Clast compositions, especially in upper third of fans, reflect bedrock source areas and clast compositions of nearby older Quaternary units. In San Bernardino Mountain area, fans emanating from areas underlain by deeply weathered Cretaceous granitic rocks are relatively fine grained and contrast with coarser grained fans emananating from areas underlain by Triassic and older rocks. Includes from youngest to oldest:

Qyf_7 **Young alluvial-fan deposits, Unit 7 (late Holocene and latest Pleistocene)**—Unconsolidated alluvial-fan deposits. Consists of gravel, sand, and silt; youngest part of Qyf. In part distinguished on basis of relative terrace levels. Restricted to southwest side of San Timeteo Badlands in northeastern Santa Ana quadrangle

Qyf_6 **Young alluvial-fan deposits, Unit 6 (late Holocene and latest Pleistocene)**—Unconsolidated alluvial-fan deposits consisting of fine- to coarse-gravel, sand, and silt; young part of Qyf. In part distinguished on basis of relative terrace levels. Restricted to Lamb Canyon area in northeastern Santa Ana quadrangle

Qyf_5 **Young alluvial-fan deposits, Unit 5 (late Holocene)**—Unconsolidated to slightly consolidated coarse-grained sand to bouldery alluvial-fan deposits having slightly dissected to essentially undissected surfaces. Stage S_7 soils in Devore area. Notably finer grained in some parts of quadrangle, especially in distal parts of fans. Braided stream pattern on surfaces of fans that is related to deposition is relatively unmodified. On south side of San Gabriel Mountains, includes large, well formed fan emanating from Lytle Creek drainage; largely boulder alluvium in headward parts of fan, grading southward into dominantly sand and gravel. West of Phelan, includes Sheep Creek fan which has distinct gray-green color, and strongly contrasts with nearly all other alluvial material in quadrangle. Sheep Creek fan is composed essentially of material derived from Pelona Schist, and mainly deposited by debris flows. Parts of unit subsequently redistributed by conventional stream flow, especially in distal areas. Fans of Qyf_5 sequence are younger than Qyf_4 fans based mainly on relative position in terrace riser sequence and on superposition and overlap relations of adjacent fans

Qyf_4 **Young alluvial-fan deposits, Unit 4 (late Holocene)**—Unconsolidated to slightly consolidated silt, sand, and coarse-grained sand to bouldery alluvial-fan deposits having slightly to moderately dissected surfaces. Stage S_7 soils in Devore area. Fans emanating from canyons on south side of San Gabriel Mountains contain large proportion of coarse boulders, especially in upper parts. Fans emanating from canyons on south side of San Bernardino Mountains contain coarse boulders in upper parts, but grade over short distances southward into sand and pebble alluvium. On south side of both ranges, typically braided stream pattern on surfaces of fans related to deposition is only slightly modified. Large area of Qyf_4 between Granite Mountains and Mojave River is slightly consolidated silt and sand, that contains lenses and individual matrix-supported clasts generally less than 2 cm across. Represents large area of coalesced fan material. Surface is smooth and undulating, showing only slight dissection in upper parts. Unit in this part of quadrangle may contain some axial-valley deposits, especially near western end of Granite Mountains. Age relative to Qyf_5 and Qyf_3 based mainly on overlap relations of adjacent fans and degree of dissection compared to fans in general area

Qyf_3 **Young alluvial-fan deposits, Unit 3 (middle Holocene)**—Slightly to moderately consolidated silt, sand, and coarse-grained sand to bouldery alluvial-fan deposits having slightly to moderately dissected surfaces. In Devore area, unit has stage S_6 or incipient stage S_5 soils developed. West of Mojave River, consists of relatively uniform, medium brown silt and sand containing sparse granule and pebble lenses and scattered, matrix-supported, pebble-sized clasts. Fan surfaces are slightly to moderately dissected, and in many places show low amplitude, rolling surfaces having swales and ridges parallel to axes of fans. In this area, may include some Qyf_2 and Qyf_4 deposits. Cut by several large Qyw washes incised to depths as great as 4 m, containing active medial Qw channels too small to map

Qyf_2 **Young alluvial-fan deposits, Unit 2 (early Holocene)**—Slightly consolidated coarse-grained sand to bouldery alluvial-fan deposits having moderately dissected surfaces and, in Devore area, well-developed S_5 soils. Widespread on both north and south sides of San Gabriel and San Bernardino Mountains, mainly forming relatively small fans. On south side of mountains, especially San Gabriel Mountains, fans contain high percentage of boulders. On north side of San Bernardino Mountains, east of Mojave River, fans are made up largely of sand- to pebble-sized clasts in a silty matrix. There, most show very indistinct stratification; surfaces are relatively smooth, but are cut by discreet, wide, deeply incised channels

Qyf_1 **Young alluvial-fan deposits, Unit 1 (early Holocene and late Pleistocene)**—Slightly to moderately consolidated silt, sand, and coarse-grained sand to bouldery alluvial-fan deposits having moderately dissected surfaces. Has well-developed S_5 soils on south side of San Gabriel and San Bernardino mountains. Appears to form major fill that was deposited throughout San Bernardino Valley region during transition between late Pleistocene and Holocene (McFadden and Weldon, 1987; Morton and Matti, 1987). Also, widespread on north side of San Bernardino Mountains, but mainly forming relatively small fans. On south side of mountains, especially San Gabriel Mountains, fans contain much higher percentage of boulders than on north side of San Bernardino Mountains, east of Mojave River. There fans are made up largely of sand- to pebble-size clasts, and most show very indistinct stratification

Qya **Young axial-channel deposits (Holocene and late Pleistocene)**—Slightly to moderately consolidated silt, sand, and gravel deposits. Units distinguished from each other on basis of soil-profile development, relative position in local terrace-riser succession, and degree of erosional dissection. In central and eastern San Gabriel Mountains, some deposits contain abundant boulders derived from steep valley sides and steep tributary canyons. Unit in that area also may include some very young alluvial-fan deposits (Qf) and young alluvial-fan deposits (Qyf) emanating from tributary canyons and gulches, especially along Prairie Fork of San Gabriel River. Includes:

Qya_6 **Young axial-channel deposits, Unit 6 (Late Holocene)**—Fluvial deposits along canyon floors. Consists of unconsolidated sand, silt, and clay-bearing alluvium. Youngest part of Qya. In part distinguished on basis of relative terrace levels

Qya_5 **Young axial-channel deposits, Unit 5 (late Holocene)**—Young part of late Quaternary valley fill. Consists mainly of thin- to thick-bedded very fine to medium sand that varies from white and light gray (10YR 8/1 and 7/1) to very pale brown (10YR 8/3 and 8/4 to 7/3). Sand is interlayered with subordinate pebbly fine sand and dark-colored organic-rich layers. On south side of Transverse Ranges, unit commonly capped by weak A/C soil (San Emigdio fine sandy loam of Woodruff and Brock, 1980, map sheet 10). South of mountain front, forms large and small benches along Santa Ana River, Yucapia Creek, and Cajon Wash. Although not differentiated, some deposits mapped as Qw and Qyw adjacent to Mojave River may be included in this unit

Qya_4 **Young axial-channel deposits, Unit 4 (late Holocene)**—Forms thin veneers resting on strath terraces incised into unit Qya_3, or forms low terrace risers standing one meter or less above active washes. Consists of pale brown and very pale brown (10YR 6/3 to 8/3) fine to coarse sand and pebbly sand that coarsens upstream to poorly sorted fine to coarse sand and sandy-pebble to small-cobble gravel. On south side of Transverse Ranges, unit capped by weak $A/AC/C_{ox}$ soils (Hanford coarse sandy loam and Tujunga loamy sand of Woodruff and Brock, 1980, map sheet 10). Occupies inactive channels adjacent to Mill Creek and forms benches along Santa Ana River, City Creek, and Yucaipa Creek. Although not mapped, some deposits mapped as Qw and Qyw flanking main channel of Mojave River may be part of this unit

Qya_3 **Young axial-channel deposits, Unit 3 (middle Holocene)**—Forms terrace risers standing 1 to 2 m above active washes. Unit probably is no more than 2 to 5 m thick, and consists of pale brown and very pale brown (10YR 6/3 to 7/3 and 7/4 to 8/4) fine- to coarse-grained sand and pebbly sand that coarsens up-stream to poorly sorted fine- to coarse-grained sand and sandy pebble to small-cobble gravel. On south side of Transverse Ranges, unit capped by weak to moderate $A/AC/C_{ox}$ soils (Tujunga loamy sand and gravelly loamy sand of Woodruff and Brock, 1980; locally includes Soboba gravelly loamy sand). In Yucaipa Valley region, unit represents aggradational event, and formed as fluvial sediment, back-filled valleys buttressing against high-standing older alluvial deposits. Extensively developed adjacent to Santa Ana River channel, and on northeast side of Cajon Wash, flanking Shandin Hills on both sides

Qya_2 **Young axial-channel deposits, Unit 2 (early Holocene)**—Forms terrace risers intermediate to those of Qya_1 and Qya_3. Consists of pale brown and very pale brown, fine- to very coarse-grained sand and pebbly sand that coarsens upstream to poorly sorted sand and sandy pebble to small-cobble gravel. Areally very restricted compared to other Qya units

Qya_1 **Young axial-channel deposits, Unit 1 (early Holocene and late Pleistocene)**—Forms terrace risers standing several meters above active washes. Probably is less than 5 m thick and consists of pale brown and very pale brown (10YR 6/3 to

8/3) fine- to very coarse-grained sand and pebbly sand that coarsens up-stream to poorly sorted sand and sandy pebble- to small-cobble gravel. Unit is capped by moderately developed $A/AC/B_{cambric}/C_{ox}$ soils (grouped variously by Woodruff and Brock, 1980, into Greenfield and Tujunga loamy sand and sandy loam and Oak Glen gravelly sandy loam). In Yucaipa Valley region, unit formed as fluvial sediment, backfilled valleys, buttressing against high-standing older alluvial deposits. In San Bernardino Valley area, unit is part of region-wide fill that was deposited during transition between late Pleistocene and Holocene (McFadden and Weldon, 1987; Morton and Matti, 1987)

Qyv **Young alluvial-valley deposits (Holocene and late Pleistocene)**—Fluvial deposits along valley floors. Consists of unconsolidated sand, silt, and clay-bearing alluvium. Includes:

Qyv_1 **Young alluvial-valley deposits, Unit 1 (early Holocene and late Pleistocene)**—Fluvial deposits along valley floors west of Casa Loma Fault. Consists of unconsolidated sand, silt, and clay-bearing alluvium

Qyc **Young colluvial deposits (Holocene and late Pleistocene)**—Undissected to slightly dissected, unconsolidated to slightly consolidated, relatively stabilized deposits of sediment, rock fragments, and soil material deposited by rain wash or slow continuous downslope creep. In northwestern San Bernardino Mountains, largely derived from redistribution of extensive grus developed on Cretaceous and Jurassic units. Minor soil development

Qyt **Young talus deposits (Holocene and late Pleistocene)**—Slightly to moderately dissected, consolidated to cemented deposits of angular and subangular pebble-, cobble-, and boulder-size material that form scree and rubble on hill slopes and at base of slopes. In most cases, debris is angular and unsorted. In some areas, probably includes localized chutes of Qt and active talus. In San Gabriel Mountains, includes distal parts of some talus cones that gradationally pass into slopewash-like deposits originating from finer grained material preferentially washed from talus

Qysw **Young slope-wash deposits (Holocene and late Pleistocene)**—Unconsolidated to slightly consolidated sand, cobbles, and pebbles deposited by water not confined to channels. Rarely more than a few meters thick, except locally at bases of some broad, extensive slopes. Surfaces show incipient dissection. Probably includes colluvium at places, and colluvial deposits. Especially in northwestern part of quadrangle probably includes slope-wash materal

Qyls **Young landslide deposits (Holocene and late Pleistocene)**—Slope-failure deposits that consist of displaced bedrock blocks and (or) chaotically mixed rubble. Slightly dissected or modified surfaces. Deposits may or may not be active under current range of climatic conditions. Widespread throughout quadrangles, but found as concentrated, multiple slides in steep areas of highly fractured Mesozoic granitic rocks and in areas underlain by Mesozoic Pelona Schist, especially along or near San Andreas Fault Zone. Large area of Qyls west of Bluecut is made up of numerous large and small landslides. Concentration of young landslides at head of Bear Canyon near east edge of San Bernardino quadrangle, contain numerous low-angle, subhorizontal gouge and breccia zones that probably formed at time of landsliding. Very abundant Qyls landslides in Puente Formation in Chino Hills, in Bedford Canyon Formation in Santa Ana Mountains, and in Tertiary and Quaternary units in San Joaquin Hills

Qypl **Young playa deposits (Holocene and late Pleistocene)**—Pale-brown to pale-gray silty, sandy clay, and clayey silt. Relatively coherent where completely dry. Slightly elevated, hummocky, and shows slight dissection by low gradient streams compared to modern playa deposits

Qye **Young eolian deposits (Holocene and late Pleistocene)**—Silt and medium- to fine-grained sand. Relatively large deposits east and west of Mojave River are thin and in places include patches of alluvial-fan deposits not completely covered by eolian material. Subtle, modified dune morphology preserved in parts of large deposit east of Mojave River. Slightly dissected by thin, discontinuous, poorly developed stream channels oriented mainly parallel to dune crests. Numerous, small, discontinuous eolian deposits too small to show at map scale are scattered east and west of Mojave River. Includes:

$Qyed_1$ **Young eolian deposits (dune sand), Unit 1 (early Holocene and late Pleistocene)**—Slightly consolidated to moderately consolidated, yellowish brown (10YR 5/4) to pale brown (10YR 6/3) and light brownish gray (10YR 6/2), fine- to medium-grained sand, silty sand, and slightly gravelly sand; locally contains layers of sandy pebble gravel and gravelly sand. Found east of Lytle Creek-Cajon Creek Wash on south side of Shandin Hills. Similar to unit $Qoed_3$. Forms large northwest-trending dunes that appear to be broadly linguoid to longitudinal

$Qyes_1$ **Young eolian deposits (sheet sand), Unit 1 (early Holocene and late Pleistocene)**—Slightly consolidated to moderately consolidated, yellowish brown (10YR 5/4) to pale brown (10YR 6/3) and light brownish gray (10YR 6/2), fine- to medium-grained sand, slightly gravelly sand, sandy pebble gravel, and gravelly sand. Gravelly beds represent fluvial deposits interstratified with finer-grained eolian deposits that mainly are sand. Restricted to area east of Lytle-Creek-Cajon Creek Wash, west and southwest of Shandin Hills. On east side of wash forms low rolling surfaces adjacent to unit $Qyed_1$, and is lithologically similar to that unit

Qys **Young surficial deposits (Holocene and late Pleistocene)**—Sand to boulder deposits not assigned to any specific surficial materials unit of this age. Includes wash, alluvial-fan, colluvial, and valley-filling deposits. Slightly dissected, slightly consolidated. Most small deposits in northern San Bernardino Mountains are in inactive parts of stream channels, and are mixtures of grus, valley-filling sediment, and slumped or sheetwashed sediment from sides of stream valleys. Almost all deposits assigned to this unit were identified from aerial photographs, and not observed directly

Qypt **Young peat deposits (Holocene)—**Deposits of low density peat and peaty sediments (Newport Beach 7.5' quadrangle)

Qow **Old wash deposits (late to middle Pleistocene)**—Slightly to moderately indurated, gravel and sand alluvial wash deposits. Slightly dissected; typically elevated above modern washes

Qof **Old alluvial-fan deposits (late to middle Pleistocene)**—Moderately- to well-consolidated silt, sand, and gravel. Subunits are distinguished on basis of soil-profile development, degree of dissection, and relative position in local terrace-riser succession. On south side of San Bernardino Mountains, reddish-brown alluvial-fan deposits of primarily sand- to boulder-sized clasts are moderately consolidated and slightly to moderately dissected. They have moderate to well developed pedogenic soils ($A/AB/B/C_{ox}$ profiles with B_t horizons). On north side of San Bernardino Mountains, Qof deposits near east edge of quadrangle are mainly coarse debris flows consisting of angular boulders in matrix ranging from small boulders to silt. They are essentially unstratified, and have moderately well developed soil horizons and well dissected surfaces. Old fan deposits southeast of Hesperia, east of Mojave River, are stream-deposited, consisting of poorly to moderately well stratified pebble- to boulder-bearing sand, containing pebble to boulder lenses. Fan surfaces are cut by well defined channels separated by relatively smooth surfaces having moderately well developed soil horizons. West of Sheep Creek, on north side of San Gabriel Mountains, Qof fans consist of massive to poorly bedded, sand to boulder alluvium. Many show 2-m-thick soil profiles having well developed B_1 horizons ranging from dark brown to orangish-brown. Moderately well consolidated; highly dissected (Kenney, 1999). In Santa Ana quadrangle, extensive Qof deposits surround Lakeview Mountains, flank both sides of

Santiago Creek east of Orange, and occur at places in and along Elsinore trough. Includes:

Qofv **Old alluvial-fan deposits and young alluvial-valley deposits (Holocene and late to middle Pleistocene)**—Reddish-brown, gravel and sand alluvial-fan deposits; moderately indurated. Includes discontinuous younger alluvial-valley deposits locally

Qof_3 **Old alluvial-fan deposits, Unit 3 (late to middle Pleistocene)**—On south side of San Bernardino Mountains, moderately dissected interstratified sand and gravel capped by soils having B_t horizons a few tens of centimeters thick (Greenfield soils of Woodruff and Brock, 1980). Unit occurs in alluvial fans that flank Yucaipa Ridge and San Bernardino Mountains west of mouth of Mill Creek Canyon. Southeast of Hesperia and east of Arrastre Canyon, unit is reddish-brown in upper meter, grading downward to mediun brown; primarily sand- to boulder-sized clasts; moderately consolidated and variably dissected. Cut by deep canyons, but relatively smooth, undulating, elevated surfaces; commonly ponded against $Qvof_1$. Distinguished primarily by relative overlap relations at fan margins and relative dissection. East and west of Sheep Creek, fans are similar to those southeast of Hesperia, but surfaces are modified by numerous low-relief arroyos. In Santa Ana quadrangle, extensive Qof_3 deposits south and southwest of Riverside

Qof_2 **Old alluvial-fan deposits, Unit 2 (late to middle Pleistocene)**—On south side of San Bernardino Mountains, moderately dissected interstratified sand and gravel capped by soils having B_t horizons as much as 50 cm thick (Ramona soils of Woodruff and Brock, 1980). Unit occurs in alluvial fans that flank Crafton Hills, Yucaipa Ridge, and San Bernardino Mountains, and locally within the ranges (photo 362). On north side of San Bernardino Mountains, south of Rabbit Lake, unit is largely massive debris flows having irregular, varibly disseced, bouldery surfaces. Proximal parts of fans are reddish-brown in upper meter, and have much higher sand and gravel fraction near surface; moderately consolidated; surface littered with abundant, very large, angular boulders. Unit commonly flanks and laps onto $Qvof_2$. Distinguished mainly by relative degree of dissection and by overlap relations at fan margins

Qof_1 **Old alluvial-fan deposits, Unit 1 (middle Pleistocene)**—On south side of San Bernardino Mountains, moderately dissected interstratified sand and gravel capped by soils having B_t horizons as much as 50 to 150 cm thick (~~photo 567)~~ (Ramona soils of Woodruff and Brock, 1980). On north side of San Bernardino Mountains, reddish-brown alluvial fan deposits of primarily sand- to boulder-sized clasts that are moderately consolidated and slightly to moderately dissected. Distinguished as terraces cut into locally older Qof sediments. On north side of San Bernardino Mountains, chiefly restricted to small area northeast of Silverwood Lake. There, distinguished from other Quaternary units using aerial photographs; deposits are distinctly elevated and more dissected than Qyf units, but less dissected than locally older Qof units

Qoa **Old axial-channel deposits (late to middle Pleistocene)**—On south side of San Bernardino Mountains, consists of moderately to well consolidated silt, sand, and gravel having moderate to well developed pedogenic soils ($A/AB/B/C_{ox}$ profiles with B_t horizons). Subunits are distinguished on basis of soil-profile development and relative position in local terrace-riser succession. Consists of two main deposits (Qoa_1 and Qoa_2) that filled valley areas as result of deposition by Oak Glen and Yucaipa Creeks and their tributaries, and third (Qoa_3) that forms thin veneer on strath terrace cut into Qoa_2. Qoa units rest unconformably on underlying San Timoteo Formation. Mapped as undifferentiated Qoa only west of Santa Ana River, near Crestmore. Includes:

Qoa_7 **Old axial-channel deposits, Unit 7 (late Pleistocene)**—Moderately indurated, slightly dissected gravel, sand, silt, and clay-bearing alluvium. Youngest subdivision of Qoa. Correlates with Qoa_7 unit in Oceanside 30' x 60' quadrangle south of Santa Ana quadrangle

Qoa_3 **Old axial-channel deposits, Unit 3 (late to middle Pleistocene)**—On south side of San Bernardino Mountains, alluvial-valley deposit that forms thin veneer of sand and pebbly sand on strath terrace incised into unit Qoa_2. Capped by soils having thin to moderate B_t horizons (Greenfield soils of Woodruff and Brock, 1980). Unit very restricted, mapped only in southeastern part of quadrangle

Qoa_2 **Old axial-channel deposits, Unit 2 (late to middle Pleistocene)**—On south side of San Bernardino Mountains, moderately dissected interstratified sand and gravel capped by soils having B_t horizons as much as 50 cm thick (Ramona soils of Woodruff and Brock, 1980). Unit mapped only in southeastern part of quadrangle. In valley of Oak Glen Creek, north of Yucaipa, unit Qoa_2 forms widespread fill more than 10 m thick that rests unconformably on unit Qoa_1. On bench beneath City of Yucaipa, unit Qoa_2 is more restricted in distribution and forms thin veneer deposited on strath incised into Qoa_1

Qoa_1 **Old axial-channel deposits, Unit 1 (late to middle Pleistocene)**—On south side of San Bernardino Mountains, moderately dissected interstratified sand and gravel capped by soils having B_t horizons as much as 150 cm thick (Ramona soils of Woodruff and Brock, 1980). Unit occurs in and south of valley of Oak Glen Creek, north of Yucaipa, in southeastern part of quadrangle. There, consists of poorly sorted sand and pebble-cobble-boulder gravel preserved beneath overlying unit Qoa_2. In Yucaipa Valley, Qoa_1 forms widespread body deposited by stream flows of Yucaipa and Oak Glen Creeks that converged southwest and flowed down ancestral Live Oak Canyon

Qov **Old alluvial-valley deposits (late to middle Pleistocene)**—Moderately indurated, commonly slightly dissected sand, silt, and clay-bearing alluvium. Some deposits include thin alluvial deposits of Holocene age

Qoc **Old colluvial deposits (late to middle Pleistocene)**—Slightly to well dissected, unconsolidated to slightly consolidated, stabilized deposits of sediment, rock fragments, and soil material deposited by rain wash or slow continuous downslope creep. Forms small, discontinuous deposits at various places in quadrangle, but most abundantly in northwesternmost and northeasternmost parts

Qols **Old landslide deposits (late to middle Pleistocene)**—Slope-failure deposits that consist of chaotically mixed rubble and (or) displaced bedrock blocks (terminology follows Varnes, 1978). Moderately dissected, and probably inactive under current climatic and tectonic conditions. Large area of multiple slides mapped in Yucaipa Ridge area in southeastern part of quadrangle; there slides developed almost entirely in Mill Creek Formation of Gibson (1971). Large area of multiple slides also mapped on east side of San Antonio Ridge in upper part of San Gabriel River drainage; there slides mainly developed in Pelona Schist

Qop **Old paralic deposits, undivided (late to middle Pleistocene)**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on now emergent wave cut abrasion platforms preserved by regional uplift (photos 418 and 419). Where more than one number shown (e.g. $Qop_{2\text{-}4}$) those deposits are undivided. Qop_5 is found in the Oceanside 1:100,000-scale quadrangle to the south, but is not known to occur in Santa Ana quadrangle. Includes:

Qop_7 **Old paralic deposits, Unit 7**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 9-11 m Bird Rock terrace. Age about 80,000 years. In database, unit is queried because correlation with well dated Qop_7 in Oceanside 1:100,000-scale quadrangle to the south is uncertain

Qop_6 **Old paralic deposits, Unit 6**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 22-23 m Nestor terrace. Age about 120,000 years.

Qop_4 **Old paralic deposits, Unit 4**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 34-37 m Stuart Mesa terrace. Age about 200,000-300,000 years

Qop_3 **Old paralic deposits, Unit 3**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 45-46 m Guy Fleming terrace. Age about 320,000-340,000 years

Qop_2 **Old paralic deposits, Unit 2**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 55m Parry Grove terrace. Age about 413,000 years

Qop_1 **Old paralic deposits, Unit 1**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 61-63 m Golf Course terrace. Age about 450,000 years

Qop_{2-6} **Old paralic deposits, Units 2-6, undivided**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 22-55m terraces

Qop_{3-6} **Old paralic deposits, Units 3-6, undivided**—Paralic deposits consisting of poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of silt, sand and cobbles. These deposits rest on the 22-46 m terraces

Qopf **Old paralic deposits overlain by alluvial-fan deposits (late to middle Pleistocene)—**Areas where old paralic deposits are capped by extensive but thin, discontinuous, younger, locally derived, sandy alluvial fan deposits

Qolb **Old lacustrine deposits (bar) (late to middle Pleistocene)**—Pale-brown to pale-gray silty, sandy clay, and clayey silt. Has higher sand and silt component than younger lacustrine deposits. Relatively coherent when completely dry. Slightly elevated and incipiently dissected. Along margins, mixed with and includes some eolian deposits (Qoe). Mapped only around Rabbit Lake (dry) in northeastern part of quadrangle

Qoe **Old eolian deposits (late to middle Pleistocene)**—Stablized silt and medium- to fine-grained sand. Unconsolidated to slightly consolidated. Mapped only around Rabbit Lake (dry) in northeastern part of quadrangle

$Qoed_3$ **Old eolian deposits (dune sand), Unit 3 (late to middle Pleistocene)**—Slightly consolidated to moderately consolidated, yellowish brown (10YR 5/4) to light yellowish brown (10YR 6/4) and very pale brown (10YR 7/4), fine- to medium-grained sand and lesser amounts of silty sand and slightly gravelly sand that is well sorted to poorly sorted. Occurs on Rialto-Colton terrace west of Lytle-Creek-Cajon Creek Wash and north of Santa Ana River. Depositional structures are texturally massive to finely laminated. Forms large north-trending longitudinal dunes. Unit may be as much as 80 ft thick where dune forms are tallest (Clarke, 1977)

$Qoes_3$ **Old eolian deposits (sheet sand), Unit 3 (late to middle Pleistocene)**—Slightly consolidated to moderately consolidated, yellowish brown (10YR 5/4) to light yellowish brown (10YR 6/4) and very pale brown (10YR 7/4), fine to medium sand and lesser amounts of silty sand and slightly gravelly sand that is well sorted to poorly sorted; locally contains layers of sandy pebble gravel and gravelly sand. Occurs on Rialto-Colton terrace west of Lytle-Creek-Cajon Creek Wash and north of Santa Ana River. Similar to unit $Qoed_3$, except lacks surface dune forms. Depositional structures are texturally massive to finely laminated. Forms sheets and low rolling upper surfaces adjacent to dunes of unit $Qoed_3$

Qos **Old surficial deposits (late to middle Pleistocene)**—Reddish-brown alluvial deposits not assigned to any specific surficial materials unit of this age. Chiefly sand- to boulder-sized clasts that are moderately consolidated and slightly to moderately dissected. Includes alluvial-fan, colluvial, and valley-filling deposits. Forms small, discontinuous deposits at various places in quadrangle, but most abundantly in Lake Arrowhead area, along eastern edge of quadrangle, and in San Gabriel Canyon area

Qvof **Very old alluvial-fan deposits (middle to early Pleistocene)**—Moderately to well consolidated silt, sand, gravel, and conglomerate. Subdivided units are distinguished on basis of soil-profile development, relative position in local terrace-riser succession, and overlapping relationships. In much of Peninsular Ranges area, unit is moderately well consolidated orangish brown sand and silt that is typically well dissected (photo 21). Very extensively developed on north side of San Bernardino and San Gabriel mountains, especially in area between Mojave River and Sheep Creek alluvial fan. Includes upper part of unit Meisling and Weldon (1989) term Victorville fan deposits (photos 354 and 295). Typically consists of medium to dark, reddish-brown lithic arkose. Moderately to well consolidated; in places, supports natural and artifical vertical faces 10 m high. Grain size variable over wide range, but mostly medium to very coarse sand; ranges from sparsely to highly conglomeratic. Bedding features obscure in much of unit, most commonly defined by lensoidal pods of conglomerate or conglomeratic, lithic arkose. Contains abundant, conspicuous clasts of Pelona Schist in most of unit. In places subdivided into:

$Qvof_3$ **Very old alluvial-fan deposits, Unit 3 (middle to early Pleistocene)**—In Yucaipa area and northwestward along and near San Andreas Fault, limited to localized deposits of brown silty sand a few meters thick that overlies unit $Qvof_2$. Consists of well consolidated, crudely stratified, light yellowish-brown (10YR 6/4 to 5/4), texturally massive to faintly laminated, poorly sorted, fine- to very coarse-grained sand. Capped by A/AB/B soils having Bt horizons as much as 1 to 2 m thick (Ramona soils as mapped by Woodruff and Brock, 1980). Extensively developed in Grand Terrace area north of Riverside. There, unit consists of thick, yellowish-brown, massive to moderately well bedded, sparsely conglomeratic arkose. Moderately well consolidated. Matrix supported, sparsely distributed pebble beds are common locally. On north side of San Bernardino Mountains, near east edge of quadrangle, unit consists of massive debris flow deposits containing unsorted, unbedded, angular and subrounded boulders up to 1 m across. Upper meter of deposits is orangish-brown, grading downward to light and medium brown. Upper surfaces are littered with angular and subrounded boulders

$Qvof_2$ **Very old alluvial-fan deposits, Unit 2 (early Pleistocene)**—In Yucaipa area and northwestward along and near San Andreas Fault, unit forms sequence of sand and subordinate gravel as much as 30 m thick. Well dissected, well consolidated, but friable, well stratified, medium- to very coarse-grained sand containing abundant pale pink, potassium feldspar angular granules and pebbles; locally capped by veneer of unit $Qvof_3$ or by A/AB/B soil. On north side of San Bernardino Mountains, near east edge of quadrangle, unit consists of massive debris flow deposits consisting of angular and subrounded boulders and lesser sand and gravel. Upper part is pale orangish-brown, grading downward to light and medium brown. Probably more than 10 m thick. Deeply incised compared to Qof fans. Flanked and overlapped by Qof_2 and $Qvof_3$ debris flows, and cut by thrust faults partly responsible for uplift of range

$Qvof_1$ **Very old alluvial-fan deposits, Unit 1 (early Pleistocene)**—In Yucaipa area and northwestward along and near San Andreas Fault, unit is reddish-brown, strongly pigmented alluvial fan deposits. Primarily sand- to pebble-sized clasts, but includes deposits containing cobbles and boulders. Typically well-consolidated and has well-dissected surfaces. On south side of San Bernardino and San Gabriel Mountains fan surfaces are extremely dissected and capped by stage S_1 soils. On north side of San Bernardino Mountains, east of Mojave River, unit is highly variable from place to place depending chiefly on source area and proximity to range front. Near east edge of quadrangle, perched erosional remnants of fans at range front consist of boulder conglomerate debris flows. North of range front, midway between east edge of quadrangle and Mojave River, unit is several tens of meters thick, consisting of indistinctly bedded, conglomeratic, lithic arkose. Moderately well consolidated. Uppermost part is highly pigmented, ranging from reddish-brown to dark orangish brown. Clasts are mostly mixed granitic rocks, ranging from small pebbles to boulders 30 cm across. Unit is cut by large canyons, and is elevated relative to surrounding Quaternary units. Debris flows may be present, but much of unit here is stream deposited

Qvoa **Very old axial-channel deposits (middle to early Pleistocene)**—Alluvial deposits dominated by sand, but containing scattered gravel and pebble layers, and silt, and clay-bearing alluvium. Typically well consolidated to moderately to well-indurated, reddish-brown, highly pigmented in upper parts. May not show generic relationship to modern drainages, but originally deposited on canyon floors. In places, includes thin, discontinuous alluvial deposits of Holocene age. Deposits on Gavilan-Lakeview surface in Lakeview Mountains are moderately well-indurated, light gray gravelly sand containing abundant biotite. Deposits in Quail Valley and Railroad Canyon area contain rounded cobbles. Includes:

$Qvoa_5$ **Very old axial-channel deposits, Unit 5 (middle to early Pleistocene)**—Moderately to well-indurated, reddish-brown, mostly very dissected gravel, sand, silt, and clay-bearing alluvium deposited on canyon floors. Youngest part of Qvoa

$Qvoa_4$ **Very old axial-channel deposits, Unit 4 (middle to early Pleistocene)**—Moderately to well-indurated, reddish-brown, mostly very dissected gravel, sand, silt, and clay-bearing alluvium deposited on canyon floors. Younger part of Qvoa

$Qvoa_3$ **Very old axial-channel deposits, Unit 3 (middle to early Pleistocene)**—In areas east and west of mouth of Santa Ana River, unit consists of alluvial deposits, but locally includes regolith or pedogenic-soil profile developed on San Timoteo Beds. Unit is deeply dissected and capped by mature A/AB/B soils. East of San Timoteo Canyon, sediment is well consolidated, reddish brown, silty, fine- to coarse-sand containing scattered pebble to cobble gravel layers. Westward, unit is interstratified yellowish-tan sand and gravel interlayered with Bt-bearing paleosols having 7.5YR to 5YR hues. In Yucaipa Canyon south of Dunlap Acres, unit has more pronounced reddish hue, is more dissected, and pedogenic surface soil is thicker and better developed. Locally, unit scours irregularly into underlying San Timoteo Beds, and consists of brown, interlayered sandy and gravelly sediment that is slightly to moderately consolidated

$Qvoa_2$ **Very old axial-channel deposits, Unit 2 (early Pleistocene)**—Well consolidated, reddish brown, silty, fine- to coarse-sand containing scattered pebble to cobble gravel. Restricted to limited area in Plunge Creek drainage east of San Bernardino

$Qvoa_1$ **Very old axial-channel deposits, Unit 1 (early Pleistocene)**—Well consolidated, highly pigmented, reddish brown, silty, fine- to coarse-sand containing scattered pebble to cobble gravel

Qvov **Very old alluvial valley deposits (late to middle Pleistocene)**—Fluvial deposits flanking valley floors or perched erosional remnants. Consists of well-indurated, moderately dissected sand, silt, and clay-bearing alluvium. Some deposits may include thin alluvial deposits of Holocene age

Qvosw **Very old slope-wash deposits (middle to early Pleistocene)**—Highly pigmented, reddish brown, fine- to coarse-sand and gravel. Moderately well consolidated, and moderately dissected. Restricted to single area in Granite Mountains in northeastern corner of quadrangle. Could be side-hill erosional remnant of different Qvo unit

Qvols **Very old landslide deposits (middle to early Pleistocene)**—Slope-failure deposits that consist of displaced bedrock blocks and (or) chaotically mixed rubble. Geomorphic form of landslides poorly, or not at all, preserved. Inferred to have accumulated late in main uplift history of Transverse Ranges. In San Bernardino Mountains includes large multiple slides in canyon of City Creek and numerous scattered slides along mountain front within one or 2 km of San Andreas Fault. In San Gabriel Mountains, includes two large, multiple slide masses at Crystal Lake (photos 302 and 303) and Alpine Canyon in upper reaches of North Fork of San Gabriel River. Deposits in both slide areas are highly dissected

Qvop **Very old paralic deposits (middle to early Pleistocene)**—Paralic deposits consisting of interfingered strandline, beach, estuarine and colluvial deposits. Mostly poorly sorted, moderately permeable, reddish-brown silt, sand and cobbles. These deposits rest on now-emergent wave-cut abrasion platforms preserved by regional uplift

Qvos **Very old surficial deposits (middle to early Pleistocene)**—Well dissected, slightly to moderately consolidated alluvium; light yellowish brown to yellowish brown. In Yucapia area, contains angular to subangular clasts of locally derived gneissic and granitic rocks. Crudely bedded to very thick bedded, poorly sorted sand and granule-bearing sand interlayered with subordinate granule- and pebble-bearing gravel. Also forms limited exposures in Plunge Creek area and in Ord Mountains, and numerous small exposures in Jurupa Hills

Qvor **Very old regolith (middle to early Pleistocene)**—Surficial weathering profile developed on San Timoteo formation; has mature A/AB/B soil profile having Bt horizon as much as 1 to 3 m thick (Kendrick and others, 1994; Kendick, 1996). Reddish-brown, higly dissected. Developed on both *in situ* and transported material. Locally, Qvor is included within unit $Qvoa_3$. West of mouth of San Timoteo Canyon, unit Qvor contains metaquartzite clasts recycled from quarzite conglomerate member of San Timoteo Beds (QTstcq). Also forms limited exposures in Devil Canyon and near Cajon

PENINSULAR RANGES ASSEMBLAGE

Pauba Formation (Pleistocene)—Siltstone, sandstone, and conglomerate (photo 233) (Murrieta, Wildomar, and Bachelor Mountain 7.5' quadrangles). Named by Mann (1955) for exposures in Rancho Pauba area about 3.2 km southeast of Temecula. Vertebrate fauna from Pauba Formation are of late Irvingtonian and early Rancholabrean ages (Reynolds and Reynolds, 1990a; 1990b). Includes two informal members:

Qps **Sandstone member**—Brown, moderately well-indurated, cross-bedded sandstone containing sparse cobble- to boulder-conglomerate beds

Qpf **Fanglomerate member**—Grayish-brown, well-indurated, poorly sorted fanglomerate and mudstone

Qlh **La Habra Formation (Pleistocene)**—Nonmarine mudstone, fluvial sandstone, and conglomerate. First described by Eckis (1934) for deposits in La Habra area; Durham and Yerkes (1959) formalized name. Occurs in La Habra and Yorba Linda 7.5' quadrangles. Upper two-thirds of formation is chiefly friable, gray to brown, sandy to pebbly mudstone. Lower part of formation is gray to brown, massive to crudely bedded, coarse-grained to pebbly sandstone. Unit has basal conglomerate consisting of yellowish-tan to brownish-gray massive or very crudely bedded, pebbly sandstone and conglomerate, which fills channels cut in underlying strata. Conglomerate has about 15 degree discordance with underlying beds. Locally contains clasts of white siltstone derived from Puente Formation Mudstone in upper part locally contains thin marly beds, which have freshwater snails, ostracodes, and plant remains. Formation ranges from 60 to 300 m thick

Sandstone and conglomerate of Wildomar area (Pleistocene and Pliocene)—Unnamed sandstone and conglomerate unit unconformably overlain by Pauba Formation (Kennedy, 1977) in Murrieta and Wildomar 7.5' quadrangles. Coarse-grained sandstone, pebbly sandstone, and conglomerate (Kennedy, 1977) exposed in vicinity of Wildomar in Murrieta 7.5' quadrangle (photo 232). Most of unit is friable to relatively well consolidated, pale gray to greenish gray, crudely and discontinuously bedded. Feldspars are commonly decomposed. Lower part yields vertebrate fauna of late Blancan age, 2 to 3 Ma; upper part yields fauna of Irvingtonian-age, less than 0.85 Ma (Reynolds and Reynolds, 1990a, 1990b; Reynolds and others, 1990). At Chaney Hill in Murrieta area, unit contains 0.7 Ma Bishop Ash (Merriam and Bishoff, 1975). Estimated maximum thickness is 75 m. Includes two informal subdivisions:

QTws **Sandstone**—Primarily friable, pale yellowish-green, medium-grained, caliche-rich sandstone

QTwc **Conglomerate**—Primarily cobble-and-boulder conglomerate. Conglomerate clasts are locally derived

Qch **Coyote Hills Formation (Pleistocene)**—Chiefly nonmarine mudstone and pebbly sandstone in La Habra 7.5' quadrangle; contains some intertidal(?) deposits in western part. Mudstone is grayish, massive, and friable; sandstone is medium- to coarse-grained or pebbly, and thickly bedded. First described and named by Yerkes (1972) for deposits in Coyote Hills south of Puente Hills. At its type locality, unit is about 220 m thick; upper 150 m is 60 percent mudstone and 40 percent sandstone, lower 65 m is pebbly sandstone (Yerkes, 1972). Coyote Hills Formation unconformably rests on San Pedro Formation

Qsp **San Pedro Formation (Pleistocene)**—Shallow marine sandstone and pebbly sandstone (La Habra 7.5' quadrangle). Upper part consists of white to brown, friable, massive sandstone, which contains abundant marine mollusks, and locally includes conglomerate beds. In places, pebbly sandstone forming base of upper part is locally well indurated. Lower part consists of brown to gray, massive, silty sandstone which contains scattered marine mollusks. First described as San Pedro sand by Dall in 1898; named for exposures at Harbor Hill, near head of San Pedro Harbor. Formalized as San Pedro Formation by Kew (1923). Maximum exposed thickness in Puente Hills area is 100 m; thickness in subsurface is about 535 m (Yerkes, 1972). In southern part of La Habra 7.5' quadrangle, unit is subdivided into four mappable units. In succession, consists of a lower sequence of siltstone and claystone (Qsp_1); overlain by sandstone, in part conglomeratic (Qsp_2); overlain by siltstone and claystone (Qsp_3); and an upper unit of sandstone, in part conglomeratic (Qsp_4)

San Timoteo Beds (Pleistocene and Pliocene)—Lithologically diverse sandstone, conglomeratic sandstone, and conglomerate; nearly all sandstone is arkosic and much is lithic. Forms badlands topography (photo 12). Named by Frick (1921) for upper Pliocene, vertebrate-bearing, nonmarine strata in San Timoteo Canyon. Upper part of San Timoteo beds contain vertebrate fauna of earliest Pleistocene Irvingtonian I age (Repenning, 1987); Eckis (1934) had earlier suggested Pleistocene age for upper part of section in 1934. Albright (1997) shows vertebrate fossils are throughout most of upper part of unit. Lower part of San Timoteo Beds is Pliocene. Clasts within unit appear to be entirely derived from Transverse Range sources similar in composition to rocks presently exposed in eastern San Gabriel Mountains, central San Bernardino Mountains, and in San Bernardino-Yucaipa area (Matti and Morton, 1993). In earlier work, contact between San Timoteo Beds and underlying Mount Eden

Formation inconsistently placed at various stratigraphic positions. In this report, contact is placed at boundary between older fluvial-lacustrine deposits (Mount Eden Formation) and younger fluvial-alluvial fan deposits (San Timoteo Beds). Age of this boundary is about 4.3 Ma (B. Albright, written commun., 1998). Includes five informal members and local subdivision of three of those:

Qstu **Upper member (Pleistocene)**—Medium- to thick-bedded, moderately to well sorted, moderately indurated, very fine- to coarse-grained sandstone interlayered with subordinate pebbly sandstone and pebble to small-cobble gravel. Sandstone intervals are distinctly yellowish gray throughout much of unit. Sandy matrix of gravel beds is lighter colored than typical sand beds, and ranges from light gray to pale yellow and light yellowish brown. Clasts in gravel layers are subrounded to subangular, and represent most nearby basement rocks. Locally includes pebbly, coarse-grained arkosic sandstone, here informally referred to as Reche Canyon member (Qstr). Upper part of unit contains middle Pleistocene (Irvingtonian-II) Shutt Ranch local fauna dated as about 780 to 990 Ka (Albright, 1997, 1999a, 1999b). Also contains late Pliocene to early Pleistocene Irvingtonian I, Shutt Ranch and El Casco local faunas, about 1.8 Ma (Repenning, 1987; M.O. Woodburne, oral commun., 2003). Erodes to form sharp-ridged badlands topography. Locally subdivided into:

Qsts **Conglomeratic sandstone beds**—Conglomeratic sandstone that appears to be derived from adjacent sedimentary beds. Forms small lens-shaped body along crest of anticline in western part of San Timoteo Badlands

Qstcq **Quartzite-bearing conglomerate beds**—Distinctive, well-indurated, conglomerate consisting largely of clasts derived from central part of San Bernardino Mountains. Characterized by quartzite clasts derived from Precambrian terrain and by megaporphyry clasts (Matti and Morton, 1993; Morton and others, 1986). Beds found in upper part of upper member. Contains early Pleistocene Irvingtonian I, Olive Dell local fauna (Repenning, 1987), about 1.3 Ma

Tstm **Middle member (Pliocene)**—Dominant lithology is light-gray, pebbly to cobbley, moderately to well-indurated, medium- to coarse-grained sandstone containing conglomerate beds up to 9 m in thickness (photo 420). Pale brown- to light-gray fined-grained sandstone to pebbly sandstone is subordinate. Overall, member consists of about 70 percent sandstone and 30 percent conglomerate; conglomerate more abundant in upper part. Includes common reddish-brown stratigraphic intervals consisting of oxidized sandstone, which are not paleosols, and reddish-brown clay-rich intervals, which may be paleosols. Erodes to form sharp-ridged badlands topography. Forms hogbacks on north side of San Timoteo Canyon. Included within Tstm is highly deformed sandstone, pebbly sandstone, and conglomerate (Tstd) located along western part of badlands adjacent to San Jacinto Fault Zone. Stratigraphic position of Tstd within Tstm is not known

Tstl **Lower sandstone member (Pliocene)**—Mostly gray, moderately well indurated, well-sorted fine-grained sandstone containing subordinate pebble lenses, and sparse medium-grained sandstone beds. Represents distal flood plain deposit. Erodes to form slightly more rounded badlands topography than younger part of San Timoteo beds. Base of unit at many places is interval of buff to reddish-brown fine- to thick-bedded coarse-grained arkosic sandstone ($Tstl_1$). In much of Tstl, a section of mostly greenish-gray claystone, siltstone, and thick, poorly bedded, coarse-grained sandstone ($Tstl_2$) lies above $Tstl_1$

Tstrl **Ripple-laminated member (Pliocene)**—Consists principally of interbedded sandstone and mudrock. Dominant lithology is moderately well indurated, ledge-forming, thin- to medium-bedded, well-sorted pale-brown sandstone (photo 421). Sandstone contains characteristic climbing ripple laminations, convoluted bedding, and locally cross-laminations (photo 422). Interbedded with subordinate thin-to medium-bedded intervals of fissile to hackly-fracturing mudrock. Unit has prominate reddish-brown interval in Lamb Canyon area

Tstf **Fine-grained member (Pliocene)**—Hackly fracturing to locally fissile, dark gray-green mudrock. Weathers to form smooth rounded slopes (photo 423)

QTs **Unnamed sedimentary rocks in Riverside and Corona areas (early Pleistocene to late Pliocene?)**—Lithologically diverse, moderately indurated, gray to brown, coarse-grained sandstone, pebbly sandstone, and conglomerate (photo 239). In Riverside West 7.5' quadrangle, most clasts in unit were derived from San Bernardino Mountains. In Riverside area, unit appears to be derived from units found in Santa Ana River drainage. Southeast of Riverside, in Riverside East 7.5' quadrangle, clasts are locally derived from Peninsular Ranges sources

QTt **Conglomerate of Temescal area (early Pleistocene to late Pliocene?)**—Cobble conglomerate deposited on deeply weathered surface of Paleocene(?) age, Corona South 7.5' quadrangle. Clasts appear to be locally derived.

QTc **Conglomeratic sedimentary rocks of Riverside West 7.5' quadrangle (early Pleistocene to late Pliocene?)**—Boulder conglomerate containing locally derived granitic and metamorphic clasts. Underlain by cobble conglomerate containing clasts derived from San Bernardino basin and San Bernardino Mountains area. Locally derived boulder conglomerate is brownish-gray; underlying San Bernardino–provinance cobble conglomerate is gray and contains rusty-and black-stained clasts locally. Cobble conglomerate appears to be derived from units in Santa Ana River drainage

QTn **Sedimentary rocks of Norco area (early Pleistocene to late Pliocene?)**—Conglomerate. In Norco area, Corona North 7.5' quadrangle, this conglomeratic unit includes both locally derived clasts as well as quartzite clasts derived from San Bernardino Mountains

Tta **Temecula Arkose (Pliocene)**—Mainly pale greenish-yellow, medium- to coarse-grained, indurated sandstone (Bachelor Mountain 7.5' quadrangle). Includes thin discontinuous beds of tuffaceous sandstone, siltstone, and claystone, and some pebble and conglomerate beds containing locally derived clasts. Named by Mann (1955) for exposures of nonmarine fluvial sandstone exposed southeast of Temecula. Kennedy (1977) assigned unit late Pliocene Blancan IV-V mammal age (2.2 to 2.8 My) based on vertebrate assemblages collected east of quadrangle. Assemblages include *Nannippus, Hypolagus, Tetrameryx, Equus,* and *Odocoileus* (Golz and others, 1977). Later work establishes first occurrence of *Tetramerx* as Irvingtonian I rather than late Blancan (Woodburne, 1987), placing Temecula Arkose age nearer 1.9 Ma (late Pliocene) than 2.2 Ma. A microtine fauna from unit in Radec area, about five miles east of Santa Ana quadrangle, is considered to have age of 4.6 Ma (Blancan I) (Repenning, 1987). Thickness of Temecula Arkose ranges from 90 to over 550 m (Kennedy, 1977)

Tf **Fernando Formation (Pliocene)**—Siltstone, sandstone, pebbly sandstone, and conglomerate. Name introduced by Eldridge and Arnold (1907) for marine deposits on northwest side of San Fernando Valley. Formalized by Kew (1924) for similar-appearing rocks in Ventura basin. Durham and Yerkes (1964) defined current usage in Santa Ana 30' x 60' quadrangle. In Puente Hills, Fernando Formation is about 1825 m thick (Yerkes, 1972). Lower part equivalent to Repetto Formation in Los Angeles Basin (Woodring, 1938). Includes two members separated by regional erosional unconformity:

Tfu **Upper Member**—In eastern part of Puente Hills consists of sandstone, pebbly sandstone, and sandy conglomerate. In western part of Puente Hills, upper member consists of three units. From youngest to oldest; (1) 250 m of pale gray, thick-bedded to massive, friable, fine- to medium-grained sandstone and brownish-gray, massive, pebbly sandstone; (2) 590 m of pale gray, massive, poorly sorted, friable, micaceous rock ranging from siltstone to medium-grained sandstone; and (3) 200 m of sandstone, pebbly sandstone, and pebbly conglomerate (Yerkes, 1972). Sandstone is generally massive, pale gray to brownish-gray, silty, fine- to coarse-grained, poorly sorted, and friable. Pebbly sandstone is brownish-gray thick-bedded to massive, poorly sorted, and friable. Locally subdivided conglomerate (Tfuc) is brown and consists of clasts up to 45 cm in length; Tfuc is about 490 m thick in western part of Puente Hills. Abundant marine mollusks occur in upper part of member

Tfl **Lower member**—Siltstone, sandstone and conglomerate in northwestern part of Puente Hills. Includes brownish-gray to pale-gray, sandy, micaceous siltstone, fine- to medium-grained friable sandstone, and brownish-gray, unsorted, massive, pebbly conglomerate. Contains local beds of intraformational breccia, and locally common foraminifera. Conglomerate at base of member contains angular clasts of white Miocene-age siltstone and near-black diabase. Member is up to 730 m thick. Includes zone of predominantly conglomeratic rock (Tflc) of unknown thickness and unknown extent

Tn **Niguel Formation (Pliocene)**—Marine interbedded sandstone, conglomeratic sandstone, and conglomerate; widespread in San Juan Capistrano 7.5' quadrangle. Named by Vedder (1957) for exposures in San Juan Capistrano 7.5' quadrangle. Sandstone is brownish-gray, coarse grained, and poorly sorted. Brownish-gray conglomerate, consists of unsorted clasts 2.5 to 25 cm in diameter, and contains blocks of locally derived siltstone. Marine mollusks suggest deposition in sublittoral-depth water (Vedder, 1960)

Tns **Sandstone of Norco area (Pliocene)**—Poorly exposed, unnamed, marine sandstone near city of Norco (Corona North 7.5' quadrangle). Unconsolidated, greenish-yellow sandstone and sparse conglomerate lenses. Locally contains abundant, poorly preserved shallow marine fossils including *Anadara* cf. *A. trilineata* (Conrad)*, Chione* sp., *Lucinoma* cf. *L. annulata* (Reeve), and *Diodora* sp. (J.D. Mount, per. commun., 1973). Unit may represent shallow-water eastward extension of Fernando Formation. Sparse conglomerate lenses include clasts of exotic silicic volcanic rocks. In places, nonconformably buttressed against granitic rock (photo 231). Ash at base of formation deposited on granite in what are interpreted to have been tide pools, is ash of Taylor Canyon (written. commun., A.M. Sarna-Wojcicki, 1990) having age of 2.6 Ma

Tc **Capistrano Formation (early Pliocene and Miocene)**—Marine sandstone and siltstone; widespread in San Joaquin Hills area. Named by Woodford (1925) for exposures of marine strata near city of San Juan Capistrano. In Santa Ana quadrangle, includes one member and one separately mapped facies:

Tco **Oso Member**—White to light gray, massive, medium- to coarse-grained, friable sandstone. Contains scattered matrix-supported pebbles and cobbles. Named by Vedder and others (1957) for marine sandstone in coastal Orange County. Upper part contains foraminifers of Kleinpell's upper Mohnian or Delmontian Stage (Vedder and others, 1957), and in area of San Juan Capistrano to Dana Point, late Miocene and early Pliocene foraminifera, shark teeth, echinoids, and whalebones (White, 1956, 1971; Ingle, 1971, 1972; Vedder, 1972)

Tcs **Siltstone facies**—White to pale gray, massive to crudely bedded, friable, siltstone and mudstone. Informally designated by Morton and Miller (1981) for exposures in southern Orange County. Contains sandstone and calcareous mudstone beds, and sparse diatomaceous and tuffaceous beds. Up to 730 m thick

Tme **Mount Eden Formation of Fraser (1931), undifferentiated (early Pliocene and Miocene)**—Sandstone, mudrock, conglomeratic sandstone, and sedimentary breccia (Lakeview and El Casco 7.5' quadrangles). First described as Eden beds by Frick (1921), but name was preempted. Fraser (1931) informally designated same unit the Mount Eden Formation. Named for exposures in vicinity of Mount Eden, El Casco 7.5' quadrangle. Albright (1997), Frick (1921), May and Repenning (1982), and Repenning (1987), described vertebrate fauna from Mount Eden Formation and Axelrod (1937, 1950) described flora. Includes five informal members:

Tmeh **Heterogeneous member (Miocene)**—Green, olive green, and gray sandstone, pebbly sandstone, and minor limestone (photo 424); locally contains abundant limey concretions. Mudrock subordinate in this member. Southeastward, unit is progressively better indurated, and in southeastern exposures is ledge-forming sandstone and pebbly sandstone. Well indurated rock north of Mount Eden contains middle Miocene, late Hemphillian Mount Eden local fauna; about 5.3 Ma (Repenning, 1987) or 5.6 Ma (Albright, 1997)

Tmea **Arkosic and lithic sandstone member (Miocene)**—Mostly thick-bedded, indistinctly bedded, moderately to well-indurated, buff, gray, greenish-gray, and reddish-brown, coarse-grained arkosic and lithic sandstone, pebbly sandstone, and conglomerate (photos 425 and 426). Contains some interbeds of fine-grained sandstone, siltstone, and rare shale. Includes sparse limey concretions, which are not as common as in overlying heterogeneous member. Unit is possibly coeval or in part coeval with conglomeratic sandstone. Contains tongues of monolithologic boulder breccia (Tmeb). Giant clasts in breccia are up to 6 m in diameter (photos 235 and 236). Apparently represents debris flow deposits. Breccia tongues occur at several different horizons mostly in Lamb Canyon and Laborde Canyon areas. Clasts are entirely tonalite of Lamb Canyon, a massive sphene-bearing biotite-hornblende tonalite, which crops out in northeastern part of the El Casco 7.5' quadrangle

Tmec **Conglomeratic sandstone member (Miocene)**—Reddish-brown, massive to indistinctly bedded, coarse-grained sandstone, pebbly sandstone, and conglomerate (photo 234). Basal unit of Mount Eden Formation of Frasier (1931). Lower part is dominated by conglomerate and upper part by sandstone. Moderately- to well-decomposed clasts are locally derived Peninsular Ranges Province basement rocks

Tch **Sandstone and conglomerate in southeastern Chino Hills (early Pliocene and Miocene)**—Poorly exposed marine and nonmarine sedimentary sandstone and conglomerate in Arena Blanca syncline area of southeastern Chino Hills (Prado Dam 7.5' quadrangle). Stewart and Stewart (1930) and Woodford and others (1944) reported Pliocene foraminifera from these rocks. Similar appearing rocks southeast to Wardlow Wash, Bedford Canyon, and Brown Canyon are included in this unit (Gray, 1961). Smith (1960) described Pliocene foraminifera from these rocks. A meager megafauna was collected on northwest side of Bedford Canyon and included a fragment of *Cantharus* sp. of Pliocene age (Gray, 1961). In Chino Hills this unit was differentiated from underlying Puente Formation by Daviess and Woodford (1949) and by Gray (1961) but was included within Puente Formation by Durham and Yerkes (1964). Fossils obtained from sand-and-gravel quarry included marine invertebrate and nonmarine vertebrate faunas and nonmarine flora (R.E. Reynolds, written commun., 1998). Vedder (oral commun. to T.H. McCulloh, 1997) identified a relatively large molluscan taxa from material collected by Reynolds. Vedder considered best correlation of molluscan taxa is to lower part of Fernando Formation and upper part of Capistrano Formation. Foraminifera collected in 1996(?) were identified as Delmontian age (T.H. McCulloh, oral commun., 1997). Indicates unit at least in part coeval with Sycamore Canyon member of Puente Formation

Tp **Puente Formation, undifferentiated (early Pliocene and Miocene)**—Marine sandstone, siltstone, and shale underlying most of Puente Hills and extending into adjacent areas. Named by Eldrige and Arnold (1907) for exposures in Puente Hills. English (1926) extended distribution of Puente Formation to area south of Puente Hills, distinguishing three units, from youngest to oldest; (1) shale, sandstone, and conglomerate (2) sandstone, and (3) shale. Daviess and Woodford (1949) subdivided Puente Formation in northwestern Puente Hills into four members, from youngest to oldest, (1) Sycamore Canyon member, (2) upper siltstone member, (3) sandstone member, and (4) lower siltstone member.

Schoellhamer and others (1954) later designated formalized member names that are in current usage as follows:

Tpsc **Sycamore Canyon Member (early Pliocene and Miocene)**—Predominantly sandstone and pebble conglomerate (photo 230). Named by Daviess and Woodford (1949) for exporsures at Sycamore Canyon in northwestern Puente Hills, San Dimas 7.5' quadrangle. Sycamore Canyon Member is laterally variable, composed of varying amounts of pale gray, thick-bedded to massive, medium- to coarse-grained, friable sandstone; pale gray, thin-bedded, siliceous siltstone; pale gray, poorly bedded siltstone, and brownish-gray, massive conglomerate. Contains bathyal depth foraminiferal fauna (Yerkes, 1972). Includes zone of predominantly conglomeratic rock (Tpscc) of unknown extent

Tpy **Yorba Member (Miocene)**—Siltstone and sandstone; siltstone predominates (photo 229). Named by Schoellhamer and others (1954) for Yorba Bridge east of community of Atwood (fig. 1). White to gray, thin bedded, micaceous and siliceous siltstone and sandy siltstone. Siltstone contains beds of fine-grained sandstone and white to pale gray limy concretions and concretionary beds. In eastern Puente Hills, upper part of Yorba contains large boulders enclosed in relatively fine-grained rock and is interpreted as turbidity current deposit (Durham and Yerkes, 1959). Included in Tpy is a zone of predominantly conglomeratic rock (Tpyc) of unknown extent

Tpsq **Soquel Member (Miocene)**—Sandstone and siltstone; sandstone predominates (photo 228). Named by Schoellhamer and others (1954) for exposures in Soquel Canyon in eastern Puente Hills. Gray to yellowish-gray, massive to well-bedded, medium- to coarse-grained, poorly sorted sandstone interbedded with matrix-supported pebbly sandstone. Many sandstone beds are graded. Locally conglomeratic (Tpsqc). Lower part commonly contains ellipsoidal calcite-cemented concretions 30 cm to 1.5 m in diameter

Tplv **La Vida Member (Miocene)**—Siltstone and subordinate sandstone. Named by Schoellhamer and others (1954) for exposures near La Vida Mineral Springs in eastern Puente Hills. Light-gray to black, massive to well-bedded, generally friable siltstone. Weathered surfaces are typically white or pale gray. Locally consists of porcellaneous siltstone or shale. Contains widespread fish remains, abundant foraminifera, local phosphate nodules, and sparse limy siltstone. Interbedded sandstone beds range from 2 cm to over 1 m thick. Includes a few beds of vitric tuff

Tlm **Lake Mathews Formation (Miocene)**—Poorly exposed sequence of massive, greenish-gray mudstone and minor conglomerate, and poorly bedded white to gray sandstone, pebbly sandstone, and conglomerate (photos 27, 28, and 29) (Lake Mathews 7.5' quadrangle). Name introduced by Proctor and Downs (1963) and formalized by Woodford and others (1971). Contains vertebrate fauna including *Ustattochoeerus* cf. *Californicus* (Merriam) (Proctor and Downs, 1963) indicating a Claredonian age (Woodburne, 1987) for formation

Tcgr **Rhyolite clast conglomerate of Lake Mathews area (Miocene?)**—Massive, indurated, coarse-grained, sandstone-matrix, cobble conglomerate (photos 30 and 427) (Lake Mathews and Steele Peak 7.5' quadrangles). Matrix feldspars largely altered to clay. Cobbles include exotic red rhyolite in addition to locally derived clasts. Occurs as three slightly elevated channel deposit remnants on 640 m Gavilan-Lakeview erosional surface of Woodford and others (1971)

Tcg **Conglomerate of Lake Mathews area (Miocene?)**—Massive, indurated, coarse-grained, sandstone-matrix, cobble conglomerate (Lake Mathews 7.5' quadrangle). Similar to rhyolite clast conglomerate of Lake Mathews area (Tcg), but lacks rhyolite clasts

Tm **Monterey Formation (Miocene)**—Siliceous and diatomaceous marine siltstone and sandstone correlated with Monterey Formation (Blake, 1856; Kew, 1923; Bramlette, 1946) of central California. Predominantly siltstone and sandstone. Interbedded white to pale brown, thinly laminated siltstone and tan, fine- to medium-grained feldspathic sandstone. Contains abundant foraminifera and fish remains; locally contains diatom fragments. In Capistrano area, lower part of Puente Formation grades laterally southward into Monterey Formation (Vedder and others, 1957)

Tvsr **Santa Rosa basalt of Mann (1955) (Miocene)**—Very fine-grained olivine basalt (photos ~~428,~~ 429 and 430). Remnants of basalt flows having relatively unmodified flow surfaces (Murrieta, Wildomar, and Sitton Peak 7.5' quadrangles). Hawkins (1970) provides detailed petrologic description of basalt. Originally described by Fairbanks (1892) and informally named by Mann (1955) for basalt flows in vicinity of Rancho Santa Rosa, west of Temecula. Name also has been applied to basalts in general area of Temecula and Santa Ana Mountains, but in this report, is restricted to rocks in area west of Temecula. Southwestern part of Santa Rosa basalt of Mann (1955) extruded on deeply weathered surface of low relief similar to Paleocene age surfaces found elsewhere in southern California. Also, western part of unit, and where found in vicinity of Elsinore Peak, was extruded on sedimentary rocks closely resembling Paleogene-age rocks. Morton and Morton (1979) report whole-rock conventional potassium-argon ages for Santa Rosa basalt of 6.7 and 7.4 Ma. Slightly older age of 8.7 Ma was obtained by Hawkins (1970)

Tvtb **Basalt of Temecula area (Miocene)**—Includes scattered exposures of basalt north and east of Temecula, and a small exposure of vesicular basalt within valley area of Elsinore Fault zone near Wildomar (Mann, 1955; Kennedy, 1977; Hull, 1990). East of Temecula there are a few exposures of vesicular basalt and what appears to be a dissected cinder cone and scattered volcanic bombs (Mann, 1955)

Tvh **Basalt of Hogbacks (Miocene)**—Basalt capping Hogbacks northeast of Temecula (Murrieta 7.5' quadrangle). Remnant of channel-filling basalt flow. Thin deposit of unconsolidated gray stream gravel underlies axial part of channel-filling basalt. Basalt is less vesicular than most of Santa Rosa basalt of Mann (1955) and tends to break into slabby fragments. Whole-rock conventional potassium-argon ages are 10.4 and 10.8 Ma (Morton and Morton, 1979)

Tg **Glendora Volcanics, undifferentiated (Miocene)**—Volcanic flow rocks ranging from rhyolite to basalt interlayered with breccia (photo 218), tuff, and locally, sedimentary conglomerate (photo 220). Partly intercalated with undifferentiated part of Topanga Group (Tt) and partly underlies lowest Tt strata (Shelton, 1955; Morton, 1973). Forms very discontinuous, heterogeneous, highly faulted exposures along southern part of San Gabriel Mountains, and in San Jose and Puente Hills. Internal stratigraphy poorly established due to faulting and discontinuous exposure. Consists of:

Tgr **Rhyolite and dacite flows**—Finely layered, gray to reddish-gray, felsic rhyolite and rhyolite to dacite. Rocks are about 90 percent rhyolitic glass containing about 10 percent very fine grained phenocrysts of oligoclase and trace amounts of tridymite. In some areas unit contains perlite and autobrecciated flow-rock. At north end of Puente Hills, rocks are pervasively silicified and pyritized (Shelton, 1955)

Tgrb **Rhyolite and dacite breccia**—Angular fragments of gray, finely layered, spherulitic glass in tuffaceous matrix. Restricted to single, small area at north end of Puente Hills (Shelton, 1955)

Tga **Andesite flows**—Light- to dark-gray andesite and andesite flow breccia; very large proportion of unit is breccia. Andesite averages about 60 percent aphanitic groundmass and 40 percent sub-millimeter phenocrysts. All andesite has plagioclase phenocrysts, but content and distribution of mafic mineral phenocrysts is highly variable; varieties include hypersthene-bearing, augite-hypersthene-bearing, hornblende-bearing, and biotite-bearing (Shelton, 1955)

Tgj **Tuff breccia of Johnson Peak area**—Massive, orangish-brown-weathering tuff breccia composed of andesite blocks as large as 3 m, in fine-grained tuffaceous matrix. Andesite blocks average about 15 percent of rock, matrix about 85 percent. Poorly consolidated; easily eroded (Shelton, 1955)

Tgb **Basalt flows**—Fine-grained basalt flow rock, commonly vesicular. Mostly holocrystalline, consisting of plagioclase, augite, opaque minerals, and trace olivine. Flow structure and pillow structure well defined at some places (photo 219). Flow breccia developed locally (Shelton, 1955)

Tvep **Basalt of Elsinore Peak (Miocene)**—Black vesicular basalt capping Elsinore Peak. Overlies a thin sequence of Paleogene(?) sandstone. Whole rock conventional potassium-argon age of basalt is 11.6 Ma and $^{40}Ar/^{39}Ar$ age is 11.2 Ma (R. Fleck, written commun., 1998). Occurs in Wildomar 7.5' quadrangle

Tsob **San Onofre Breccia (middle Miocene)**—Chiefly marine sedimentary breccia, conglomerate, and lithic sandstone (photos 4, 5, 6, 7, 8, 9, and 10) (Laguna Beach and San Juan Capistrano 7.5' quadrangles). Unit is characterized by clasts of blueschist and related rocks derived from Catalina Schist (Woodford, 1924). Named by Ellis and Lee (1919) for exposures in San Onofre Hills, San Diego County. Detailed descriptions of petrology and paleontology are given by Woodford (1925), who described unit as "San Onofre facies of Temblor Formation" based on occurrence of *Turritella ocoyana* fauna in sandstone underlying breccia. San Onofre Breccia consists of green, greenish-gray, gray, brown, and white, massive to well bedded, mostly well-indurated breccia with interbedded conglomerate, sandstone, siltstone, and mudstone. Well-bedded fine-grained parts and poorly bedded to massive coarse parts of unit are discontinuous, grading laterally into one another. Local diatomaceous shale and tuff beds. Contains *Turritella ocoyana*. Breccia consists of large angular clasts derived from basement rock sources offshore to west. Unit is up to 900 m thick

Tt **Topanga Group (middle Miocene)**—Marine sandstone, siltstone, and shale. Named by Kew (1923) for predominantly sandstone unit in Santa Monica Mountains; further subdivided by Vedder (1957). Stratigraphic nomenclature used here follows revision of Yerkes and Campbell (1979) and treats original Topanga Formation as being of group rank, but treats described members as formations. Kew (1923) recognized similar rocks in Puente Hills, Santa Ana Mountains, and San Joaquin Hills. At type locality, Topanga Canyon, unit contains middle Miocene fauna characterized by *Turritella ocoyana*. Topanga Group mapped as undifferentiated in Azusa area. Contains much conglomerate (photos 502 and 503) and minor extrusive volcanic rock (photo 219) in that area. In Santa Ana quadrangle, north and west of Santa Ana Mountains, Topanga Group includes three formations, from youngest to oldest:

Ttp **Paulerino Formation**—Pale gray, massive, tuffaceous sandstone and thin-bedded siltstone. Contains some breccia interbeds and locally andesite breccia. Named and designated as member by Vedder (1957) for exposures in San Joaquin Hills, coastal Orange County; here raised to formation rank. Contains assemblage of middle Miocene foraminifera

Ttlt **Los Trancos Formation**—Pale gray to brownish-gray, thin- to medium-bedded siltstone and fine-grained sandstone. Includes some interbedded medium- to coarse-grained sandstone and shale beds. Named and designated as member by Vedder (1957) for exposures in San Joaquin Hills, coastal Orange County; here raised to formation rank. Foraminifera indicate middle Miocene age. Member is up to 945 m thick

Ttb **Bommer Formation**—Gray to brownish-gray, thick-bedded, medium- to coarse-grained sandstone and interbedded fine-grained sandstone and siltstone (photo 431). Locally conglomeratic. Named and designated as member by Vedder (1957) for exposures in San Joaquin Hills, coastal Orange County; here raised to formation rank. Contains middle Miocene megafossils

Tvem **El Modeno Volcanics, undifferentiated (middle Miocene)**—Andesite, tuff, tuff-breccia, and basalt (photos 574, 575, and 576). Named by Schoellhamer and others (1954) for volcanic rocks exposed 5 km east of settlement of El Modeno on northwestern side of Santa Ana Mountains (not to be confused with town of El Modena). Yerkes (1957) gives detailed description of El Modeno Volcanics. Includes:

Tvema **Andesitic volcanic rocks**—Extrusive volcanic rocks; primarily of andesitic composition

Tvemt **Tuff and tuff breccia**—Clastic volcanic rocks; primarily tuff and tuff breccia

Tvemb **Basalt**—Extrusive volcanic rocks; primarily of basaltic composition

Volcanic intrusive rocks associated with El Modeno Volcanics (middle Miocene)—Chiefly diabasic textured shallow intrusive rocks, but also includes porphyritic intrusive rock primarily of andesitic composition. Most rocks are thoroughly altered and decomposed. Includes:

Tiemd **Diabasic intrusive rocks**—Fine grained diabase

Tiema **Andesitic intrusive rocks**—Fine grained andesite, porphyritic

Tvss **Vaqueros, Sespe, Santiago, and Silverado Formations, undivided (early Miocene, Oligocene, and Paleocene)**—Sandstone and conglomerate. See individual unit descriptions for information on rocks of this undivided unit

Tv **Vaqueros Formation (early Miocene, Oligocene, and late Eocene)**—Predominantly sandstone. Originally described as Vaqueros sandstone by Hamlin (1904) for marine deposits in Los Vaqueros Valley along east slope of Santa Lucia Range in central California. Correlation with southern California deposits is based upon *Turritella inezana* fauna. In San Joaquin Hills, unit consists of brownish-gray, massive- to thick-bedded sandstone and sandy siltstone, having interbeds of siltstone and shale, mudstone, and minor conglomerate. Shale and siltstone are thin bedded. Up to 1,160 m thick in quadrangle (Vedder, 1970). Contains early Miocene shallow-water marine megafossil assemblage

Ts **Sespe Formation (early Miocene, Oligocene, and late Eocene)**—In San Joaquin Hills area, Sespe is varied colored from gray to red (photo 214), massive to thick bedded, nonmarine conglomerate (photos 216 and 217), conglomeratic sandstone and clayey and silty sandstone. Bedforms are poorly developed. Watts (1897) originally described unit as Sespe brownstone formation. It was later described by Eldridge and Arnold (1907) and redefined by Kew (1924) for nonmarine conglomeratic deposits exposed in Sespe Creek in Ventura County, where Sespe conformably underlies marine Vaqueros Formation. Continental vertebrate fossil collections range in age from Eocene to early Miocene (Bailey and Jahns, 1954; Woodburne 1987)

Tvs **Sespe and Vaqueros Formations, undifferentiated (early Miocene, Oligocene, and late Eocene)**—Interbedded marine and nonmarine sandstone and conglomerate assigned to Sespe and Vaqueros formations (photo 215). In Puente Hills, Santa Ana Mountains, and San Joaquin Hills, marine fossil-bearing strata of Vaqueros Formation are bed-by-bed interlayered with nonmarine rocks of Sespe Formation to degree that formations cannot be mapped as separate units. Mixed unit locally includes boulder conglomerate (Woodford and others, 1973)

Tcga **Conglomerate of Arlington Mountain (Paleogene?)**—Cobble conglomerate. Found in two small areas north of Arlington Mountain along boundary of Lake Mathews and Riverside West 7.5' quadrangles. Conglomerate is composed of exotic welded tuff casts (photos 20, 432, and 433), some of which contain piemontite, a characteristic mineral in welded tuff clasts in conglomerates of Poway Group (Woodford and others, 1968). Minor clasts of exotic quartzite (photos 434 and 435) also occur within unit. Welded tuff clasts appear identical to those common in Sespe Formation and in conglomerate of Eocene Poway Group found in quadrangle to south. Very localized exposures of identical-appearing conglomerate occur at crest of ridge east of town of Lake Elsinore in eastern part of Elsinore 7.5' quadrangle. Reworked volcanic clasts are also found in some Pleistocene alluvial deposits adjacent to conglomerate

Tsa **Santiago Formation (middle Eocene)**—Continental and marine sandstone and conglomerate (photos 213 and 214). In Santa Ana quadrangle first described by

Dickerson (1914) and correlated with Tejon Formation to north. Later Woodring and Popenoe (1945) proposed name Santiago Formation for exposures at Santiago Creek on west side of Santa Ana Mountains. They considered Santiago Formation to be late Eocene. Later Schoellhamer and others (1981) assigned it to middle Eocene. Lower part of formation consists of conglomerate composed of clasts of quartzite, volcanic rocks, granitic rocks, sandstone, and metaconglomerate, none of which appear to be of local origin (Schoellhamer and others, 1981). Conglomerate overlain by thick sequence of pale gray feldspathic sandstone and lesser interbedded siltstone. Lower part of sandstone contains marine mollusks; silicified wood is common in upper part of sandstone, which is probably nonmarine

Tsi **Silverado Formation (Paleocene)**—Nonmarine and marine sandstone, siltstone, and conglomerate (photo 204). Dickerson (1914) first recognized Paleocene rocks in Santa Ana Mountains, and based on faunal similarities, correlated strata with Martinez Formation of central California. Woodring and Popenoe (1945) described unit in detail and named it Silverado Formation. Formation was deposited on deeply weathered erosional surface (photo 208). Rocks underlying Silverado are characteristically saprolitic. Silverado Formation consists of basal conglomerate overlain by relatively thin sequence of sandstone and siltstone. Distinctive Claymont clay bed overlies sandstone and siltstone sequence, and is overlain by thick sequence of sandstone, siltstone, and conglomerate that includes second clay bed, known as Serrano clay bed. Basal conglomerate is thoroughly weathered, 2- to 25-m-thick, massive, pale gray to reddish-brown, pebble conglomerate. Very locally is boulder conglomerate. Overlying conglomerate is sandstone and siltstone which is also thoroughly weathered, consisting largely of quartz and clay. Claymont clay bed is 1- to 3-m thick, brown, green, and gray clay that weathers to distinctive brownish-red. Bed is mostly clay, partly pisolitic, and has scattered quartz grains in it. Locally, supports large-scale clay operation. Upper part of unit above Claymont clay bed is diverse section of marine and nonmarine sandstone, siltstone, and conglomerate, and includes Serrano clay bed. Latter is about 1 m thick, pale gray to white, and composed of nearly equal amounts plastic clay and quartz. In addition to clay (photos 206 and 207), upper part of section contains carbonaceous shale and lignite beds. Thicker lignite beds were locally mined for fuel. Upper part of unit also contains abundant marine mollusks. Some eastern exposures of formation contain distinctive and diagnostic Paleocene *Turritella pachecoensis.* Basal conglomerate (Tsicg) and Serrano Clay (Tsis) are subdivided locally

Kwl **Williams and Ladd Formations, undifferentiated (Late Cretaceous)**—Sandstone, siltstone, and conglomerate. Upper parts generally coarse grained, thick to massively bedded; lower parts include relatively thick shale zone

Williams Formation (Late Cretaceous)—Sandstone and conglomeratic sandstone. Named by Popenoe (1937, 1942) for exposures near mouth of Williams Canyon in northern Santa Ana Mountains. He divided unit into Pleasants Sandstone Member and Schulz Ranch Member. Woodring and Popenoe (1945) renamed Schulz Ranch Member the Schulz Ranch Sandstone Member, which was further subdivided into Schulz Ranch Sandstone Member and Starr Member (Morton and others, 1979). Later, name Schulz Ranch Sandstone Member was shortened to Schulz Ranch Member (Morton and others, 1979). Formation consists of very resistant, cliff-forming, white to brownish-gray, massive-bedded, poorly sorted feldspathic sandstone, pebbly sandstone, and conglomeratic sandstone. Basal part of section includes conglomerate. Locally contains siltstone beds, 3 to 8 m thick, interbedded with conglomeratic sandstone. Calcite cemented spheroidal concretions a few centimeters to a meter in diameter found locally. Unconformably rests on Holz Shale Member of Upper Cretaceous Ladd Formation. Subdivisions include:

Kwps **Pleasants Sandstone Member**—Marine sandstone. Upper part is poorly bedded, white to pale gray, feldspathic sandstone, which generally is coarser grained than sandstone in lower part. Lower part is sandstone and thin-bedded, biotite- and muscovite-bearing sandstone. Massive sandstone contains biotite and black carbonaceous fragments and scattered conglomerate lenses. Fossiliferous concretions are common. Just south of Mojeska (fig. 1) in northeastern El Toro 7.5' quadrangle, upper part of Pleasants Sandstone Member is coarse-grained conglomeratic sandstone ($Kwps_1$)

Kwsr **Schulz Ranch Member**—Marine sandstone and conglomerate. Sandstone typically coarse-grained white-to-brownish-gray. Most is massive; less commonly crossbedded. Contains scattered matrix-supported pebbles and cobbles and sparse siltstone interbeds. Erosionally resistant; forms prominent cliffs. Locally subdivided into Schulz Ranch upper unit (Kwsru), consisting of gray-white, coarse- to fine-grained, thin bedded to massive, slightly to moderately consolidated conglomeratic sandstone that grades down section into a lower unit (Kwsrl). Lower unit consists of light olive-gray, well-bedded, well-consolidated siltstone that is underlain by, and interfingers with, poorly bedded to well-bedded to massive, silty conglomerate and very coarse-cobble fanglomerate

Kwst **Starr Member**—Fanglomerate and sandstone. Starr Member is nonmarine, pale gray, deeply weathered fanglomerate and interbedded white friable sandstone. Most clasts are deeply weathered biotite granitoids, but some are from Jurassic Bedford Canyon Formation and Cretaceous Santiago Peak Volcanics. Interfingers with Schulz Ranch Member

Kl **Ladd Formation, undifferentiated (Late Cretaceous)**—Conglomerate, sandstone, siltstone, and shale. Named by Popenoe (1942) for exposures just west of mouth of Ladd Canyon (fig. 1), northern Santa Ana Mountains. Popenoe divided formation into Baker Canyon Conglomerate Member and Holz Shale Member

Klhs **Holz Shale Member**—Interbedded marine shale, siltstone, sandstone, and localized conglomerate beds (photo 436). Sandstone beds are mostly massive, but locally crossbedded. Unit contains 5 cm to 1 m calcite cemented concretions. Foraminifera are widespread and megafossils abundant in places. Except for resistant conglomerate beds, Holz Shale weathers to form smooth rounded slopes. Unit includes prominent zone of concentrated sandstone and conglomerate beds (Klhsc)

Klbc **Baker Canyon Conglomerate Member (Late Cretaceous)**—Marine and locally nonmarine(?) conglomerate (photos 200, 201, and 203). Lower part is gray conglomerate containing clasts up to 2 m across, derived mainly from granitic and volcanic rocks. Granitic clasts appear to be from Cretaceous Peninsular Ranges batholith and volcanic clasts from Cretaceous Santiago Peak Volcanics. Upper part of conglomerate is brown conglomeratic sandstone and pebble conglomerate. Sparse sandstone beds contain abundant mollusk shells (photo 202). Conglomerate is similar to conglomerate of underlying Trabuco Formation, and locally interfingers with it. Pelecypods indicate deposition in primarily shallow-water environment

Ktr **Trabuco Formation (Late Cretaceous)**—Unfossiliferous, mainly brown to maroon, massive, nonmarine conglomerate with local sandstone and siltstone beds (Popenoe, 1941). Packard (1916) named Trabuco Formation for exposures in Harding Canyon, 4.8 km north of Trabuco Canyon in northern Santa Ana Mountains. Clasts, up to 1 m in diameter, but mostly range from 8 to 15 cm. Locally derived from Cretaceous Peninsular Ranges batholith, Cretaceous Santiago Peak Volcanics, and from meta-siltstone and sandstone of Jurassic Bedford Canyon Formation. Trabuco Formation rests unconformably on Santiago Peak Volcanics and Bedford Canyon Formation. Locally subdivided into upper unit (Ktru), consisting of reddish-brown, thoroughly weathered bouldery conglomerate, and lower unit (Ktrl) consisting of light brownish-gray fanglomerate. Clast size larger in lower unit where largest clasts are as much as 2.4 m across

Granitic rocks of the Peninsular Ranges Batholith

Klct **Tonalite of Lamb Canyon (Cretaceous)**—Massive to faintly foliated hornblende biotite tonalite. Informally named here for exposures in headward part of Lamb Canyon, just northeast of Santa Ana quadrangle (Beaumont 7.5' quadrangle). Included in Lakeview Mountain tonalite by Larsen (1948). Rock is characterized by relatively abundant sphene crystals. Weathers to form landscape of very large boulders. Emplacement age, based on uranium-lead composition of zircon is 94 Ma (W.R. Premo, written commun., 1999)

Kmeg **Granite of Mount Eden (Cretaceous)**—White to pale gray, leucocratic, medium- to coarse-grained, massive to foliated granite (photo 199). Informally named here for exposures in vicinity of Mount Eden (El Casco and Lakeview 7.5' quadrangles). Included within Perris quartz diorite by Dudley (1935) and Lakeview Mountain tonalite by Larsen (1948). Characterized by muscovite and small bright red garnets. Comprises pluton at Mount Eden and forms sills and dikes in metamorphic rocks to southeast. Dikes and sill rocks are mostly well foliated, concordant with foliation in surrounding metamorphic rocks

Kthgd **Granodiorite of Tucalota Hills (Cretaceous)**—Elongate pluton comprised of massive, light-colored biotite granodiorite. Informally named here for Tucalota Hills (fig. 1) (fig. 1) in eastern part of Bachelor Mountain 7.5' quadrangle, which are underlain by this granodiorite. Included within Woodson Mountain granodiorite by Larsen (1948)

Klt **Tonalite near mouth of Laborde Canyon (Cretaceous)**—Intensely fractured biotite hornblende tonalite. Informally named here for exposures just west of mouth of Laborde Canyon (fig. 1) in northeast corner of Lakeview 7.5' quadrangle. Fault bounded, small discontinuously and poorly exposed tonalite adjacent to Claremont fault (photo198). Fairly dark, foliated tonalite having relatively large amounts of hornblende and abundant, thin, small mesocratic inclusions

Khqd **Hypersthene quartz diorite (Cretaceous)**—Very mafic, hypersthene quartz diorite. Exposed on two small hills between Ryan Airport and State Highway 74 in Winchester 7.5' quadrangle. Dark-gray, massive, fine- to medium-grained, homogeneous appearing hypersthene-biotite quartz diorite. Distinguished by relatively high color index, small grain size, lack of inclusions, and abundant hypersthene. Intrusive into monzogranite of Tres Cerritos

Ktcg **Monzogranite of Tres Cerritos (Cretaceous)**—Medium- to coarse-grained, foliated to subgneissic, subporphyritic biotite monzogranite (photos 437 and 438). Informally named here for exposures in eastern part of Tres Cerritos (fig. 1), located in eastern part of Lakeview 7.5' quadrangle. Included within Perris quartz diorite by Dudley (1935) and within Bonsall tonalite by Larsen (1948). Pale-tan-weathering, leucocratic, containing potassium feldspar crystals up to 2.5 cm in length. Biotite comprises about 5 percent of rock in most of unit; locally as high as 10 percent. Biotite typically forms groups of small plates. In gneissic parts of unit, biotite occurs as coatings on s-surfaces. Oligoclase margins are commonly myrmekitic where plagioclase is in contact with potassium feldspar. Includes segregation bodies of aplitic- and granitoid-textured rock, and at south end of Tres Cerritos, several small masses of biotite schist

Lakeview Mountains pluton (Cretaceous)—Composite pluton composed mainly of biotite-hornblende tonalite (Lakeview and adjacent parts of Winchester and Perris 7.5' quadrangles). Named Lakeview quartz-hornblende diorite by Dudley (1935) and Lakeview Mountain tonalite by Larsen (1948). Larsen's usage of Lakeview Mountain tonalite included much of granitic and metamorphic rocks in Mount Eden area, and a variety of granitic rocks within San Jacinto Mountains and in area south of Hemet. Morton (1969) restricted usage to pluton underlying most of Lakeview Mountains and southern part of Bernasconi Hills as originally used by Dudley (1935). Uranium-lead zircon age of tonalite is 100 Ma_{id} and 98 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of hornblende is 98.6 Ma and conventional potassium-argon age of biotite is 92.4 Ma (uranium-lead age, W.R.. Premo written commun., 1999 and Ar/Ar age, L. W, Snee, written commun., 1999, potassium-argon age, F.K. Miller, written commun., 1980). Includes:

Klmp **Pegmatite dikes**—Granitic pegmatites common in central part of pluton and rare elsewhere in pluton, except for small area near southern margin. Most pegmatite dikes are steeply dipping and tabular-shaped. Dikes are compositionally and texturally zoned, having an outer wall zone of coarse- and extremely coarse-grained intergrowths of alkali feldspar, quartz, and biotite, in which graphic intergrowths of quartz and alkali feldspar are common (photo 173). Within outer wall zone, is inner core zone of extremely pegmatitic-textured alkali feldspar, quartz, muscovite, schorl, and garnet. Large pegmatite dikes have intermediate zone similar to inner zone but crystals are larger. Single tourmaline crystals in larger dikes are up to 1 m in length. Cores of larger dikes are massive quartz and giant perthite crystals (photos 124, 174, 175, and 176). Epidote and zeolite minerals are widespread minor constituents. A distinctive assemblage of uncommon minerals occurs within larger pegmatite dikes includes bismutite, beyerite, pucherite, bismuthinite, microlite, yttrocolumbite-tantalite (photo 586), cyrtolite, allanite, pyrochlore, sphalerite, chalcocite, uranophane, xenotime, and thorogummite

Klmt **Tonalite**—Gray, medium- to coarse-grained, massive to foliated, biotite hornblende tonalite lacking potassium feldspar. Most abundant rock type in Lakeview pluton. Tonalite characterized by presence of ubiquitous schlieren, and in much of body, tonalite is essentially all schlieren. Schlieren renders tonalite extremely heterogeneous at outcrop scale producing rocks that range in composition from leucocratic to melanocratic (photos 169 and 168). Schlieren range in shape from relatively tabular to wispy layers and in size from a few centimeters in width to sizes mappable at 1:24,000 (Morton, 1969; 1972; Morton and others, 1969). Mineralogic composition of tonalite without variability introduced by schlieren is, quartz 13 to 32 percent, plagioclase (andesine) 34 to 70 percent, biotite 7 to 22 percent and hornblende 4 to 29 percent (photos 439 and 440). Mafic minerals average about 25 percent of tonalite. Accessory minerals are apatite, zircon, magnetite-ilmenite, and sphene. Colorless small masses of cumingtonite form central parts of some hornblende crystals. Ellipsoidal melanocratic inclusions are common and widespread. Dark gray tonalite along southern contact of pluton, forms thin septa of foliated, porphyritic looking rock which results from stumpy, black hornblende prisms set in a fine-grained granoblastic matrix of biotite, quartz, and plagioclase. Texture is interpreted as protoclastic. Long dimension of septa parallel pluton contacts

Klml **Leucocratic rocks**—Elongate masses of white rock composed of andesine and quartz appear to be mega-scale leucocratic schlieren. These leucocratic masses texturally resemble typical Lakeview Mountains tonalite, except overall grain size is slightly reduced due to dearth of mafic minerals which are generally larger than other minerals in typical tonalitic rock. Biotite and hornblende, where present in small amounts, are extremely poikilitic. Rare muscovite occurs as small crystals interstitial to plagioclase, and may or may not be primary

Klmm **Melanocratic rocks**—Lenticular masses of melanocratic and hypermelanic rock that includes compositions ranging from about 50 percent biotite and hornblende to rock that is essentially all biotite and hornblende. Scattered throughout most of pluton, but concentrated in central and northeast part. These bodies are interpreted to be very large-scale schlieren-like masses; minerals are same as those of typical Lakeview Mountains tonalite, but slightly larger in grain size

Klmtg **Lakeview Mountains tonalite and granodiorite, undifferentiated**—Mixed tonalite of Lakeview Mountains pluton and granodiorite. Found along margin of Lakeview Mountains pluton in southern part of Bernasconi Hills (Perris 7.5' quadrangle)

Klmc **Comb-layered gabbro**—Elongate body of comb-layered gabbro occurs along southern margin of pluton (photo 441, ~~442~~) (Moore and Lockwood, 1973). Gabbro consists of folded layers of alternating labradorite-rich gabbro and hornblende or augite-rich rock. Labradorite crystals are elongate normal to layering, and mostly branch upwards to form feather-like crystals. Rocks are typically brown-to gray-weathering

Klmg **Hypersthene hornblende gabbro**—Small masses of hypersthene hornblende gabbro scattered through pluton, but slightly concentrated in central and northeastern parts. At a distance, readily discernible from tonalite, as they are darker and weather to form brown outcrops. Masses are elongate and range in length from 1 to more than 100 m

Krct **Tonalite of Reinhardt Canyon Pluton (Cretaceous)**—Biotite-hornblende tonalite containing abundant and varied inclusions (photo 177). Here informally named tonalite of Reinhardt Canyon pluton for arcuate-shaped band of exposures that define body in Reinhardt Canyon area, east side of Lakeview Mountains pluton (Lakeview 7.5' quadrangle). Pluton included in Perris quartz diorite by Dudley (1935) and in Bonsall tonalite by Larsen (1948). Tonalite is gray, medium-grained, generally well-foliated. Biotite and hornblende occur in subequal amounts, aggregating 15 to 20 percent of rock. Very sparse untwinned potassium feldspar occurs locally. Accessory minerals are zircon, magnetite-ilmenite, apatite, sphene, and secondary white mica, epidote, and chlorite. Unit characterized by moderate to abundant dark, discoidal to plate-shaped and elongate-shaped inclusions; near-vertical elongate-shaped inclusions gives rise to locally pronounced large-scale lineation (photos 178, 179, and 180). Except for southern 460 m of western boundary, pluton is gradational into Lakeview Mountains pluton; along southern 460 m of western border, two plutons are separated by a thin septum of gneissic rock. Most of eastern contact dips steeply to east or is nearly vertical; locally, contact with country rocks is hair-line sharp. Age relations between pluton and Lakeview Mountains pluton are ambiguous. Tonalite of Reinhardt Canyon pluton is distinguished from tonalite of Lakeview Mountains pluton by finer grain size, rare schlieren, and more abundant and more attenuated inclusions

Kbpg **Monzogranite of Bernasconi Pass (Cretaceous)**—Irregularly porphyritic biotite and biotite-hornblende monzogranite. Included by Larsen (1948) with rocks he referred to as "granodiorite west of Lakeview", and by Dudley (1935) with Perris quartz diorite. Informally named here for exposures in hills south of Bernasconi Pass (Perris 7.5' quadrangle). Buff- to tan-weathering, medium-grained, hypidiomorphic-granular to porphyritic, foliated biotite and biotite-hornblende monzogranite. Potassium feldspar phenocrysts up to 2.5 cm in length appear to be late forming, and in part replace parts of inclusions. Contains common to abundant, well-oriented, discoidal to plate-shaped melanocratic inclusions (photos 191, 190, and 192). In places rock is migmatitic, composed of nearly equal amounts monzogranite and inclusion-like rock (photos 193, 195, 196, and 194). Weathers to form large boulders, many of which are several meters in length (photo 189). Southern part of monzogranite contains widespread aplitic dikes. Includes:

Kbpm **Migmatitic rock within monzogranite of Bernasconi Pass**—Relatively large bodies of migmatitic rock within Kbpg consisting of about equal amounts monzogranite and mafic rocks, which resemble inclusions and have diffuse contacts (photos 193, 195, 196, and 194)

Keh **Tonalite of Elephant Hill (Cretaceous)**—Mesocratic, medium-grained biotite hornblende tonalite. Poorly exposed due to intense, deep decomposition by weathering. Contains dark, small, ellipsoidal inclusions. Limited to poor exposures extending east 1.5 km from Elephant Hill (fig. 1), west of Pomona. Exposed in road cuts on State Highway 71 east of Elephant Hill. Tonalite is similar to tonalitic granitic rocks in Peninsular Ranges batholith, and differs from tonalitic granitic rocks found in San Gabriel Mountains, chiefly by magnetic properties and initial Sr ratio

Ktbh **Tonalite of Bernasconi Hills (Cretaceous)**—Gray, medium-grained, massive to crudely foliated, hypidiomorphic-granular biotite-hornblende tonalite. Informally named here for series of small elongate tonalite plutons exposed in Bernasconi Hills (fig. 1) (Perris 7.5' quadrangle). Included within Perris quartz diorite by Dudley (1935) and within Bonsall tonalite by Larsen (1948). Biotite and hornblende occur in subequal amounts averaging several percent each. Potassium feldspar comprises up to several percent of tonalite. Oriented mafic minerals define foliation. Contains abundant, widespread fine grained mafic inclusions ranging in size from 2.5 to 30 cm. Inclusions are equant to elongate; elongation parallel to foliation in enclosing tonalite. Unit weathers to form slopes densely covered by gray, well-rounded boulders of disintegration (photo 197)

Box Springs plutonic complex (Cretaceous)—Box Springs plutonic complex is an elliptical, flat-floored, basin-shaped, composite granitic complex centered on Box Springs Mountains (fig. 1), east of Riverside (photos 181 and 182). Interpreted as lower part of granitic diapir. Complex has core of essentially massive to indistinctly layered biotite tonalite (photo 185) surrounded by zone of foliated biotite granodiorite to tonalite (photo 443). Progressively outward from biotite granodiorite to tonalite zone is a discontinuous zone of foliated, heterogeneous porphyritic granodiorite (photos 444 and 186), followed by uniform porphyritic granodiorite. Other compositionally and texturally diverse granitic rocks also occur within complex, but in smaller amounts. All rocks of complex were included in Perris quartz diorite by Dudley (1935) and in Bonsall tonalite by Larsen (1948). Units are described in general order from core outward; order does not imply relative sequence of intrusion. Includes:

Kpd **Granitic pegmatite dikes**—Most are relatively small, typically tabular granitic pegmatite dikes. Subordinate large dikes are compositionally and texturally zoned, having an outer border and wall zone of coarse- and extremely coarse-grained intergrowths of alkali feldspar, quartz, and biotite. Outer zone encloses core of alkali feldspar and quartz. In some dikes, intermediate zone consists of alkali feldspar, quartz and a variety of accessory minerals including garnet, tourmaline, columbite-tantalite, and monazite

Kbt **Biotite tonalite (Cretaceous)**—Massive, fine- to medium-grained, equigranular biotite tonalite; forms core of Box Springs plutonic complex. Much has faint to moderately prominent, very regular compositional layering. Rocks contain about 35 to 40 percent quartz and 6 to 12 percent biotite. Hornblende is absent and potassium feldspar ranges from 1 to 4 percent. Mineral alignment is poorly developed or absent, but much of rock has incipient to well developed primary layering defined by differences in mafic mineral concentrations. Unit contains sparse, equant to elliptical-shaped, fine grained, mesocratic inclusions (photo 187); some have relatively mafic rims. Inclusions tend to be aligned parallel to compositional layering. Uranium-lead zircon ages of rock are 98.6 Ma_{id} and 100.4 Ma_{ip} (W. R. Premo, written commun., 1999)

Kbfg **Biotite granodiorite and tonalite**—Light gray, medium- to coarse-grained foliated biotite granodiorite and tonalite (photo 443). Contains 25 to 35 percent quartz, 8 to 15 percent biotite, and minor hornblende. Potassium feldspar occurs as small interstitial grains and sparse subhedral phenocrysts up to 1.5 cm in diameter. Potassium feldspar appears to progressively decrease inward within unit; tonalite most abundant in inner part. Mesocratic discoidal inclusions oriented parallel to foliation are common, but not abundant. Grades into biotite tonalite unit (Kbt)

Kbfgi **Biotite granodiorite and tonalite containing abundant inclusions**—Biotite granodiorite and tonalite similar to that found in Kbfg, but containing abundant discoidal, mafic inclusions (photo ~~188~~); restricted to eastern part of complex, east of biotite granodiorite and tonalite unit (Kbfg)

Kbhg **Heterogeneous porphyritic granodiorite**—Heterogeneous porphyritic granodiorite and subordinate tonalite. In most places surrounds biotite granodiorite and tonalite unit (Kbfg). May pinch out northward beneath Quaternary and Tertiary deposits. In southern part, complex is more completely exposed and unit is absent on west side. Medium- to coarse-grained, light-gray, foliated, and porphyritic; subhedral potassium feldspar crystals are up to 2.5 cm long. Quartz ranges from 25 to 35 percent; biotite and subordinate hornblende, from 10 to 15 percent. Uneven distribution of mafic minerals imparts heterogeneous appearance that distinguishes rock from surrounding units. Discoidal mesocratic inclusions oriented parallel to foliation are widespread. Unit typically cut by numerous dikes of leucocratic granitic rock and pegmatite

$Kbhg_1$ **Layered heterogeneous porphyritic granodiorite**—Heterogeneous porphyritic granodiorite that has pronounced layering defined chiefly by variations in grain size

Kbg **Porphyritic granodiorite**—Coarse-grained, light gray, foliated, porphyritic biotite granodiorite (photos 186 and 444) and subordinate tonalite. In most places where adjacent to heterogeneous porphyritic granodiorite unit (Kbhg), contact is gradational. Groundmass is plagioclase, quartz (30 to 40 percent), and mafic minerals (5 to 10 percent). Mafic minerals are biotite and sparse hornblende, which are distinctly more evenly distributed than in heterogeneous granodiorite (Kbhg). Subhedral potassium feldspar phenocrysts are up to 2.5 cm in length. Discoidal mesocratic inclusions are oriented parallel to foliation

Kbft **Biotite-hornblende tonalite**—Light- to medium-gray, medium- to coarse-grained, foliated tonalite. Contains 20 to 25 percent quartz and about 25 percent biotite and hornblende in subequal amounts. Hornblende and biotite occur as ragged crystals. Potassium feldspar present, but sparse. Anhedral, interstitial sphene is conspicuous accessory mineral. Contains abundant, fine-grained, mesocratic, ellipsoidal- to discoidal-shaped mafic inclusions aligned parallel to foliation (photos 188 and 445)

Kbht **Heterogeneous biotite tonalite**—Light-gray, inequigranular, foliated biotite tonalite, ranging from medium to coarse grained. Restricted to northwestern Box Springs Mountains, at boundary between San Bernardino and Santa Ana quadrangles. Distinguished from other rocks in complex by leucocratic character. Contains 1 to 4 percent biotite as thin, subhedral plates, irregularly concentrated and aligned to produce wispy, swirled foliation. Leucocratic tonalite encloses pods and lenses of tonalite containing about 15 percent biotite as large ragged plates. Both types of tonalite contain abundant quartz (30 to 40 percent) and very sparse potassium feldspar (1 percent or less). Contains dispersed, mesocratic, discoidal inclusions and abundant granitic pegmatite dikes

Kbgt **Heterogeneous granodiorite and tonalite**—Light- to medium-gray, medium- to coarse-grained, texturally heterogeneous, foliated, hornblende-biotite tonalite and granodiorite. Best exposures are on Blue Mtn, 3 km northeast of Highgrove, and in La Loma Hills, northwest of Highgrove (fig. 1). Moderately abundant discoidal, mesocratic inclusions oriented parallel to foliation

Kba **Amphibolitic gabbro**—Dark-gray to black, fine- to medium-grained, foliated, hornblende-rich amphibolitic gabbro forming lenses and elongate masses within heterogeneous granodiorite and tonalite (Kgbt). Foliation is parallel to foliation in that unit

Val Verde Pluton (Cretaceous)—Large, relatively uniform pluton composed of biotite-hornblende tonalite; extends from Perris 7.5' quadrangle northward into Riverside East and Riverside West 7.5' quadrangles. Termed Perris quartz diorite by Dudley (1935), Val Verde tonalite by Osborn (1939), and included within Bonsall tonalite by Larsen (1948). Name Val Verde is adopted here based on detailed study of Osborn (1939) near Val Verde (Steele Peak 7.5' quadrangle). Name Val Verde is from former settlement and railway siding midway between Perris and Riverside (fig. 1). Apparently steep-walled Val Verde Pluton is eroded to mid-pluton level. Emplacement age of pluton is 105.7 Ma_{id}. $^{40}Ar/^{39}Ar$ age of hornblende is 100 Ma, biotite 95 Ma and potassium feldspar 88.5 Ma (uranium-lead ages, W.R.. Premo written commun., 1999; Ar ages, L. W, Snee, written commun., 1999). Includes:

Kvt **Val Verde tonalite**—Gray-weathering, relatively homogeneous, massive to well-foliated, medium- to coarse-grained, hypautomorphic-granular biotite hornblende tonalite (photos 446 and 447); is principal rock type of Val Verde Pluton. Contains about equal amounts biotite and hornblende, quartz and plagioclase. Potassium feldspar generally present, but constitutes less than two percent of rock. Where present, foliation typically strikes northwest and dips moderately to steeply northeast (photo 166). Northern part of pluton contains younger, intermittently developed, northeast-striking foliation. In central part of pluton, tonalite is mostly massive, and contains a few segregational masses of mesocratic to melanocratic tonalite. Elliptical to pancake-shaped, mesocratic to melanocratic inclusions are common (photo 167).

Kvtk **Potassium feldspar-bearing tonalite**—Thin zone of heterogeneous biotite-hornblende tonalite containing more than two percent, but less than 10 percent potassium feldspar; located along part of contact with biotite schist on west side of pluton

Kvti **Inclusion-rich tonalite**—Subequal amounts of biotite-hornblende tonalite and melanocratic inclusion-like rock. Rock has migmatitic appearance

Kgr **Granophyre (Cretaceous)**—Gray, aphanitic to very fine-grained, granophryic textured granitic rock. Composed of granophryic intergrowths of quartz and alkali feldspars. Contains some fine-grained pyrite which oxidizes to give rock rusty appearance

Green Acres gabbro Complex (Cretaceous)—Medium- to very-coarse-grained olivine-bearing gabbro that weathers gray to black. Named for community of Green Acres on southeast side of Lakeview Mountains (Morton, 1969) in northern part of Winchester 7.5' quadrangle. Included within San Marcos gabbro by Larsen (1948). Most gabbro is hypidiomorphic-granular; poikilitic rock is common and porphyritic rock less common. Weathers to form semi-smooth slopes littered with scattered small boulders. Includes rare orbicular gabbro and protoclastic flaser gabbro. Contains several small septa of quartzofeldspathic, biotite quartz-feldspar, and graphitic schist. Quartzo-feldspathic mylonite occurs locally in northern part of gabbro complex. Complex includes common granitic pegmatite dikes and some andalusite-bearing dikes. One granitic pegmatite dike in southern part of complex contains mass(es) of gabbro converted to biotite-hydrobiotite-vermiculite and contains andalusite, some of which has cores of blue corundum crystals. Some pegmatite dikes are mylonitized. Color of decomposed gabbro and soil derived from gabbro is typically dark red-brown. Includes:

Kgab **Heterogeneous mixture of olivine, pyroxene, and hornblende gabbros**—Northern part of Green Acres gabbro Complex is very heterogeneous mix of gabbro, including olivine, pyroxene, and hornblende gabbro intruded by quartz diorite and tonalite. Slopes covered with gabbro rubble generally mask presence of quartz diorite and tonalite. Some is orbicular gabbro (photo 162)

Kgao **Olivine gabbro**—Southern half of Green Acres gabbro Complex is mostly olivine gabbro, which ranges from a few percent to about one-third olivine (Fo_{75} to

Fo_{87}) (photo 163). Kelyphitic rims are common around olivine. Anorthite (an_{90}) makes up 30 to 90 percent of gabbro as anhedral to subhedral, complexly twinned crystals. Stubby, anhedral orthopyroxene in thin section is nearly colorless to very pale-pink, and pleochroic, commonly forming overgrowths of, or intergrowths with, clinopyroxene or hornblende. Augite occurs as anhedral, tabular to irregular-shaped, colorless crystals, some of which contain schiller-like intergrowths of a violet, platy, nearly opaque mineral. Augite is commonly mantled with brown and (or) green hornblende. Hornblende occurs as both brown hornblende and nearly colorless to very light green hornblende. Latter occurs primarily in reaction rims (kelyphyitic rims) intergrown with spinel around olivine; brown hornblende occurs most commonly as both interstitial crystals and as subhedral crystals. Opaque minerals, including magnetite, occur adjacent to olivine and as symplectic intergrowths with amphibole. Colorless- to light-green chlorite is abundant in some protoclastic gabbro. Planar, vein-like hornblende-spinel masses are locally common in gabbro having abundant olivine. Small hornblende gabbro dikes are mineralogically similar to that of enclosing olivine gabbro. Some dikes are fine to medium grained, mesocratic to melanocratic hornblende gabbro; others consist of porphyritic hornblende olivine gabbro

Kgah **Hornblende-rich gabbro**—Fine- to medium-grained, melanocratic hornblende gabbro. In thin section, brown prismatic hornblende imparts nematoblastic texture to this gabbro. Typically consists of 46 percent brown hornblende, 7 percent green hornblende, 9 percent clinopyroxene, 2 percent olivine, 34 percent calcic plagioclase, and 2 percent opaque minerals

Kgat **Troctolite**—Troctolite. Small elliptical intrusion of distinctive rock composed of about 45 percent anorthite (an_{90}), 36 percent olivine (Fo_{85}), 11 percent clinopyroxene, 3 percent orthopyroxene, 2 percent hornblende, 2 percent spinel, and about 5 percent iddingsite (photos 161 and 164). Kelyphitic rims mantle most olivine crystals (photos 448 and 449). Large subhedral anorthitic plagioclase crystals impart a slightly porphyritic texture to rock

Kgaa **Anorthositic gabbro**—Pale gray-weathering, leucocratic, labradorite-anorthite gabbro. Anorthosite is composed essentially of calcic plagioclase, containing small, variable amounts of olivine and (or) pyroxene

Kgam **Metagabbro**—Several small bodies of metagabbro derived from Green Acres gabbro are included within Lakeview Mountains tonalite and granodiorite (Klmtg) in southern part of Lakeview Mountains. These bodies contain abundant masses of chlorite and blue-green hornblende

Gavilan Ring Complex (Cretaceous)—Composite ring structure consisting of a variety of granitic rocks that range from monzogranite to tonalite (Steele Peak, Lake Mathews, and Elsinore 7.5' quadrangles). Informally named here for exposures in Gavilan Plateau area, Steele Peak and Lake Mathews 7.5' quadrangles. Western part of complex was termed Estelle quartz diorite and eastern part included in Perris quartz diorite by Dudley (1935). Western part of complex was termed Estelle tonalite and eastern part was included within Bonsall tonalite by Larsen (1948). Hypersthene is a characteristic mineral of many rocks in complex. Based on texture, depth of erosion is greater in eastern part of complex than in western part. Rocks on west side of complex (photo 155) commonly have hypabyssal texture and appear to grade into volcanic textured rock. Several gold mines (e.g., Good Hope, Gavilan, and Santa Rosa Mines), which constituted the Pinacate mining district (Sampson, 1935), are located within complex. Gold apparently occurred in arsenopyrite bearing quartz veins. Near-circular Arroyo del Toro pluton located in center of ring complex, but may or may not be related to ring complex. Includes:

Kgg **Hypersthene monzogranite**—Massive hypersthene monzogranite; nearly black where fresh (photos 153 and 154), dark-brown-weathering (photo 150). Contains biotite, hornblende, hypersthene, and clinopyroxene as mafic phases.

Rock has sparse small mesocratic inclusions, which are commonly lighter colored than monzogranite. Quarried as 'black granite' building stone in past (photo 153). Zircon age is 109 Ma_{id} and 106 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of biotite is 104.5 Ma and potassium feldspar 99.3 Ma (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999)

Kgt **Massive-textured tonalite**—Brown-weathering, massive, relatively heterogeneous, hypersthene-bearing biotite-hornblende tonalite. Most abundant rock type in complex. Equant-shaped mesocratic to melanocratic inclusions are common. Uranium-lead zircon age is 112.9 Ma_{id} and 113.6 Ma_{ip} (uranium-lead ages, W.R. Premo written commun., 1999)

Kgtf **Foliated tonalite**—Gray, medium-grained, foliated biotite-hornblende tonalite containing irregular-shaped to discoidal mafic inclusions (photo 151). Most of tonalite lacks hypersthene. Unit restricted to northern part of complex

Kgti **Tonalite containing abundant mesocratic inclusions**—Moderately fine-grained tonalite containing abundant, small, platy mesocratic inclusions (photo 156). Tonalite lacks hypersthene, which is common to most of complex. Uranium-lead zircon age is 108.6 Ma_{id} and 109.1 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of hornblende is 106 Ma, biotite 103 Ma and potassium feldspar 98.5 Ma (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999)

Kgh **Hypabyssal tonalite**—Massive, hypabyssal-textured tonalite and lesser granodiorite in southwestern part of complex. Contains small, equant shaped mesocratic inclusions

Kgct **Coarse-grained biotite-hornblende tonalite**—Massive to foliated, relatively light colored, coarse-grained tonalite that weathers to form very large boulders of disintegration. Grain-size distinguishes unit from other biotite-hornblende tonalite in complex

Kght **Heterogeneous tonalite**—Medium-grained, foliated biotite-hornblende tonalite, containing moderately abundant to abundant, small, biotite-hornblende granodiorite intrusions. Rock contains moderately abundant elliptical- to pancake-shaped, mesocratic to melanocratic inclusions

Kmp **Micropegmatite granite (Cretaceous)**—Named by Larsen (1948) for pink-tinted, leucocratic outcrops of granite in Corona North quadrangle. Granite is very distinctive in thin section, characterized by micropegmatitic texture

Kmpc **Micropegmatite and granodiorite of Cajalco Pluton, undifferentiated (Cretaceous)**—Mixed unit of micropegmatite and massive granodiorite to monzogranite. Related to, but not mapped as part of Cajalco Pluton

Ktd **Tonalite dikes of Mount Rubidoux (Cretaceous)**—Light gray, fine- to medium-grained, massive to foliated, hornblende-clinopyroxene-hypersthene-biotite tonalite. Contains discoidal mafic inclusions

Kmrg **Granite of Mount Rubidoux (Cretaceous)**—Massive granite characterized by coarse grain size and presence of hypersthene and fayalitic olivine (Riverside West 7.5' quadrangle) (photo 149). Termed "coarse leucogranite of Rubidoux Mountain" by Larsen (1948). Inequigranular; average grain size 5 mm; Potassium feldspar crystals are up to 12 mm in length. Biotite and hornblende aggregate about 5 percent, and hypersthene and olivine occur as sparse constituents. Most of granite is devoid of inclusions. Uranium-lead zircon ages are 109 Ma_{id} and 107.3 Ma_{ip}, and $^{40}Ar/^{39}Ar$ age of biotite is 98 Ma and potassium feldspar 93 Ma (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999)

Krg **Granite of Riverside area (Cretaceous)**—Medium- to coarse-grained, massive- to faintly-foliated, leucocratic biotite granite (Riverside East and West 7.5' quadrangles). Typically contains about 1 to 3 percent biotite. Inclusions are sparse or absent except locally in western part of body where granite contains 2 to 8 percent biotite and sparse to abundant inclusions of quartz diorite, granodiorite, and fine-grained mafic rock. At Mount Rubidoux, rocks contain sparse hypersthene and fayalitic olivine and moderately abundant equant inclusions of dark-gray fine-grained rock. Rock at Mount Rubidoux termed "fine leucogranite of Rubidoux Mountain" by Larsen (1948). Distinguished from granite of Mount Rubidoux (Kmrg) mainly by grain size

Kmhg **Mount Hole Granodiorite (Cretaceous)**—Massive, light colored hornblende-biotite granodiorite. Named by Larsen (1948) for exposures at Mount Hole (fig. 1), Corona North 7.5' quadrangle. Weathers to form large boulders of disintegration

Klst **La Sierra Tonalite (Cretaceous)**—Moderately dark-colored, massive biotite tonalite. Named by Larsen (1948) for exposures in vicinity of La Sierra (Corona North 7.5' quadrangle). Much of tonalite is altered to secondary minerals, especially epidote and chlorite. Includes some zones of tonalite thoroughly altered to epidote, quartz, and chlorite and locally tourmaline and sulfide minerals

Katg **Granodiorite of Arroyo del Toro Pluton (Cretaceous)**—Light gray, medium-grained, massive, very homogeneous, and inclusion-free hornblende-biotite granodiorite (photos 157, 158, 450, and 451) (Steele Peak and Elsinore 7.5' quadrangles). Some of rock in western part of pluton is slightly porphyritic; typical rocks are even grained. Informally named here for Arroyo del Toro, located in center part of pluton. Termed Steele Valley granodiorite by Dudley (1935) and included by Larsen (1948) within Woodson Mountain granodiorite. Near circular Arroyo del Toro pluton is located in center of Gavilan ring complex, but may or may not part of ring complex. Uranium-lead zircon ages of pluton are 108.6 Ma_{id} and 111 Ma_{ip}. $^{40}Ar/^{39}Ar$ biotite age is 104.3 Ma and potassium feldspar 98.5 Ma (uranium-lead ages, W.R. Premo written commun., 1999 and potassium-argonr ages, L.W, Snee, written commun., 1999)

Cajalco Pluton (Cretaceous)—Mostly biotite and biotite-hornblende monzogranite and granodiorite (Lake Mathews and Corona North 7.5' quadrangles). Informally named here for exposures in Cajalco Canyon area (fig. 1), Lake Mathews 7.5' quadrangle. Rocks of Cajalco Pluton were included within Cajalco quartz monzonite by Dudley (1935) and within Woodson Mountain granodiorite by Larsen (1948). Body is a shallow-level pluton emplaced by magmatic stoping into largely volcanic and volcanoclastic rocks. It is tilted eastward and eroded to progressively greater depths from west to east. Upper part of pluton contains a very prominent halo of tourmalinzed rock. Uranium-lead zircon ages are 109.5 Ma_{id} and 112.6 Ma_{ip}. (uranium-lead ages, W.R. Premo written commun., 1999). Includes:

Kcto **Tourmalinized monzogranite and granodiorite**—Monzogranite and granodiorite variably replaced by tourmaline. Also includes some tourmalized volcanic rock in western part of pluton. Tourmaline is extremely fine-grained to aphanitic. Tourmalinized rock ranges from incipient fracture-replacing-tourmaline, through tourmalized mafic minerals, to completely tourmalized coal-black rock-bodies over one hundred meters in length. Northeast striking joints are preferential sites for most extensively tourmalinized rock. Tourmaline sequentially replaces biotite and hornblende followed in order by feldspar and quartz. All variations in degree of replacement are found. Where only quartz remains as primary mineral, tourmalinized rock is distinctive, white-dappled, black rock resembling porphyry (photo 147). Only rock that is essentially all tourmaline, is mapped as Kcto. Tourmalinized rock is very resistant to erosion and stands out as small, bold, black hills, locally termed tourmaline blow-outs. Cobbles of tourmaline rock are locally abundant in Miocene Lake Mathews Formation. Very locally pink, radiating, fibrous to prismatic masses of dumortierite occur rather than tourmaline. One dumortierite-bearing 'dike' located in Temescal Canyon contains large sprays of radiating prismatic dumortierite. Tourmalinized rock contains small amounts of iron sulfide(s) and very locally cassiterite (photo 148). Tin was discovered about 1853 in a large mass of tourmalinized rock in Eagle Valley area (fig. 1), Lake Mathews 7.5' quadrangle. Cassiterite-bearing rock was intermittently mined from 1860 to about 1892 (Sampson, 1935). Over 250,000 pounds of tin was smelted in 1891-1892.

Kcg **Monzogranite**—Most of western part of pluton is medium-grained, equigranular, hypautomorphic-granular to subporphyritic monzogranite and subordinate granodiorite. Includes variable amounts of angular inclusions, mostly, if not entirely derived from stoping of Estelle Mountain volcanics of Herzig (1991). Number, size, and reliability of idenity of inclusion parent rock increases from east to west. In western part of pluton included masses of volcanic rock comprise large volume of pluton. In northern and northeastern part of pluton stoped masses of hornblende gabbro are abundant. Unit includes relatively fine-grained leucogranite, especially in area northwest of Lake Mathews

Kcgd **Granodiorite**—Most of eastern part of pluton is medium grained, equigranular, hypautomorphic granular granodiorite and subordinate monzogranite. Granodiorite includes variable amounts of angular inclusions

Kct **Tonalite—**Masses of mafic biotite-hornblende tonalite. Represents deepest part of pluton

Kcgq **Granodiorite and quartz latite, undifferentiated**—Nearly equal amounts of plutonic and volcanic rock; in some areas, unit is mostly quartz latite. Found near intrusive contacts with Mesozoic volcanic rocks

Kcgb **Granodiorite and gabbro, undifferentiated**—Mixed granodiorite and gabbro. In northern and northeastern part of pluton granitic rock contains high concentrations of stoped hornblende gabbro. In some areas granite and gabbro are intimately intermixed producing very heterogeneous rock

Kgbd **Gabbroic dikes, Domenigoni Valley area (Cretaceous)**—Relatively fine-grained, massive, black, hornblende gabbro occurs as thin (few meters thick) dikes in Domenigoni valley area (Romoland and Winchester 7.5' quadrangles). Dikes cut both granodiorite of Domenigoni Valley Pluton and adjacent metamorphic rocks. Shown only as lines on geologic map

Domenigoni Valley Pluton (Cretaceous)—Massive, isotropic, gray, medium-grained, biotite-hornblende granodiorite and tonalite (photos 133, 134, 135, and 137) (Winchester and Romoland 7.5' quadrangles). Larsen (1948) used name Domenigoni granodiorite for exposures in Domenigoni Valley area, but included western part of pluton in his Bonsall tonalite unit. Erosion exposes only upper part of pluton. Pluton consists of two parts separated by kilometers-wide pendant of metasedimentary rock and gabbro. Foliated rock found only in southeastern part of pluton. Unit contains moderately abundant to abundant, equant-shaped, mesocratic inclusions, which are sparse or lacking around margins of pluton. Two relatively consistent, steeply dipping, joint sets are present throughout pluton; one strikes northeast, other northwest. Dacite-quartz latite dike swarm was emplaced along northwest striking joint set. Contacts between pluton and older rocks are knife-edge sharp (photo 138). Grain size of granodiorite-tonalite is unchanged at contact. At most places there are little change in mineralogy or fabric of host rocks, except local deflection of schistosity within a few meters of contact. In some places in northeastern part of pluton, schistosity is deflected 60 to 90 m from contact. Southeastern part of pluton, however, coincides with westward deflection of metamorphic foliation to parallel contact of pluton. Apophysis of pluton is well exposed in highway cut on US 215 at Sun City. Rock there contains abundant inclusions of contact metamorphosed impure quartzite, lithic graywacke, and phyllite. Siliceous carbonate bearing inclusions consist of pyroxene hornfels mineral assemblages including wollastonite, diopside, and grossularite (photo 452). East of Quail Valley (fig. 1), small apophyses of granodiorite occur in thoroughly fragmented quartz-rich metasedimentary rock that is pervasively penetrated by smaller irregular masses of granodiorite. Includes:

Kld **Quartz latite dikes**—Light- to dark-gray, fine-grained, massive- to well-foliated and lineated, biotite, biotite-hornblende, and hornblende quartz latite. Some dike rock contains small needle-like hornblende crystals. Swarm of quartz latite dikes occur in eastern part of Domenigoni Valley Pluton. A few dikes extend into metasedimentary country rock and some occur entirely within metasedimentary rocks. Dikes are more resistant to erosion than enclosing rock and form conspicuous ribs and walls (photo 139). Included as part of Domenigoni Valley Pluton, because they are largely restricted to pluton. Most are foliated in contrast to massive granodiorite. Streaks of biotite, and less commonly oriented hornblende crystals, give rise to pronounced and regular lineation (photo 140)

Kdvg **Granodiorite and tonalite of Domenigoni Valley**—Relatively uniform, massive hornblende-biotite granodiorite grading into tonalite. This is principal rock type of Domenigoni Valley Pluton. Contains some mafic rich rocks in southern part of pluton. Common accessory minerals are zircon, sphene, apatite, and magnetite-ilmenite. Minute rutile crystals impart bluish opalescence to quartz. Small masses of epidote and/or tourmaline rock occur locally and appear to replace granodiorite to tonalite. Contains moderately abundant to abundant equant mafic inclusions. Uranium-lead zircon age is 117.8 Ma_{id} and 112.8 Ma_{ip} and $^{40}Ar/^{39}Ar$ age of 104 Ma for biotite and 95.5 Ma for potassium feldspar (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999)

Kgbf **Fine grained hornblende gabbro, Railroad Canyon area (Cretaceous)**—Fine-grained hornblende gabbro constituting dikes, sills, and small elongate plutons. Emplaced in phyllite in Railroad Canyon area (fig. 1) (Elsinore 7.5’ quadrangle)

Paloma Valley Ring Complex (Cretaceous)—Composite ring dike intrusion. Named and described by Morton and Baird (1976) for exposures in Paloma Valley area. Complex is located in Murrieta, Romoland and Elsinore 7.5’ quadrangles. Included within Woodson Mountain granodiorite and San Marcos gabbro by Larsen (1948). Ring complex consists of older, elliptical in plan, single ring-dike and two subsidiary short-arced dikes. A younger ring-set of thin dikes is largely within older ring dike. Older dike consists of granodiorite and monzogranite with vertical walls emplaced into gabbro by ring fracturing and magmatic stoping of gabbro. Younger ring-dike consists of hundreds of granitic pegmatite dikes. Most pegmatite dikes are 30 cm to over 1 m in thickness, and define a domal ring-dike geometry in which outer dikes are moderately to steeply outward dipping and pass inward to near horizontal dikes in center. Spatially associated with younger dikes in center of complex, are bodies of granophyre that contain stringers of granitic pegmatite. Younger dikes are interpreted as products of volatile-rich magma that filled a domal set of fractures resulting from cauldron subsidence. Granophyre is interpreted as a product of pressure quenching of pegmatite magma and attendant loss of volatiles. Uranium-lead zircon ages of rock from atypical hornblende-bearing granodiorite from western part of older dike is 121 Ma_{id} and 118.5 Ma_{ip}. $^{40}Ar/^{39}Ar$ age of hornblende 117.7 Ma and biotite 118.8 Ma. (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999) Includes:

Kpvgr **Granophyre**—Pale gray, very fine grained, porphyritic, granophyre (photos 453 and 454). Phenocrysts of altered plagioclase are in groundmass of granophyric intergrowths of quartz within potassium feldspar and sodic plagioclase. Pyrite is ubiquitous accessory mineral, and where oxidized, discolors outcrops reddish-brown (photo 132). Network of pegmatitic-textured stringers averaging 2.5 cm thick cuts much of granophyre. Stringers are compositionally and texturally zoned, having fine-grained margins and coarse-grained interiors

Kpvp **Pegmatite dikes**—Linear to arcuate, leucocratic pegmatite dikes typically 30 cm to 1 m thick (photo 126). Most are texturally and compositionally zoned. Outer zones are coarse-grained granite composed of quartz perthite, and sodic plagioclase, and may or may not contain biotite and minor magnetite. Inner zone consists of pegmatitic-textured perthite, sodic plagioclase, quartz, biotite, and (or) muscovite, and accessory magnetite, schorl, garnet, and epidote. Quartz-crystal-lined vugs found locally. Graphic intergrowths of quartz and perthite are common in rock transitional between coarse-grained granite and pegmatitic textured granite. Dikes that lack pegmatitic cores consist entirely of coarse to extremely coarse grained granitoid textured rock, with or without graphic intergrowths

Kpvg **Monzogranite to granodiorite**—Pale gray, massive, medium-grained hypidiomorphic-granular biotite monzogranite (photo 128), and less abundant hornblende-biotite granodiorite forming older ring dike. Plagioclase is an$_{20}$ to an$_{35}$, subhedral, tabular crystals. Contains inclusions of small to large stoped blocks of gabbro (photos 130 and ~~128~~)

Kpvt **Tonalite**—Foliated biotite-hornblende tonalite. In eastern part of complex grades into granodiorite

Kpvgb **Granodiorite and gabbro, undifferentiated**—Granodiorite of Paloma Valley ring complex containing abundant masses of stoped hornblende gabbro

Ksmg **Monzogranite of Squaw Mountain (Cretaceous)**—Informally named here for exposures of monzogranite at Squaw Mountain (Wildomar 7.5' quadrangle). Consists of massive, fairly homogeneous, moderately leucocratic, coarse-grained, biotite monzogranite (photo 456). Weathers to form large boulders of disintegration (photo 455). Uranium-lead zircon age is 120 Ma$_{id}$ and 123 Ma$_{ip}$. ^{40}Ar/^{39}Ar age of hornblende is 111 Ma, biotite 111 Ma, and potassium feldspar 103 Ma (uranium-lead ages, W.R. Premo written commun., 1999; potassium-argon ages, L.W. Snee, written commun., 1999)

Kts **Tonalite of Slaughterhouse Canyon (Cretaceous)**—Informally named here for exposures of tonalite along Slaughterhouse Canyon, Wildomar 7.5' quadrangle (photo 457). Relatively fine-grained dark gray, massive biotite-hornblende tonalite (photo 458). Contains small equant-shaped mafic inclusions. Sample of tonalite from near head of Slaughterhouse Canyon gave uranium-lead zircon ages of 122 Ma$_{id}$ and 125 Ma$_{ip}$. ^{40}Ar/^{39}Ar age of hornblende is 120 Ma, biotite 111 Ma, and potassium feldspar 103 Ma. (uranium-lead ages, W.R. Premo written commun., 1999; Ar ages, L.W. Snee, written commun., 1999)

Generic Cretaceous granitic rocks of the Peninsular Ranges Batholith

Kp **Granitic Pegmatite dikes (Cretaceous)**—Leucocratic, mostly tabular, pegmatite-textured granitic dikes. Most dikes range in thickness from a few centimeters to over a meter. Larger dikes are typically zoned compositionally and texturally, having a border and wall zone consisting of coarse-grained biotite, quartz, and alkali feldspars. Intermediate zone consists of large to giant crystals of quartz and alkali feldspars, and commonly contain muscovite, schorl, and garnet. Core zone consists of quartz and alkali feldspars. Line-rock layering is rare. Pegmatite dikes within gabbro and metadunite may contain andalusite, sillimanite, cordierite, and dumortierite. Where gabbro has been incorporated into pegmatite it is converted to vermiculite-hydrobiotite containing crystals of andalusite, some of which have cores of corundum

Kg **Granitic dikes (Cretaceous)**—Includes texturally diverse group of leucocratic granitic dikes composed mainly of quartz and alkali feldspars. Dikes range in thickness from few centimeters to over a meter and are up to several hundred meters in length (photo 459). Most are tabular; some are texturally and compositionally unzoned, irregular-shaped bodies. Some dike rocks have foliated or gneissoid fabrics. Textures are mostly coarse grained and equigranular, granitic, but range from aplitic to pegmatitic. Common characterizing and accessory minerals include biotite, muscovite, and garnet

Kgu **Granite, undifferentiated (Cretaceous)**—Leucocratic fine-to coarse-grained massive granite and biotite monzogranite. Most is equigranular and consists of quartz and alkali feldspars. In leucocratic granite, biotite is a widespread varietal mineral. Muscovite-bearing granite occurs at Bell Mountain, Romoland 7.5' quadrangle

Kmgt **Monzogranite and tonalite, undifferentiated (Cretaceous)**—Undifferentiated biotite monzogranite and biotite-hornblende tonalite. Restricted to single occurrence in eastern part of Box Springs Mountains (fig. 1) (Sunnymead 7.5' quadrangle)

Kgd **Granodiorite, undifferentiated (Cretaceous)**—Biotite and hornblende-biotite granodiorite, undifferentiated. Most is massive and medium grained. North of Skinner Lake (fig. 1), well lineated, poorly foliated biotite granodiorite intrudes impure quartzite of the rocks of Menifee Valley (T̄Rmu); the quartzite has been tectonically deformed to produce well oriented (essentially vertical) rod-shaped inclusions in the granodiorite (photo 460).

Kgbh **Biotite-hornblende granodiorite (Cretaceous)**—Medium grained, mostly massive-textured biotite-hornblende granodiorite. Restricted to small areas in Jurupa Mountains

Kt **Tonalite, undifferentiated (Cretaceous)**—Gray, medium-grained biotite-hornblende tonalite, typically foliated (photos 461 and ~~459~~)

Ktm **Tonalite and mafic rocks, undifferentiated (Cretaceous)**—Subequal amounts of foliated, gray, medium-grained biotite-hornblende tonalite and mesocratic to melanocratic inclusion-like rock, which gives rise to migmatitic appearing rock

Kqd **Quartz diorite, undifferentiated (Cretaceous)**—Medium- to coarse-grained biotite-hornblende quartz diorite. Most is slightly to well foliated with discoidal to pancake-shaped melanocratic inclusions in foliation plane. Grades into diorite and biotite-hornblende tonalite

Kdqd **Diorite and quartz diorite, undifferentiated (Cretaceous)**—Dark gray, medium- to coarse-grained mixtures of hornblende diorite and biotite and biotite-hornblende quartz diorite

Kd **Diorite, undifferentiated (Cretaceous)**—Mostly fine- to medium-grained, massive, dark gray to black hornblende diorite

Kht **Heterogeneous tonalitic rocks (Cretaceous)**—Tonalite. Heterogeneous with respect to texture and composition. Restricted to Jurupa Mountains in southern San Bernardino quadrangle

Kgdt **Granodiorite and tonalite, undifferentiated (Cretaceous)**—Dominantly tonalite but ranging to granodiorite. Heterogeneous with respect to texture and composition. Restricted to Jurupa Mountains (fig. 1) in southern San Bernardino quadrangle

Kgb **Gabbro, undifferentiated (Cretaceous)**—Mainly hornblende gabbro. Includes Virginia quartz-norite and gabbro of Dudley (1935), and San Marcos gabbro of Larsen (1948). Typically brown-weathering, medium-to very coarse-grained hornblende gabbro (photo 127); very large poikilitic hornblende crystals are common, and very locally gabbro is pegmatitic. Much is quite heterogeneous in composition and texture. Includes noritic and dioritic composition rocks

Khg **Heterogeneous granitic rocks (Cretaceous)**—A wide variety of heterogeneous granitic rocks occur in Santa Ana quadrangle. Some heterogeneous assemblages include large proportions of schist and gneiss (photo 463). Rocks in Santa Ana Mountains include a mixture of monzogranite, granodiorite, tonalite, and gabbro. There, tonalitic composition rocks are most abundant rock type. Tonalite from Hot Springs Canyon (fig. 1), Cañada Gobernadora 7.5' quadrangle gave uranium-lead zircon age of 119.2 Ma_{id} and 116.5 Ma_{ip}. (W.R. Premo, written commun., 1999). Heterogeneous granitic rocks adjacent to, east, and south of Lakeview Mountains and Reinhardt Canyon pluton contain large amount of metamorphic rock (photo 464). Adjacent to the southern part of the Lakeview Mountains pluton biotite-hornblende tonalite is structurally complex. Zones of crudely foliated tonalite containing ellipsoidal mafic inclusions (2nd generation inclusions) are interleaved with more intensely foliated tonalite containing thiner mafic inclusions (3rd generation). Some outcrops contain inclusions partly transposed from 2nd to 3rd generation inclusions (photos 464, 465, and ~~466~~). Except for southern part, granitic component consists of potassium feldspar-bearing tonalite and granodiorite. Unit is submerged (Khgs) in Perris Reservoir

End granitic rocks of the Peninsular Ranges Batholith

Ks **Serpentinite (Cretaceous)**—Small body of highly deformed, slickensided, greenish-brown serpentine within Santiago Peak Volcanics (Corona South 7.5' quadrangle)

Kc **Carbonate-silicate rock (Cretaceous)**—Small body of reddish-brown carbonate-silicate rock spatially associated with serpentinite (Ks)

Kvsp **Santiago Peak Volcanics (Cretaceous)**—Basaltic andesite, andesite, dacite, rhyolite, volcaniclastic breccia, welded tuff, and epiclastic rocks (Herzig, 1991); widespread in northern Santa Ana Mountains. Originally named Black Mountain volcanics by Hanna (1926), but name was pre-empted. Larsen (1948) renamed unit Santiago Peak Volcanics for exposures in vicinity of Santiago Peak (photo 118), northern Santa Ana Mountains. Rocks are very heterogeneous, discontinuous, and poorly exposed. Most of unit is hydrothermally altered; alteration was contemporaneous with volcanism. Zircon ages of Santiago Peak Volcanics range from 123 to 134 Ma (Anderson, 1991), making it coeval with older part of Peninsular Ranges batholith

Kvspi **Intrusive rocks associated with Santiago Peak Volcanics (Cretaceous)**—Shallow porphyritic intrusive rocks principally of intermediate composition. Composed of plagioclase, clinopyroxene and altered orthopyroxene. Silicic porphyries composed of plagioclase, quartz, and altered pyroxene and biotite (Herzig, 1991)

Kvem **Estelle Mountain volcanics of Herzig (1991) (Cretaceous)**—Heterogeneous mixture of rhyolite flows, shallow intrusive rocks, and volcaniclastic rocks (photo 467) (Corona South, Lake Mathews, Alberhill, and Elsinore 7.5' quadrangles); andesite is rare. Informally named by Herzig (1991) for exposures in vicinity of Estelle Mountain, Lake Mathews 7.5' quadrangle. These rocks were termed Temescal dacite-porphyry by Dudley (1935) and Temescal Wash quartz latite porphyry by Larsen (1948). Zircon age of rock from unit collected west of Lake Mathews, Lake Mathews 7.5' quadrangle, is 125.8 Ma (Anderson, 1991)

Kvr **Rhyolite of Estelle Mountains volcanics of Herzig (1991) (Cretaceous)**—Rhyolite; relatively uniform and homogeneous

Ksv **Intermixed Estelle Mountain volcanics of Herzig (1991) and Cretaceous(?) sedimentary rocks (Cretaceous?)**—Complexly intermixed volcanic and sedimentary rocks (photos 121 and 123), which appear to be coeval; sedimentary rocks predominate

Kvs **Intermixed Estelle Mountain volcanics of Herzig (1991) and Mesozoic sedimentary rocks (Mesozoic)**—Complexly intermixed volcanic and sedimentary rocks; volcanic rocks predominate. West of Lake Mathews much of sedimentary rock predates volcanic rocks. In Elsinore 7.5' quadrangle, much of sedimentary rock appears coeval with volcanics

Jbc **Bedford Canyon Formation, undifferentiated (Jurassic)**—Slightly metamorphosed assemblage of interlayered argillite, slate, phyllite (photos 468 and 469), graywacke (photos 470 and 471), impure quartzite, and small masses of limestone. As used here, Bedford Canyon Formation is areally limited to northern part of Santa Ana Mountains. Most of unit is poorly exposed, best exposures restricted to road cuts. Bedding and primary sedimentary structures are commonly preserved (photos 472 and 473), although tightly folded bedding is common. Fissile, black argillite and slate are very fine-grained and consist of beds 2 to 8 cm in thickness. Massive bedded, impure, fine- to medium-grained, pale-gray to pale-brown quartzite and graywacke beds are 4 to 30 cm thick. Locally carbonaceous. Lenses of conglomerate (photos 474 and 475) occur sparsely through sequence. Incipiently developed transposed layering, S_1, is locally well-developed. Includes:

Jbc_1 **Bedford Canyon Formation, Unit 1**—Southern part of unit consists of brown-weathering, massive-appearing quartz-rich metasandstone and impure quartztite (photo 476). Locally has thin-layered fine grained sandy intervals and discontinuous small folds (6 to 8 cm). Locally contains abundant fine-grained dissiminated pyrite

Jbcm **Marble and limestone**—Small elongate to equant-shaped bodies of gray weathering, fine-grained marble and limestone, some fossiliferous. Ammonites occur at a few places (Imlay, 1963, 1964, and 1980; Silberling and others, 1961), and rhynchonelloid brachiopod debris is locally abundant (Gray, 1961)

Ŧmu **Rocks of Menifee Valley, undifferentiated (Triassic)**—Wide variety of low-to high-metamorphic grade metamorphic rocks (photo 460). Most places unit contains biotite schist; some low-grade rocks have primary sedimentary structures (~~photos 477 and 478~~). Includes:

Ŧmg **Graywacke**—Predominately lithic graywacke (Romoland and Winchester 7.5' quadrangles). Thick layered, massive, commonly contains angular fragments of phyllite (chips) and discontinuous layers of phyllite in low metamorphic grade rocks (photos 479 and 480). Is biotite schist in higher grade rocks

Ŧmq **Quartz-rich rocks**—Quartzite and quartz-rich metasandstone; locally conglomeratic (Elsinore and Romoland 7.5' quadrangles)

Ŧmqg **Intermixed quartzite and graywacke**—Intermixed quartzite and lithic metagraywacke (Romoland and Winchester 7.5' quadrangles); quartzite may or may not be feldspathic

Ŧmgp **Intermixed graywacke and phyllite**—Intermixed lithic metagraywacke and phyllite. Other metasedimentary rocks may be present in small amounts

Ŧmp **Phyllite**—Fissle black phyllite (photos 481 and 482). Forms thick sections in Romoland and Elsinore 7.5' quadrangles, but metamorphism and complex faulting and folding preclude estimate of stratigraphic thickness. Commonly has sheen produced by very fine-grained white mica on s-surface; locally contains small elongate prisms of fine-grained white mica, which maybe pseudomorphs after chiastolite

Ŧms **Schist**—Biotite schist, in part gradational with phyllite (Winchester and Bachelor Mountains 7.5' quadrangles). In lower metamorphic-grade rocks, consists of andalusite-biotite schist. In higher metamorphic-grade rocks, includes cordierite biotite schist (photos 483, 484, 485, and 486), and in highest metamorphic-grade rocks sillimanite schist (photos 487, 488, 489, 490, and 493), and less commonly garnet bearing schist. Some high grade rocks have rotated texture (photos 491 and 492)

Ŧmm **Marble**—Pod-like masses and elongate layers of marble and calc-silicate rocks. Occurrences in low metamorphic-grade rocks (e.g., phyllite association) are relatively fine grained, off-white to gray marble. Commonly contains masses of radiating blades of white tremolite. Small mass of fine-grained dark gray to black marble and calc-silicate rock in hills east of Sun City contains deformed and poorly preserved pelycepods and crinoids

Ŧmi **Interlayered phyllite (or schist) and quartzite**—Western part of unit is low metamorphic-grade, interlayered, relatively pure quartzite and phyllite. Eastern part of unit is higher metamorphic-grade quartzite and biotite schist. In western low metamorphic-grade part of unit, some quartzite layers in hinges of slip folds are 8 to 24 cm thick, and may be relic beds (S_0) preserved in hinges. In this area, however, there are also transposed quartzite layers (S_1) in limbs of folds that are 5 to 7 cm thick (photo 101). In areas of intermediate metamorphic-grade, quartzite layers are retransposed (S_2) and further attenuated to thicknesses of 1 to 2.5 cm. In easternmost part of unit they are transposed again (S_3) to thicknesses of about 6 mm. (Romoland and Winchester 7.5' quadrangles)

TRmn **Manganese-bearing rocks**—Layers of black manganese-bearing quartz-rich metasediments. Consists of manganese oxides-hydroxides and rhodonite in quartzite. Sparse but widespread occurrences in Railroad Canyon area (fig. 1) (Elsinore and Winchester 7.5' quadrangles). Unit has been prospected as source of manganese (Sampson, 1935)

TRma **Amphibolite**—Black elongate-shaped masses of plagioclase-hornblende rock, mainly within TRmgn (photo 109). Locally contains garnet in vugs

TRmsgn **Mixed low metamorphic grade and upper amphibolite grade rocks**—Tectonically intermixed schist, graywacke, and impure quartzite; that includes parts of units TRms, TRmg, TRmq, and TRmgn (Winchester 7.5' quadrangle). Also includes all known occurrances of metaserpentine-metadunite and related rocks (TRmds, TRmdx, and TRmdc). ***Note***: In Version 1.0 of the Geologic Map of the Santa Ana 30' x 60' quadrangle (Morton, 1999), this unit (TRmsgn) was included in unit Mzs. Based on reexamimation, eastern part of TRms is now interpreted as a broad suture zone consisting of a mixture of rock units from both sides of suture and includes metaserpentinite and related rocks that appear to be unique to this mixed unit. Included are:

TRmds **Metadunite and serpentinite**—Assemblage of largely serpentinized metadunite and related metamorphic rocks. Forms several large masses on ridge between Diamond Valley and San Jacinto Valley, locally known as Searls Ridge (fig. 1). Least altered metadunite is composed essentially of olivine and talc (photo 96). At and near outer margins of some metadunite is a layer consisting of essentially enstatite, and in some places an outer thin (few centimeters) zone of spinel-rich rock. Surrounding metadunite is selvage 0.5 to 6 m thick of massive rock containing large proportion of 2- to 5-cm-long poikiloblastic cordierite in sillimanite-biotite rock. Cordierite apparently formed from magnesium in dunite during metamorphism. Granitic pegmatite dikes intruding metadunite have outer parts containing andalusite, sillimanite (photos 494 and 495), dumortierite, and cordierite. Metadunite adjacent to pegmatite is altered to an inner layer of hydrobiotite and vermiculite; and an outer layer of chlorite and amphibole. Thoroughly serpentized metadunite (TRmsm) contains veinlets of magnesite, which was formerly mined (photo 97)

TRmdx **Amphibole- and pyroxene-bearing rocks associated with metadunite and serpentinite**—Includes wide variety of amphibole and pyroxene bearing rocks spatially associated with dunite. Ranges from white to green to black amphibolite and pyroxenite and pink anthophylite rock. Includes some carbonate rock and metasomatized schist. Isolated small exposures of these rocks are found north and south of metadunite and serpentinite (TRmds) occurrence at Double Butte (fig. 1) and in vicinity of Rawson Valley, respectively

TRmdc **Marble associated with metadunite**—Coarse-grained impure marble adjacent to metadunite (photo 100). Marble consists of calcite and variable amounts of olivine, pyroxene, amphibole, spinel, and opaque minerals. Some silicate minerals are concentrated in layers. Marble apparently is metamorphosed silica-carbonate rock associated with serpentinite

TRmgn **Biotite gneiss and schist**—Medium-to dark-gray, coarse-grained biotite gneiss and schist, and biotite-quartz-feldspar gneiss and schist, Winchester 7.5' quadrangle. Locally contains sillimanite and cordierite. Commonly includes minor amounts of quartzite and calc-silicate hornfels (photo 112). Anatectic stringers of granitic material are common. Note: This unit was referred to as Paleozoic? in Version 1.0 of the Geologic Map of the Santa Ana 30' x 60' quadrangle (Morton, 1999); subsequent isotopic study of zircons found relic zircons of Mesozoic age (Premo and others, 2002)

KgMz **Intermixed Mesozoic schist and Cretaceous granitic rocks (Mesozoic)**—Wide variety of Mesozoic schist and related metamorphic rocks mixed with granitic rocks ranging in composition from monzogranite to quartz diorite. Most granitic rocks are tonalite composition

KgPz **Intermixed Paleozoic(?) schist and Cretaceous granitic rocks (Cretaceous and Paleozoic?)**—Varied Paleozoic(?) quartzo-feldspathic biotite schist and gneiss intermixed with granitic rocks. Schist is fine to coarse grained, and ranges from moderately to highly biotite rich. Locally sillimanite-bearing. Most granitic rocks are biotite-hornblende tonalite; generally intruded parallel to schistosity. Includes some marble. Marble ranges from coarse to very coarse grained, and is mostly calcite. Color most commonly white or pale gray, but locally pale blue. Restricted to southern Jurupa Mountains northwest of Riverside

Pzu **Paleozoic(?) rocks, undifferentiated (Paleozoic?)**—Includes wide variety of metamorphic rocks; most derived from sedimentary protolith (El Casco, Lakeview, Riverside East, and Riverside West 7.5 quadrangles). Mainly intercalated biotite schist and quartzite, gneiss, and lesser amounts of hornblende gneiss, marble and associated skarn and calc-silicate rock. Sillimanite is common in biotite schist and garnet less common. Marble layers (m) within Pzu include coarse- and very- coarse grained white and gray marble occurring as pods and layers within biotite schist and gneiss. Most marble is in contact with, or is near, granitic rocks; pyroxene hornfels metamorphic mineral assemblages are common. Marble contains small amounts of diopside, forsterite, wollastonite, spinel, and graphite. Mineralogy of spatially associated skarns includes wollastonite, idocrase and garnet. Some rocks mapped as Pzu may be included with Pzsgp and Pzmp elswhere

Pzsgp **Biotite schist and gneiss (Paleozoic)**—Well foliated schist and gneiss occurring both as screens and isolated bodies in granitic rocks, and as bodies interlayered with marble (photo 74). Composition of schist and gneiss is variable, but most is biotite-bearing

Pzsg **Biotite Schist, Laborde Canyon area (Paleozoic?)**—Medium-to dark-gray, fine-grained biotite schist and biotite-quartz-feldspar schist. Locally contains sillimanite and cordierite. Commonly includes minor amounts of quartzite and calc-silicate hornfels. Restricted to east side of San Jacinto Fault in Laborde Canyon area

Pzq **Impure quartzite (Paleozoic?)**—Light-gray to light-greenish-gray, fine-to medium-grained, layered to massive, impure quartzite. Locally consists of intensely slip-folded quartzite interlayered with wollastonite rock (photo 86). Weathers reddish-brown or orangish-brown

Pzmp **Marble, Peninsular Ranges (Paleozoic?)**—White to light gray, locally bluish-gray, and pale to medium blue, coarse- to extremely coarse-grained calcite, calcite-dolomite, and predazzite marble (photos 77, 78, 79, and 80) Some cataclastic (photos 496, 497). Locally includes calc-silicate hornfels, quartzite, biotite schist, and skarn (photo 74). Most of skarn occurs along contact between marble and tonalite. Where marble in contact with tonalite, mineral assemblages of pyroxene hornfels facies are developed. At Crestmore (photo 563), marble contains upper pyroxene hornfels facies mineral assemblage; elsewhere generally intermediate pyroxene hornfels facies assemblages. At Slover Hill marble contains hornblende hornfels facies mineral assemblages. Contact zones contain a wide variety of minerals, some uncommon or rare, especially at Crestmore. Marble at New City Quarry (Victoria Ave Quarry) contains borate-bearing skarn (photos 94, 95) including ludwigite-pageite-vonsenite series (photos 92, 93), associated with magnetite. Also at the New City Quarry is prehnite skarn (photos 498, 499). At Old City Quarry chrondrodite-bearing marble (photos 500, 501) is common (photos 90, 91). Larger marble bodies have been mined for various purposes

Pzc **Calc-silicate rocks (Paleozoic?)**—Heterogeneous, massive to well-layered calc-silicate rocks accompanied by variable amounts of marble, quartzite, and biotite schist

Pzms **Marble and schist, undifferentiated (Paleozoic?)**—Heterogeneous mixture of marble and biotite schist; massive to foliated

Pza **Amphibolite (Paleozoic)**—Black hornblende amphibolite. Poorly developed foliation and locally poorly developed lineation. Includes some hornblende plagioclase rock

SAN GABRIEL MOUNTAINS ASSEMBLAGE

QTfz **Crushed rock in fault zones (Quaternary to Tertiary)**—Gouge and crushed and brecciated rock developed along fault zones related to San Andreas, San Gabriel, and Punchbowl fault zones

Qh **Harold Formation (Pleistocene)**—Sandstone, conglomeratic sandstone, and lesser siltstone and conglomerate (photo 361). Found on both sides of and within San Andreas Fault zone. Ranges from massive to relatively thin bedded; lensoidal bedding common. Tan to light-brown; some is reddish brown. Contains discontinuous carbonate-cemented layers, carbonate crack fillings and nodules. Moderately well consolidated. Most clasts are subrounded to moderately rounded, and include Mesozoic Pelona Schist, rocks of Triassic Mount Lowe Intrusive Suite, and gneiss, all characteristic of basement rocks of northeastern San Gabriel Mountains. Unit probably represents low-gradient alluvial fans and associated distal playa deposits. Ranges from about 150 m thick near Sheep Creek to about 75 m thick a few kilometers west of Cajon Pass

QTjh **Juniper Hills Formation, undifferentiated (Pleistocene and Pliocene)**—Arkosic sandstone, silty sandstone, lesser conglomerate, and thin bedded shale; generally coarse grained, poorly sorted, commonly containing pebbles and cobbles. Also includes lesser amounts of siltstone, gypsiferous shale, and coarse sedimentary breccia. Pinkish gray, pale tan, and reddish brown. Poorly to moderately-well indurated. Bedding ranges from poorly bedded in coarser grained parts to well bedded in finer grained parts. Many clasts probably recycled from Pliocene and Miocene Punchbowl Formation (Tpb). Represents interstratified and interfingering fluvial, lucustrine, and playa deposits (Barrows, 1980, 1987; Barrows and others, 1985). Named by Barrows (1987) for exposures in Juniper Hills area. Located in northwestern part of San Bernardino quadrangle, mostly south of San Andreas Fault; subdivided on basis of lithology or clast composition. Ten localized, informal subunits are differentiated and grouped by their positions relative to San Andreas, Punchbowl, and northern and southern Nadeau Faults. Between northern and southern Nadeau Faults, informal Juniper Hills subunits include: red arkose unit (QTjhr), clay-shale unit (QTjhc), siltstone unit (QTjhs), and arkosic breccia unit (QTjhb). Between San Andreas and northern Nadeau Faults, informal Juniper Hills subunits include: fine-grained unit (QTjhf) and sedimentary breccia unit (QTjhsb), but between these two faults, much of Juniper Hills Formation is undifferentiated. South of Punchbowl Fault, informal Juniper Hills subunits include: playa deposit unit (QTjhp), volcanic clast unit (QTjhv), arkosic sandstone unit (QTjha), and conglomeratic sandstone unit (QTjhcs). No Juniper Hills Formation is found between the Punchbowl and southern Nadeau faults. Where subdivided, includes:

Units between northern and southern Nadeau Faults

QTjhr **Red arkose unit**—Red to dark-red pebbly arkose and minor white and gray silty sandstone. Found only near northern Nadeau Fault where it is deformed and highly pigmented by iron oxides. Contains subrounded clasts of leucocratic granitic and varicolored volcanic rocks that are typically fractured. Resembles parts of Punchbowl Formation from which much of sediment may have been derived (Barrows and others, 1985)

QTjhc **Clay-shale unit**—Thin-bedded, greenish-gray and light-brown to nearly black, gypsiferous, silty, clayey shale. Contains very thin-bedded, flaggy, maroon sandstone, white arkose, and chalky white limy interbeds. Lacustrine. Unit develops soft, brown, expansive clay soils containing abundant chips of gypsum. Pollen suggests early Pliocene flora (Barrows, 1985)

QTjhs **Siltstone unit**—Siltstone, pale gray. Includes interbeds of fine-grained, white arkosic sandstone, and gray claystone containing dark red-brown layers (Barrows and others, 1985)

QTjhb **Arkosic breccia unit**—Arkosic breccia. White to pale gray, coarse grained, poorly sorted, angular clasts. Includes fanglomerate containing boulders of pink and pale-tan monzogranite, brownish-pink pegmatite, hornblende gabbro, hornblendite, and gray diorite. Forms lowest unit of Juniper Hills Formation between San Andreas and northern Nadeau Faults. Deposited unconformably on Mesozoic granitic rocks. Also found locally north of San Andreas Fault (Barrows and others, 1985)

Units between San Andreas and northern Nadeau Faults

QTjhf **Fine-grained unit**—Silty sandstone. Light-brown to pale-tan, thin-bedded, moderately well consolidated. Includes abundant, maroon, ellipsoidal to irregular-shaped, sandy concretions containing angular, white quartz grains, biotite, and locally abundant pebbles of Pelona Schist. Represents shallow lucastrine or playa deposits. Restricted mainly to small area 1.5 km northeast of Juniper Hills (fig. 1) between northern and southern Nadeau Faults (Barrows and others, 1985)

QTjhsb **Sedimentary breccia unit**—Angular rubble. White to light gray, poorly to moderately well stratified, coarse to very coarse grained, poorly sorted. Contains abundant clasts as large as 1 m in diameter derived from diorite gneiss and gneissic hornblende quartz diorite basement. May represent local variation of arkosic breccia unit (QTjhb) (Barrows and others, 1985)

Units south of Punchbowl Fault

QTjhp **Playa deposit unit**—Clayey siltstone and claystone. Contains abundant, white, flaky gypsum layers as thick as 3 cm. Reddish brown to dark brown, weakly consolidated, soft. Develops granular soil (Barrows and others, 1985)

QTjhv **Volcanic clast unit**—Conglomerate. Contains angular to subrounded, gray to dark-brown pebbles and cobbles of andesite from Vasquez Formation. Volcanic clasts intermixed with distinctly lesser amounts of leucocratic granitic rock clasts. Matrix is composed of light-gray, poorly-consolidated silt (Barrows and others, 1985)

QTjha **Arkosic sandstone unit**—Arkosic sandstone. Near-white, coarse-grained, poorly sorted. Appears to be derived, at least in part, from rocks of undivided Mount Lowe Intrusive Suite. Restricted to small, scattered outcrops in 4 km^2 area in northwest corner of quadrangle (Barrows and others, 1985)

QTjhcs **Conglomeratic sandstone unit**—Conglomeratic sandstone. Pebble- to cobble-sized clasts in poorly consolidated sandy matrix. Most clasts are volcanic rocks and leucocratic granitic rocks. Most volcanic rocks are conspicuously not derived from Vasquez Formation, but along with granitic rocks are probably reworked clasts derived from Punchbowl Formation (Barrows and others, 1985)

Tdc **Duarte conglomerate of Shelton (1946) (Pliocene or Miocene)**—Conglomerate containing sandy beds and lenses, and locally clay-rich beds. Restricted mainly to Bradbury area (fig. 1) and to fault-bounded exposures in Sierra Madre Fault zone. Gray, unconsolidated to poorly consolidated, relatively massive to indistinctly bedded. Clasts are mainly granitic and gneissic rocks from San Gabriel Mountains, but also includes clasts of decomposed volcanic rocks similar to volcanic rocks found in Glendora Volcanics. Clasts generally well rounded and over one meter long. Contains no fossils, but considered to be Pliocene or Miocene by Shelton (1955)

Tp **Puente Formation, undifferentiated (early Pliocene and Miocene)**—Marine sandstone, siltstone, and shale. Named by Eldrige and Arnold (1907) for exposures in Puente Hills. English (1926) extended distribution of Puente Formation to area south of Puente Hills, subdividing three units, from youngest to oldest, (1) shale, sandstone, and conglomerate (2) sandstone, and (3) shale. Daviess and Woodford (1949) subdivided Puente Formation in northwestern Puente Hills into four members, from youngest to oldest, (1) Sycamore Canyon member, (2) upper siltstone member, (3) sandstone member, and (4) lower siltstone member. Schoellhamer and others (1954) later designated formalized member names that are in current usage and which we follow here. Includes:

Tpsc **Sycamore Canyon Member (early Pliocene and Miocene)**—Predominantly sandstone and pebble conglomerate (photo 230). Sycamore Canyon Member is laterally variable, composed of varying amounts of pale gray, thick-bedded to massive, medium- to coarse-grained, friable sandstone; pale gray, thin-bedded, siliceous siltstone; pale gray, poorly bedded siltstone, and brownish-gray, massive conglomerate. Contains bathyal depth foraminiferal fauna (Yerkes, 1972). Included in Tpsc is zone of predominantly conglomeratic rock (Tpscc) of unknown extent

Tpls **Soquel and La Vida Members, undifferentiated (Miocene)**—Sandstone and siltstone. Undivided unit consists of characteristic lithologies of both members. Shown where members are too similar to be distinguished or detailed mapping is not available

Tpsq **Soquel Member (Miocene)**—Sandstone and siltstone; sandstone predominates (photo 228). Named by Schoellhamer and others (1954) for exposures in Soquel Canyon in eastern Puente Hills, in northern Santa Ana quadrangle. Gray to yellowish-gray, massive to well-bedded, medium- to coarse-grained, poorly sorted sandstone interbedded with matrix-supported pebbly sandstone. Many sandstone beds are graded. Locally conglomeratic (Tpsqc). Lower part commonly contains ellipsoidal calcite-cemented concretions 30 cm to 1.5 m in diameter

Tplv **La Vida Member (Miocene)**—Siltstone and subordinate sandstone. Named by Schoellhamer and others (1954) for exposures near La Vida Mineral Springs in eastern Puente Hills, just west of Santa Ana quadrangle. Light-gray to black, massive to well-bedded, generally friable siltstone. Weathered surfaces are typically white or pale gray. Locally consists of porcellaneous siltstone or shale. Contains widespread fish remains, abundant foraminifera, local phosphate nodules, and sparse limy siltstone. Interbedded sandstone beds range from 2 cm to over 1m in thickness. Includes a few beds of vitric tuff

Punchbowl Formation (early Pliocene and late Miocene)—Arkosic sandstone, conglomeratic arkosic sandstone, and conglomerate, and minor sandstone and freshwater limestone (photos 292 and 293) (Barrows and others, 1985). Subdivided into:

Tpbv **Volcanic-clast unit**—Arkosic sandstone, silty sandstone, and minor freshwater limestone. Most of unit is white to pinkish tan, well indurated, and prominently stratified. Arkosic sandstone is coarse grained, pebbly to cobbly, and contains matrix- and clast-supported lenses of conglomerate. Subrounded pebble and cobble clasts of granitic rocks predominate, but varicolored tuffaceous and porphyritic volcanic rocks that range in composition from rhyolite to andesite comprise up to 40 percent of clast population. Clasts of mafic granitic rocks are conspicuously absent. Silty sandstone is yellowish tan, greenish brown, and reddish brown, and is thin bedded. Freshwater limestone is thin bedded, white, and nodular (Barrows and others, 1985)

Tpbd **Diorite-clast unit**—Arkosic sandstone, and pebble-, cobble-, and boulder-bearing arkosic sandstone. Includes conglomerate lenses and beds. Clasts are generally subrounded. Most of unit is grayish white to pale pinkish gray, well cemented and coarse grained. Clasts include (1) coarse- and medium-grained, leucocratic monzogranite to granodiorite, (2) coarse-grained, mafic, gneissic diorite, (3) rocks from San Francisquito Formation, and (4) red-spotted, leucocratic granite. Clast size and abundance and proportion of gneissic clasts increase downward in unit (Barrows and others, 1985)

Tpbb **Breccia unit**—Megabreccia; dark reddish brown. Composed of debris derived from San Francisquito Formation. Very poorly sorted blocks of sandstone and conglomerate as large as 1.5 m in length. Bedding features poorly developed. Found discontinuously, and only where Punchbowl Formation rests on San Francisquito Formation (Barrows and others, 1985)

Tcd **Conglomerate and sandstone, San Sevaine Canyon area (Pliocene and Miocene)**—Moderately indurated, gray, massive to moderately well bedded, non-marine boulder conglomerate. Contains some interbeds of coarse-grained, moderately indurated sandstone. Found in very restricted exposures in footwall of Cucamonga Fault zone along San Gabriel Mountain front where conglomerate unconformably underlies units Qof_2 and $Qvof_2$ and is overthrust by Proterozoic granulitic gneiss, mylonite, and cataclasite, retrograded unit (Ꝑm). Unit is too restricted to show on 1:100,000-scale plots, but is easily located in digital coverage. Includes:

Tvc **Volcaniclastic conglomerate (Miocene)**—Conglomerate similar to conglomerate and sandstone, San Sevaine Canyon area unit (Tcd), but containing sparse clasts of argillic-altered, silicic volcanic rocks. Near mouth of San Sevaine Canyon, interlayered in very limited exposures with unit Tcd; extent beyond sparse outcrops is unknown

Tsx **Mixed marine and nonmarine sedimentary rocks (Miocene to Paleocene)**—Faulted and brecciated arkosic sandstone, conglomeratic arkosic sandstone, sandstone, and shale. Restricted to single fault slice south of Devils Punchbowl, near Valyermo (fig. 1). Arkosic and conglomeratic rocks are probably part of nonmarine Miocene Punchbowl Formation, and sandstone and shale are probably part of marine Paleocene San Francisquito Formation

Tt **Topanga Group, undifferentiated (Middle Miocene)**—Marine sandstone, siltstone, shale, and conglomerate; most of unit is coarse grained. Locally contains minor extrusive volcanic rock (photo 219). Previously correlated with Topanga Formation (Shelton, 1955; Morton, 1973). Kew (1923) originally designated predominantly sandstone unit in Santa Monica Mountains as Topanga Formation; further subdivided by Vedder (1957). Kew (1923) recognized similar rocks in Puente Hills, Santa Ana Mountains, and San Joaquin Hills. Topanga Formation was elevated to group rank by Yerkes and Campbell (1979), but they did not extend revised stratigraphic nomenclature beyond Santa Monica Mountains. Due to nomenclature problem and inexact correlation with revised Topanga stratigraphic usage in type area, Topanga-equivalent rocks in San Bernardino Mountains assemblage, except for one conglomerate unit, are mapped as undifferentiated. In Azusa area, unit consists of coarse-grained, massive to thick-bedded sandstone and conglomerate (photo 502), interbedded with fine-grained, thinly bedded sandstone, siltstone, and lesser diatomaceous, fissile, and partly silicified shale. Shale is gray to grayish-white; coarser rocks are pale tan to yellowish-tan. Conglomerate clasts are predominantly granitic and gneissic rocks, and lesser volcanic rocks (photo 503). Intercalated with Miocene Glendora Volcanics. Topanga Group in Azusa area is probable correlative with Topanga Canyon Formation in Topanga Canyon. Contains middle Miocene fauna characterized by *Turritella ocoyana*. North of Azusa, unit contains Luisian foraminifera (Shelton, 1955). In Bradbury area (fig. 1), unit consists of monolithologic conglomerate composed of gneissic quartz diorite (Topanga Formation of Morton, 1973). Conglomerate contains minor pale brown, silty sandstone to fine-grained sandstone beds. In addition to monolithologic character, conglomerate and fine-grained beds differ from other

Topanga Group rocks in Azusa area in that they contain no diagnostic fossils and only minor intercalated volcanic rocks. In central San Jose Hills, includes:

Ttbp **Buzzard Peak Conglomerate**—Conglomerate; well indurated (photo 227), containing sandy conglomerate, coarse-grained pebbly sandstone, and rare silty beds. Clasts are 60 to 75 cm in length; most appear to be derived from eastern San Gabriel Mountains. Clasts of mylonitic rocks derived from bedrock along the southern edge of San Gabriel Mountains are particulariy distinctive. Forms lowest part of Topanga Group in local area. Named by Woodford and others (1946) for thick section of largely conglomeratic rocks in the San Jose Hills. We here elevate this unit to formation rank, retaining all type area and type section definitions of Woodford and others (1946). Exposed in anticline developed in predominatly sandstone of undifferentiated Topanga Group that overlies the conglomerate. In places, thin layer of Glendora Volcanics (Shelton, 1955) separates Topanga Group rocks from the overlying Puente Formation. Up to 600 m thick at surface and 900 m thick in subsurface. Based on limited faunal assemblage, unit falls in Luisian and Relizian stages of Kleinpell (1938). Also contains fauna including *Turritella ocoyana*, Turritella. cf. *T. ocoyana topangensis*, *T. temblorensis*, *Leptopecten andersoni*, *Chione temblorensis*, *Crassostrea* cf. *titan subtitan*, and *Vertipecten nevadanu*

Glendora Volcanics (Miocene)—Volcanic flow rocks ranging from rhyolite to basalt interlayered with breccia, tuff, and locally, sedimentary conglomerate. Partly intercalated with Topanga Group, undifferentiated (Tt) in Azusa area and partly underlies lowest Tt strata (Shelton, 1955; Morton, 1973). Forms very discontinuous, compositionally and texturally heterogeneous, highly faulted exposures along southern part of San Gabriel Mountains, and in San Jose and Puente hills (photos 218 and 220). Internal stratigraphy poorly established due to faulting and discontinuous exposure. Includes:

Tg **Undifferentiated**—Tuff, water-laid tuff, tuff-breccia, flow-rock, flow-breccia, shallow intrusives, and volcanic dikes (Shelton, 1955). Composition is mostly andesite, but ranges from rhyolite to basalt, and includes some dacite

Tgr **Rhyolite and dacite flows**—Finely layered, gray to reddish-gray, felsic rhyolite and rhyolite to dacite. Rocks are about 90 percent rhyolitic glass containing about 10 percent very fine-grained phenocrysts of oligoclase and trace amounts of tridymite. In some areas unit contains perlite and autobrecciated flow-rock. At north end of Puente Hills, rocks are pervasively silicified and pyritized (Shelton, 1955)

Tga **Andesite flows**—Light- to dark-gray andesite and andesite flow breccia; very large proportion of unit is breccia. Andesite averages about 60 percent aphanitic groundmass and 40 percent sub-millimeter phenocrysts. All andesite has plagioclase phenocrysts, but content and distribution of mafic mineral phenocrysts is highly variable; varieties include hypersthene-bearing, augite-hypersthene-bearing, hornblende-bearing, and biotite-bearing andesite (Shelton, 1955)

Tgf **Fine-grained andesite**—Andesite, very fine grained, dark gray, slightly platy, commonly brecciated. Contains scattered, very small plagioclase laths and sparse tridymite grains up to 1 mm long (Shelton, 1955)

Tgi **Andesite dikes**—Fine-grained andesite, but typically slightly coarser grained than andesitic flow rocks. Porphyritic, gray, maroon, and reddish-brown. Commonly altered and highly weathered (Morton, 1973)

Tgj **Tuff breccia of Johnson Peak area**—Massive, orangish-brown-weathering tuff breccia composed of andesite blocks as large as 3 m across, in fine grained tuffaceous matrix. Andesite blocks average about 15 percent of rock, matrix about 85 percent. Poorly consolidated; easily eroded (Shelton, 1955)

Tgc **Volcanic conglomerate**—Greenish-gray to reddish-brown, poorly bedded volcanic conglomerate. Clasts are angular to subrounded andesite in quartz-deficient tuffaceous matrix. Restricted to upper part of formation (Shelton, 1955)

Tgb **Basalt flows**—Fine-grained basalt flow rock, commonly vesicular. Mostly holocrystalline, consisting of plagioclase, augite, opaque minerals, and trace olivine. Flow structure well defined at some places. Flow breccia developed locally (Shelton, 1955)

Tgbt **Palagonitic tuff and pillow lava**—Palagonitic tuff, tuff breccia, and altered basalt. Some rocks contain large fraction of basaltic glass. Basalt is vesicular and shows fairly well developed pillow structure locally (Shelton, 1955)

Tb **Basalt dikes (Miocene)**—Very fine-grained basalt and basaltic andesite dikes, rarely containing olivine phenocrysts. Fresh surfaces dark gray to near black; orange-brown where weathered. Most are less than one meter thick; few exceed 3 meters. Sharply discordant contacts with foliated host rocks. Chilled margins common where unfaulted. Particularly abundant within 2 km of San Gabriel Fault. Spatially and structurally associated with andesite dikes (unit Tad), which generally share steep dips and northwest or northeast strikes. Basalt is possibly correlative with extrusive units of Miocene Glendora Volcanics (Nourse and others, 1998). Most dikes too small to map at 1:100,000 scale

Tdg **Olivine diabase and gabbro (Miocene)**—Texturally zoned small pluton consisting of aphanitic to fine-grained olivine diabase near margins (photos 504 and 505), grading to coarse-grained olivine gabbro near its center (photos 506, 507, 508, 509, 578, and 579). Intrudes Oligocene granodiorite of Telegraph Peak (Ttp) between Cajon and Lytle Creeks (fig.1). Contains late-crystallizing, non-discrete pegmatitic clots (photos 510 and 511) which are characterized by high concentrations of ilmenite and amphibole and are cut by thin dikes of leucocratic granophyre (photos 514 and 515)

Tad **Andesite dikes (Miocene)**—Andesite ranging to basaltic andesite, containing abundant plagioclase and rare hornblende phenocrysts (photos 512 and 513). Fine- to medium-grained, equigranular to porphyritic hypabyssal rocks, medium to dark-gray or green-gray. Most dikes are less than one meter thick. Possibly correlative with extrusive units of Miocene Glendora Volcanics (Nourse and others, 1998). Moderately concentrated on central part of Lower Lytle Creek Ridge and farther west in proximity to San Gabriel Fault; sparsely scattered in southern part of San Gabriel Mountains

Tal **Andesite dike rocks (Miocene)**—Andesitic dikes. Fine- to medium-grained, equigranular to porphyritic hypabyssal rocks, medium to dark-gray or green-gray. Most dikes are less than one meter thick. Moderately concentrated on central part of Lower Lytle Creek Ridge

Tvv **Vasquez Formation (early Miocene to late Oligocene)**—Andesite ranging to basalt. Found only south of Punchbowl Fault in northwestern part of San Bernardino quadrangle. Reddish-brown-weathering, dark-gray, aphanitic to slightly porphyritic lava flows and thick, coarse volcanic breccia. Also includes lesser black, amygdaloidal basalt and pale-tan, pink, and light-green tuff-breccia layers. Latter contain large blocks of andesite. Translucent, vuggy, chalcedony-filled vesicles as large as 5 cm across are locally abundant (Barrows, 1985). Includes:

Tvt **Vasquez Formation, tuffaceous rocks**—Tuffaceous rocks and tuff breccia. Pale-tan, pink, and light-green. Typically more erosionally resistant that enclosing flow rocks. Restricted to single occurrence in Carr Canyon in northwestern corner of San Bernardino quadrangle; more widely distributed west of quadrangle

Ttd **Hypabyssal dikes (Oligocene)**—Dikes and irregular shaped bodies of rock transitional between biotite granodiorite and biotite dacite; probably represent shallow intrusions of Oligocene granodiorite of Telegraph Peak (Ttp). Restricted to two dikes flanking a dike-form mass of Ttp on Lower Lytle Creek Ridge. Dacitic rock is porphyritic, having phenocrysts of quartz, feldspar, and biotite; rocks are characterized by well oriented biotite, which imparts foliated texture to rock

Tgtp **Granodiorite of Telegraph Peak (Oligocene)**—Biotite granodiorite, ranging to biotite monzogranite. Medium- to coarse-grained; locally has finer grained chilled margin (photos 516 and 517) in Telegraph Peak area and possibly other areas. Typically massive, hypidiomorphic-granular, white-weathering biotite granodiorite. Some parts intruded by late-stage pegmatite, aplite, or rhyolite porphyry dikes. Highly fractured most places, especially near San Gabriel Fault and related fault zones in Lytle Creek area. Locally contains stoped fragments of Pelona Schist (photo 244). Generally deeply weathered on slopes and ridge tops. Intrudes greenstone unit of Mesozoic Pelona Schist (Kps) on lower Lytle Ridge. Based on analysis of several isotopic ages by different methods, McCulloh and others (2001) conclude best determination for age of granodiorite is 26.3 Ma. Miller and Morton (1977) report conventional K-Ar ages of biotite ranging from 14 Ma to 19 Ma, which probably reflect cooling history

Tgry **Granodiorite, Yucaipa area (Oligocene)**—Biotite granodiorite, ranging to biotite monzogranite. Medium grained; locally has fine-grained chilled margins. Typically massive, hypidiomorphic-granular, biotite granodiorite. Occurs as dike-form bodies intruding Mesozoic Pelona Schist (Kps) on north side of Crafton Hills (fig.1) in southeastern part of San Bernardino quadrangle. May be offset part of 26.3 Ma (McCulloh and others, 2001) granodiorite of Telegraph Peak (Ttp), or may be similar intrusion, related to granodiorite of Telegraph Peak. Rrock has uranium-lead age of 27.2 +/- 0.6 Ma on zircon (Wayne Premo, written commun., 2006)

Td **Dacite dikes (Oligocene)**—Light colored dikes of approximately dacite composition (photo 243). Very fine grained, some hornblende-bearing. Many too small to be mapped at 1:100,000 scale. Considered to be related to Oligocene granodiorite of Telegraph Peak (Ttp); spatially associated with Ttp, and probably also related to Oligocene Mountain Meadows Dacite (Tmd)

Tgh **Hypabyssal granitic rocks (Oligocene)**—Hornblende-biotite granodiorite in Shandin Hills area (fig.1) and leucocratic biotite-quartz-plagioclase porphyry on hill 2 km southeast of Shandin Hills. Granodiorite is medium and fine grained, porphyry is fine grained. Presumed to be related to Oligocene granodiorite of Telegraph Peak based on approximate composition, and on intrusive relations with Pelona Schist

Tmd **Mountain Meadows Dacite (Oligocene)**—Biotite rhyolite, quartz latite, and dacite porphyry dikes and dike-form bodies. Correlated with extrusive flows of Mountain Meadows Dacite in northern Peninsular Ranges to south by McCulloh and others (2001). Contains euhedral biotite, oligoclase, and rounded, embayed quartz phenocrysts in pale-gray, very fine-grained groundmass. Almost everywhere deeply weathered. Massive; no flow structure recognized. Considered by McCulloh and others (2001) to be intrusive. Based on analysis of several isotopic ages by different methods, McCulloh and others (2001) conclude best determination for age of dacite is 27.6 Ma

Tr **Rhyolite porphyry dikes (Oligocene)**—Light gray, tan, or white rhyolite, quartz latite, or dacite porphyry containing prominent spherical quartz phenocrysts and sparse biotite. Dikes and sills constituting dike swarm sharply intrude Pelona schist and upper plate rocks of Vincent thrust in eastern and central San Gabriel Mountains. Genetically related to Telegraph Peak granodiorite and Mountain Meadows Dacite, and in southern part of San Gabriel Mountains, may be same as unit Tmd. Dikes do not show on geologic map plot, but are in database and can be made to plot. Southern part of dike swarm is dextrally displaced along San Gabriel Fault (McCulloh and others, 2001)

TKtp **Pelona Schist and granodiorite of Telegraph Peak (Oligocene and Mesozoic)**—Muscovite schist unit of Pelona Schist (Kps) closely intruded by numerous dikes, sills, and small bodies of granodiorite of Telegraph Peak (Ttp). Fine scale of intrusive rocks and schist bodies precludes mapping them separately at 1:100,000 scale

Tsf **San Francisquito Formation (Paleocene)**—Sandstone, conglomeratic sandstone, conglomerate, and shale (photo 287) (Barrows, 1985). In general, coarse-grained rocks make up most of lower part of formation, and shale containing scattered sandstone beds typify upper part. Sandstone is thick bedded to massive, and contains marine fossils. It is interbedded with pebbly to cobbly sandstone, conglomerate (photo 286), medium- to coarse-grained arkosic sandstone, and shale. Most shale is mapped separately as unit Tsfs. Arkosic sandstone is yellowish to redish brown, and characterized by abundant angular quartz grains. Includes:

Tsfs **Shale unit**—Shale and argillaceous shale (photo 288). Dark brown to black, thin bedded. Contains abundant ellipsoidal, erosionally resistant concretions, nodules, or highly cemented lenoidal masses. Fragmental carbonaceous material fairly common along bedding planes; gypsum is locally abundant. Compared to sandstone beds making up much of San Francisquito Formation, shale beds are much more deformed, and in places are isoclinally folded (Barrows, 1985). Sparse sandstone beds are commonly disrupted (photos 289 and 290) so that shale completely encloses blocks of sandstone

Tsfc **Conglomerate unit**—Conglomerate, clast and matrix supported. Thick bedded to massive, some beds 6 m thick (photo 286). Clasts are well-rounded, resistant pebbles and cobbles of graphic granite, granophyre, quartz, aplite, diorite gneiss, quartz-feldspar gneiss, and quartzite. Clasts also include a wide variety of altered volcanic pyroclastic and flow rocks, ranging in composition from dacite to quartz latite. Near faults, clasts show conspicuous tectonic polish (Barrows, 1985)

Tsfl **Limestone lenses**—Limestone breccia. Light brown to gray, fossiliferous. Contains petrified toredo-bored wood fragments, and locally, marine mollusk fossils

Tsfb **Basal boulder conglomerate unit**—Boulder conglomerate in shale and sandstone matrix. Found only locally, 2 km southeast of Big Rock Springs (fig. 1) in northwestern part of San Bernardino quadrangle, at base of formation, where San Francisquito is deposited on Mesozoic Gneiss of Pinyon Ridge (Mzpr). Boulders are large, some as large as 4m across. They are well rounded to spherical, very smooth, and composed of hornblende diorite gneiss, granodiorite, and leucocratic granitic rocks. Provonence of boulders is unknown; they differ compositionally from basement rocks on which they are deposited

Kpu **Pelona Schist, undifferentiated (Mesozoic)**—Predominatly siliceous schist; greenschist and lower amphibolite metamorphic grade. Spotted gray, albite-bearing schist is most common lithology. Forms very thick tectonic section in eastern and central San Gabriel Mountains; also extensively exposed northwest of quadrangle. Transposition of bedding throughout unit precludes establishment of stratigraphic succession or stratigraphic thickness of sequence; position of one predominant rock type relative to another denotes structural and not stratigraphic relationship. Metamorphosed chert(?) having convoluted layering commonly contains spessartite and barite. Chlorite is widespread in lower grade schist. Biotite is rare except in northeastern part of Crafton Hills (fig. 1) where Pelona atypically consists of biotite schist. Undifferentiated Pelona Schist unit contains thick sequences of greenstone, most commonly in structurally higher parts. Greenschist grade greenstone consists of epidote, chlorite, and albite; lower amphibolite grade greenstone consists mainly of hornblende. Quartzite and siliceous carbonate layers occur locally. Unit contains scattered masses of coarse-grained actinolite-talc rock, and manganese-rich siliceous rock that includes rhodonite, and piemontite-bearing rock. Locally contains bright green fuchsite. Primary sedimentary and volcanic features destroyed by metamorphism and deformation; all layering is probably transposed bedding (photo 264). Age is poorly established. Includes following subunits, but no relative ages are implied by order listed:

Kpg **Pelona Schist, greenstone unit**—Dark-green to greenish-gray, foliated, indistinctly layered chlorite-epidote-albite greenstone (photos 274, 518, 519, 520, 521, 522, 523, 524, and 525). Forms scattered layers mainly in upper third of unit; thickest layer is about 60 m thick (Ehlig, 1981). Most metachert and carbonate-bearing rock in Pelona appear to be spatially associated with greenstone. Locally contains hornblende where metamorphosed to lower amphibolite grade, especially adjacent to Oligocene granodiorite of Telegraph Peak (Ttp). Greenstone is highly fractured and relatively prone to landslides

Kps **Pelona Schist, muscovite schist unit**—Spotted muscovite-albite-quartz schist and siliceous schist southwest of San Andreas and Punchbowl fault zones (photos 268, 269, 526, and 527). Spotted muscovite schist is relatively homogeneous in appearance, well layered, and fissile. Has localized quartz-rich layers, and contains sparse masses of talc and (or) tremolite rock. Biotite is rare, but stilpnomelane is widespread (photos 270, 271, 272, 273, 528, and 529). Spotted appearance is due to small porphyroblasts of dark-gray albite; gray color is apparently due to included carbon (photos 530 and 531). Parts of Pelona that are dominated by siliceous schist include interlayered tan to gray muscovite schist, quartzite, spotted albite schist, greenstone, and biotite-bearing schist; rarely, masses of carbonate-tremolite and talc-rich rock. Spotted and biotite-bearing schists are fissile. Quartzite is fine grained, and interlayered with siliceous schist. Layering ranges from submillimeter to 30 cm in thickness, averages 0.5 to 2 cm. Most of unit is highly fractured and prone to landslides

Kpa **Pelona Schist, amphibolite grade unit**—Predominantly gray medium-to coarse-grained muscovite-plagioclase schist. Typically well layered and finely schistose. Commonly contains interlayered meta-basalt (photos 532, 533, 265, and 266) consisting largely of hornblende, commonly accompanied by garnet and plagioclase. Sparse, local, and discontinuous bands of metachert and marble. Pelona rocks metamorphosed to amphibolite grade are typically coarser grained than equivalent compositions in muscovite schist unit (Kps). Extremely prone to landslides, especially in areas adjacent to major fault zones

Kpb **Pelona Schist, biotite-quartz schist unit**—Biotite schist and biotite quartzite (photo 275). Consists almost entirely of quartz and biotite, but contains minor potassium feldspar and white mica. Found only in northeast corner of Crafton Hills (fig. 1). Tenatively included within Pelona Schist, but association is not certain. Differs from typical Pelona Schist by abundance of biotite. Compositionally layered, but unlike transposed layering that characterizes most Pelona Schist, layering appears to be relic bedding. Most biotite is oriented at small angle to compositional layering. Thinly layered, fine-grained, crenulated. Very fine-grained scattered opaque minerals have dust-like appearance. Detrital zircon is common but sparse. Appears to be higher metamorphic grade than Pelona Schist faulted against it, which is dominated by greenstone. Derived from more mature protolith than any other part of Pelona Schist. Intruded by sills and dikes of Mountain Meadows Dacite (Tmd) (photo 276)

Kpm **Pelona Schist, marble unit**—Highly deformed, relatively thin marble layers spatially associated with siliceous rocks, possibly metachert. Very limited extent in San Gabriel Mountains. On geologic map restricted to single occurrence about 6 km west of Wrightwood

Kpq **Pelona Schist, quartzite unit**—Laminated to medium-thick, fine-grained quartzite and siliceous layers; original bed thickness unknown due to structural transposition. Pale tan to grayish white. Only thicker sequences shown on geologic map. Most abundant in structurally upper part of formation

Mzggm **Foliated gabbro, granodiorite, and monzogranite (Mesozoic)**—Highly heterogeneous mix of mafic to leucocratic granitic rocks. Consists of many rocks from surrounding units, but not in proportions high enough to include in those units. Restricted to single body on north flank of Mt Baden-Powell (fig. 1)

Mzhg **Heterogeneous granitic rocks, San Gabriel Mountains (Mesozoic)**—Biotite monzogranite and hornblende-biotite granodiorite. Monzogranite is leucocratic, medium to coarse grained, and equigranular. Much contains pale-pink potassium feldspar in groundmass. Typically contains biotite as only mafic mineral, but where rock grades to granodiorite, contains minor hornblende. Granodiorite is medium to coarse grained, gneissose, and moderately mafic, containing abundant hornblende. Unit contains marble, skarn, amphibolite, and gabbro inclusions. As mapped, unit may include more than one pluton

Mzpr **Gneiss of Pinyon Ridge (Mesozoic)**—Hornblende quartz diorite, ranging to equigranular granodiorite and well foliated, contorted, gneissic diorite. Medium-grained. Color index variable; locally hornblende is strikingly euhedral. Cut by numerous dikes and small bodies of leucocratic granitic rocks, pegmatite, and aplite. Age assigment based on similarity to nearby Mesozoic rocks

Deformed granitic rocks of Transverse Ranges Province (Mesozoic)—Assemblage of deformed Mesozoic granitic rocks that are part of an assemblage characteristic of upper plate rocks of Vincent Thrust in Transverse Ranges Province. Restricted to Yucaipa and northeast corner of El Casco 7.5' quadrangles. Includes:

Mzmg **Mylonitic and cataclastic granitic rocks**—Fine- to coarse-grained cataclastic granodiorite, tonalite, and quartz diorite. Has non-penetrative and penetrative fabrics, including sheared and crushed rock, brittle cataclastic fabrics, and ductile mylonitic fabrics. Separated from underlying Pelona Schist by Vincent Thrust in Crafton Hills (fig. 1)

Mzfg **Foliated granitoid rocks (Mesozoic)**—Fine- to coarse-grained leucocratic granitoid rocks having heterogeneous compositions and textures. Some rocks are biotite bearing, some are hornblende bearing and biotite deficient. Compositions appear to be mainly granodiorite to tonalite, but locally range to monzogranite and quartz diorite

Mzdy **Diorite, Yucaipa area (Mesozoic)**—Medium- to coarse-grained, texturally massive to slightly foliated biotite-hornblende diorite and quartz diorite. Restricted to single area southeast of Crafton Hills. Relative age relation to mylonitic and cataclastic granitoid rocks (Mzmg) is uncertain

KPzsg **Schist, gneiss, monzogranite, and granodiorite (Cretaceous and Paleozoic)**—Schist and gneiss (Pzgs) mixed with large proportion of monzogranite and granodiorite (Kmg). Fine scale of intrusive bodies and metamorphic rocks precludes differentiating them at 1:100,000 scale. Restricted to areas flanking lower part of Lytle Creek (fig. 1)

KPzst **Schist, gneiss, and tonalite (Cretaceous and Paleozoic)**—Schist and gneiss (Pzgs) mixed with large proportion of tonalite of San Sevaine Lookout (Kss). Fine scale of intrusive bodies and metamorphic rocks precludes differentiating them at 1:100,000 scale. Restricted to areas flanking west side of lower part of Lytle Creek

KPm **Mylonitic orthogneiss related to Vincent Thrust (Cretaceous to Proterozic)**—Heterogeneous, mylonitic orthogneiss resulting from Late Cretaceous-Paleocene movement along Vincent Thrust, which everywhere forms lower contact. Upper contact gradational into various Mesozoic, Paleozoic, and Proterozoic crystalline rocks, but in a few places capped by thin zone of ultramylonite, above which, rocks are nonmylonitic. Protolith of mylonitic orthogneiss includes, but may not be limited to, Cretaceous and Jurassic granitic rocks, Triassic Mount Lowe Intrusive Suite, Paleozoic metasedimentary rocks, and Proterozoic gneiss and anorthosite. In eastern part, derived mainly from metamorphic rocks and in western part, from Mesozoic granitic rocks. Mylonitized leucogranite layers are probably dikes of unit Klg transposed during shearing. Ubiquitous chlorite and epidote indicate deformation under greenschist or lowermost amphibolite facies. Foliation and compositional banding are parallel in much of unit, although tight folds commonly disrupt foliation. Some parts of unit display strong stretching lineation, whereas many areas lack lineation because of strong flattening strain component. Variation in thickness may be due to tectonic thinning during Tertiary extension

MzPb **Mixed metamorphic and granitic rocks of Big Dalton Canyon (Mesozoic and Proterozoic)**—Extremely heterogeneous mixture of rocks that includes biotite diorite, quartz diorite, tonalite, quartz monzonite, granodiorite, layered gneiss, augen gneiss, and rare leucocratic gneiss. Unit is cut by numerous basalt to basaltic andesite dikes, especially within 2 km of San Gabriel Fault (J.A. Nourse, written commun., 2002). Also is cut by leucocratic dikes probably related to Mountain Meadows Dacite (Tmd) or to granodiorite of Telegraph Peak (Ttp). Heterogeneity of unit appears to increase eastward. Foliation is moderately well to very well developed in most rocks, and is extremely well developed in gneissic parts of unit. Fine- to medium-grained mafic biotite quartz diorite and diorite make up at least one-third of unit. Color index of rocks is typically greater than 35, and rocks locally include small amounts of hornblendite. Proportion of quartz diorite and diorite appears to increase westward in unit. Quartz diorite and diorite part of MzPb may be approximately equivalent to oldest two units of Mount Lowe Intrusive Suite west of quadrangle as defined by Ehlig (1981), although hornblende in those two units predominates almost to exclusion of biotite there. Quartz monzonite and quartz monzodiorite unit (Trlq) of Mount Lowe Intrusive Suite clearly intrude quartz diorite and diorite. Mixed metamorphic and granitic rocks of Big Dalton Canyon contain abundant inclusions of Proterozoic layered gneiss (Pgn), and sparse, irregularly shaped bodies of poorly foliated, medium- to coarse-grained gabbro and pyroxenite. In West Fork San Gabriel Canyon (fig. 1), metamorphic and granitic rocks of Big Dalton Canyon are synformal, and are concordantly intruded on southeast by quartz diorite of Mount San Antonio (Ksa) (J.A. Nourse, written commun., 2002). East and west of lower San Gabriel Canyon, metamorphic and granitic rocks of Big Dalton Canyon are intermixed at all scales with larger amounts of Proterozoic gneiss than in other parts of unit. On Glendora Ridge (fig. 1), MzPb is intruded by rare sheets of Triassic quartz monzodiorite and quartz monzonite (unit Trlq) and abundant sill-like bodies of Jurassic(?) biotite granodiorite (unit Jgd). In Mt Baden-Powell area (fig. 1), unit is most heterogeneous, and most of it ranges from slightly to highly mylonitic. In much of this area, sheets of Mount Lowe Intrusive Suite ranging from centimeters to tens of meters thick are structurally interleaved with Proterozoic granitic and metamorphic rocks and with granitic rocks of probable Jurassic and Early Cretaceous age. Locally, Mount Lowe Intrusive Suite rocks, which are not mapped separately, make up more than 50 percent of unit. Rocks east of San Antonio Canyon and north of Icehouse Canyon (fig. 1) and on north side of Middle Fork of Lytle Creek are tentatively included in this unit. Rocks having mylonitic fabric are widespread in this area (photos 534 and 535). All parts of unit are highly deformed, including widespread development of mylonitic fabrics

Kmg **Monzogranite and granodiorite (Cretaceous)**—Medium-grained, sub-porphyritic to equigranular, massive biotite monzogranite to granodiorite, commonly leucocratic. Phenocrysts are potassium feldspar. Weathers pale gray. Occurs mainly as large, northeast striking dikes up to 0.5 km wide, cutting Cretaceous tonalite of San Sevaine Lookout (Kss), west of Lytle Creek. West of Deer Canyon (fig. 1) and south of Icehouse Canyon, orientation and shape of bodies are much more irregular, and some intrude Paleozoic metasedimentary rocks in addition to tonalite of San Sevaine. Smaller isolated bodies occur farther west in San Gabriel River drainage. Based on uranium-lead isotopic data, May and

Walker (1989) interpret age of Kmg dike near mouth of San Antonio Canyon to be 78 Ma

Klg **Leucocratic granite dikes (Cretaceous)**—Dikes and small bodies of leucocratic granitic rocks; medium- to fine-grained, massive to gneissic. Includes rocks having heterogeneous granitoid and pegmatoid textures. Highly fractured most places, commonly cut by quartz veins, locally contains flourite

Kgl **Mixed leucocratic and granitic rocks (Cretaceous)**—Leucocratic dike rocks. Includes pegmatite, aplite, alaskite, and biotite monzogranite. Weakly to moderately foliated; many exhibit buckling or boudinage structures. Most not large enough to show at 1:100,000 scale. Intrude Cretaceous quartz diorite and older rocks between San Gabriel and San Antonio Canyons (fig. 1)

Kgc **Mylonitized leucogranite (Cretaceous)**—Leucocratic biotite monzogranite having characteristic mylonitic lineation and foliation defined by ductilely deformed quartz and porphyroclastic feldspar. Pronounced grain-size reduction. Exposed near mouth of Lytle Creek where it is thoroughly fractured and decomposed due to proximity to San Gabriel Fault; weathers white. Also common north of Middle Fork Lytle Creek and Icehouse Creek (fig. 1) where unit is interlayered with mylonitized quartz diorite, granodiorite, and diorite

Kmm **Leucocratic muscovite monzogranite (Cretaceous)**—Medium- to coarse-grained, massive to weakly foliated, highly fractured muscovite monzogranite. White-weathering, largely decomposed. Restricted to small, fault- and alluvium-bounded area south of Sycamore Flat (fig. 1). Cretaceous(?) age based on similarity to nearby granitic rocks of Cretaceous age

Kcs **Monzogranite of Cloudburst Summit (Cretaceous)**—Biotite monzogranite, ranging to granodiorite. Probably includes more than one pluton, especially in eastern parts. Leucocratic, color index generally less than 8. Trace muscovite, which may be primary, found in much of unit, and trace garnet found locally. Majority of unit is medium and coarse grained, nonporphyritic, and nonfoliated, but much of northern and northeastern parts are medium and fine grained, foliated, and in places, gneissic. Leucocratic dike rocks common within and peripheral to unit, and included older rocks locally abundant near borders, especially in northern parts. Miller and Morton (1980) report conventional potassium-argon ages on biotite of 65 Ma, and 67 Ma, but consider these to be cooling ages that are younger than age of emplacement. Includes:

Kcsl **Leucocratic unit**—Biotite monzogranite. Essentially same as Kcs, but nearly all rocks are monzogranite, and are noticably more leucocratic than typical Kcs

Kpf **Monzogranite of Punchbowl Fault area (Cretaceous)**—Biotite monzogranite. Nondistinctive; found only as narrow bands bounded by strands of Punchbowl Fault. Leucocratic, highly fractured. May be offset parts of monzogranite of Cloudburst Summit (Kcs), but rocks are nondistinctive and far removed from nearest exposures of that unit

Kgp **Tonalite of Ganesha Park (Cretaceous)**—Hornblende and biotite-hornblende tonalite. Mesocratic to melanocratic, medium- to coarse-grained. Restricted to area near Ganesha Park (fig. 1) in Pomona, at east end of San Jose Hills, and to two small exposures west of there that have been mostly concealed by highway construction. Compositionally and texturally more similar to tonalites of southern San Gabriel Mountains than to those of northern Peninsular Ranges; magnetic properties of tonalite also are similar to tonalites of southern San Gabriel Mountains

Kdd **Deer diorite of Alf (1948) (Cretaceous)**—Diorite; forms discontinuous masses near contacts between tonalite of San Sevaine Lookout (Kss) and granulitic rocks (Ꝑm) to south. Medium- to coarse-grained; typically has foliation that ranges from faint to well developed. Rock consists mostly of plagioclase (andesine) and hornblende (photos 261 and 262). Hornblende occurs as stubby prisms. Near margins of bodies rock is commonly mylonitic

Kch **Charnockite (Cretaceous)—**Massive to foliated charnockite. Forms irregular to tabular masses as much as 2 km long. Restricted to southern part of eastern San Gabriel Mountains, on both sides of Day Canyon (fig. 1). Near-white, medium to coarse grained. Consists mainly of plagioclase and hypersthene, biotite, garnet, and quartz (photos 536 and 537). Much of charnockite has been affected by retrograde metamorphism, which also affects surrounding granulitic gneiss, mylonite, and cataclasite, retrograded unit (Ᵽm)

Kdc **Granodiorite of Dorr Canyon (Cretaceous)**—Biotite and hornblende-biotite granodiorite. Medium-grained, nonfoliated, and slightly porphyritic. Relatively uniform structure and texture of unit contrasts strongly with highly foliated rocks it intrudes. Cut by numerous leucocratic granitic and pegmatitic dikes. Contains mafic granitic and gabbroic inclusions from mixed metamorphic and granitic rocks of Big Dalton Canyon (MzᏢb) (R.E. Powell and J.A. Nourse, written commun., 2002). Uranium-lead age of zircon is 74 Ma (L.T. Silver, oral commun. to J.A. Nourse, 2001)

Kss **Tonalite of San Sevaine Lookout (Cretaceous)**—Mainly hornblende-biotite tonalite, ranging to granodiorite and quartz diorite. Relatively heterogeneous in compositon and fabric. Foliated, gray, medium- to coarse-grained; generally equigranular, but locally subporphyritic, containing small, poorly formed feldspar phenocrysts. Foliation defined by oriented hornblende and biotite, commonly as dark, multi-grained, flattened inclusions. Between Ontario Ridge (fig. 1) and Icehouse Canyon, includes minor bodies of porphyritic granodiorite containing conspicuous potassium feldspar phenocrysts more than 2 cm long. Locally mylonitic; even undeformed-looking rocks in unit show some deformation in thin section (photos 538, 539, 540, and 541). Contains large septa of marble, gneiss, and schist; latter two incorporated in varying degree into tonalite (photo 263). Some rocks contain scattered garnets having kelyphytic rims. Based on uranium-lead isotopic data, May and Walker (1989) estimate age of Kss from sample collected near mouth of San Antonio Canyon to be 85 Ma. Along south slopes of Ontario Ridge and Cucamonga Peak, unit includes:

Kssm **Mylonitized tonalite of San Sevaine Lookout (Cretaceous)**—Gneissic and mylonitic tonalite (photos 542, 543, 544, 545, 546, and 547 show progression of mylonitic development); foliation generally better developed than in tonalite of Sam Sevaine Lookout (Kss) unit. Mylonitic deformation is irregularly and discontinuously distributed, but is found throughout unit. Consists of intermixed Kss and mylonitized tonalite of San Sevaine Lookout, Unit 1 ($Kssm_1$). First described by Alf (1948) who termed this unit ‘Black Belt Mylonite’. Rocks in eastern part of unit, and locally to west, include unmapped zones of homogeneous mylonite similar to $Kssm_1$ (photo 258). Also forms irregular belt (not mapped) within north part of Kss on south side of Middle Fork Lytle Creek. Includes:

$Kssm_1$ **Mylonitized tonalite of San Sevaine Lookout, Unit 1 (Cretaceous)**—Mylonitized tonalitic rocks (photos 256, 257, 548, and 549). Homogeneous, relatively uniform gray, porphyroblastic mylonite zone 200 m to 400 m in width. Mylonite is tonalite composition, but ranges to diorite and monzogranite locally. Very fine grained to aphanitic, having porphyroclasts of plagioclase, quartz, and most notably, porphyroclasts or porphyroblasts of hornblende as much as 3 cm in length. Most elongate porphyroclasts or porphyroblasts show strong preferential orientation down dip. Includes dark-gray to black, aphanitic mylonite and ultramylonite layers (psuedotachylyte) approximately 3 cm thick, which in some parts of unit are highly concentrated

Kssg **Mixed tonalite of San Sevaine Lookout and gneiss (Cretaceous)**—Mainly hornblende-biotite tonalite containing numerous large and small bodies of layered gneiss (Ᵽgn). Much more heterogeneous than either Kss or Ᵽgn. Found between Sawpit and San Gabriel Canyons (fig. 1) at front of range north of Monrovia

Ksgr **Tonalite of San Gabriel Reservoir (Cretaceous)**—Biotite-hornblende tonalite, ranging to granodiorite and quartz-bearing diorite. Forms east-west elongate body at front of San Gabriel Mountains on both sides of San Gabriel Canyon. Similar to tonalite of San Sevaine Lookout (Kss), but consistently more mafic. Medium- to coarse-grained, locally containing sparse plagioclase or potassium feldspar phenocrysts up to 2 cm long. Most rocks are weakly to moderately foliated, but at some places, foliation is either strongly developed or almost absent. Hornblende typically much more abundant than biotite; average color index is about 30, but varies widely from about 15 to 40. Contains abundant gneiss bodies ranging in size from tens of centimeters to hundreds of meters in length; bodies are larger and more abundant near contacts with large mapped gneiss units. Unit is moderately heterogeneous with respect to texture and composition, but much more homogeneous than bounding Mesozoic to Proterozoic units found northward to San Gaberial Fault. Considered Cretaceous based on similarity to tonalite of San Sevaine Lookout (Kss) and quartz diorite of Mount San Antonio (Ksa)

Ksa **Quartz diorite of Mount San Antonio (Cretaceous)**—Hornblende-biotite quartz diorite; medium-grained, equigranular, weakly to moderately foliated. Massive sill-like bodies intrude Triassic rocks and Precambrian gneiss on summit and south face of Mount San Antonio (fig. 1). Similar intrusive sheets traced as far west as Coldwater Canyon (J.A. Nourse, written commun., 2002). Correlative quartz diorite is dextrally displaced by San Gabriel Fault to West Fork San Gabriel River drainage, where thick foliated body with Triassic and Proterozoic wall rocks extends southwest through Pine Mountain and Monrovia Peak to Mount Wilson. This body is bounded on south by Clamshell-Sawpit Canyon Fault. Commonly and contains conspicuous inclusions of Mount Lowe Intrusive Suite (J.A. Nourse, written commun., 2002). Intruded by veins and dikes of leucocratic granite (Klg) that may share foliation with Ksa

Klv **Heterogeneous granitic rocks of La Verne area (Cretaceous)**—Moderately heterogeneous granitic rocks, chiefly tonalite. Also includes gneissoid biotite quartz diorite and granodiorite. All rocks cut by fairly abundant dikes of leucocratic granitic rocks, pegmatite, and aplite. Restricted to single occurrence at foot of San Gabriel Mountains 3 km north-northeast of La Verne (fig. 1)

Jhc **Quartz monzodiorite of Hutak Canyon (Jurassic)**—Quartz monzodiorite ranging to quartz diorite and hornblendite. Heterogeneous to very heterogeneous with respect to composition, grain size, and texture, especially in northern part. Locally homogeneous in southern part. Generally pinkish gray to greenish gray and coarse grained. Much is highly porphyritic, having phenocrysts up to 4 cm long. Hornblende more abundant than biotite. Feldspars are typically much darker gray than those in Cretaceous granitic rocks, and potassium feldspar commonly has distinct lavender hue

Jgf **Granodiorite and quartz monzonite of Fern Canyon (Jurassic(?))**—Predominantly biotite granodiorite ranging to quartz monzonite. Much is porphyritic, containing 1- to 2-cm-long lavender to pale-gray potassium feldspar phenocrysts. Locally hornblende-bearing in Sunset Peak area and on eastern Glendora Ridge. Medium-grained, moderately to well foliated; larger phenocrysts commonly exhibit augen shapes. Intruded by leucocratic granite dikes (Klg) that share deformational fabric. Forms large, roughly oval shaped body centering between San Antonio and San Dimas Canyons (fig. 1). Texture and composition moderately variable; could include more than one intrusive body. Contains numerous, large screens of older Mesozoic diorite or quartz diorite and Proterozoic gneiss, whose distribution mimics oval form of Fern Canyon body (J.A. Nourse, written commun., 2002). Similar body exposed in East Fork San Gabriel Canyon north of San Gabriel Fault

J₨gb **Gabbro and pyroxenite (Jurassic? or Triassic?)**—Medium- to coarse-grained gabbro and pyroxenite. Forms irregular pods in quartz diorite and diorite part of

Mesozoic and Proterozoic mixed metamorphic and granitic rocks of Big Dalton Canyon unit (MzPb) and in Proterozoic layered gneiss unit (Pgn). In places, hornblende and pyroxene are recrystallized to biotite. Age is uncertain; probably Mesozoic, but appears to predate Cretaceous granitic rocks

Mount Lowe Intrusive Suite (Triassic)—Includes variety of genetically related intrusions ranging in composition from diorite to monzogranite; average composition probably quartz monzonite, but alkalic, quartz-deficient elements also range from monzonite to syenite. Part of unit may consist of single zoned intrusion. Covers about 300 km^2 in central San Gabriel Mountains (Ehlig, 1981); central part of unit lies west of San Bernardino quadrangle. Originally designated Mount Lowe Granodiorite in abstract (Miller, 1926), later termed Lowe granodiorite (Miller, 1934, 1946). Barth and Ehlig (1988) renamed unit Mount Lowe intrusion. Unit is here informally named Mount Lowe Intrusive Suite to reflect its wide compositional range. Original name by Miller (1926 and 1946) is abandoned, because (1) unit is not primarily granodiorite, (2) name does not reflect wide compositional range of unit, and (3) inconsistant name usage. Name, Mount Lowe Intrusive Suite is preferred over Mount Lowe intrusion, because unit appears to be made up of multiple intrusions, and term, intrusive suite, more closely follows guidelines of North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature, 1983). Rocks in Mount Lowe type area in Mt. Wilson 7.5' quadrangle are still useful, where representative parts of unit are well exposed in road cuts and natural exposures. In addition to a wide range in composition, unit is characterized by highly varied appearance, highly varied grain-size, grain-size reduction in much of unit, commonly disaggregated primary minerals, and abundant sphene. Ehlig (1981) and J.A. Nourse (written commun., 2002) suggest that quartz diorite and diorite widely exposed west of San Bernardino quadrangle, and to lesser degree in western part of quadrangle, are oldest part of Mount Lowe Intrusive Suite. They show these rocks are intruded by younger elements of Mount Lowe Intrusive Suite. Because of compositional differences with Mount Lowe Intrusive Suite, quartz diorite and diorite rocks are here included in Mesozoic and Proterozoic metamorphic and granitic rocks of Big Dalton Canyon unit (MzPb), but could be part of Mount Lowe Intrusive Suite. Barth and others (1990) report a uranium-lead zircon age of 218 Ma for Mount Lowe. Subdivided into following units; listed from younger to older as determined from field relations:

TRlu **Undifferentiated**—Quartz monzodiorite, ranging to quartz monzonite and quartz diorite. Mostly pale-gray; nearly everywhere foliated (photo 254). Composition, texture, and grain size vary over wide range. Much of undifferentiated unit is one of two rock types, (1) leucocratic, porphyritic quartz monzodiorite to quartz diorite containing biotite and sparse garnet, and (2) leucocratic quartz monzodiorite containing moderately abundant hornblende, abundant sphene, and lesser biotite

TRlq **Porphyritic quartz monzonite and quartz monzodiorite**—Porphyritic biotite quartz monzonite predominates, but unit is interlayered with much hornblende quartz monzodiorite (photo 255). Both varieties intrude quartz diorite and diorite parts of Mesozoic and Proterozoic metamorphic and granitic rocks of Big Dalton Canyon unit (MzPb), which J.A. Nourse (written commun., 2002) suggests may be earliest phase of Mount Lowe Intrusive Suite. Phenocrysts in quartz monzonite are 2- to 6-cm-long potassium feldspar; west of quadrangle, Ehlig (1981) reports phenocrysts up to 10 cm in length. Color index in both quartz monzonite and quartz monzodiorite averages 7, rarely exceeds 10, but is moderately variable at all scales. Hornblende in quartz monzodiorite is near-phenocrystic, averaging 0.5 to 1 cm in length; hornblende-dominated rocks may or may not contain biotite. Both quartz monzonite and quartz monzodiorite are moderately to well-foliated, and show grain-size reduction, tectonic rounding of phenocrysts, and disaggregation of hornblende. Includes:

Ꞧll **Porphyritic biotite quartz monzonite**—Porphyritic biotite quartz monzonite. Locally subdivided from Ꞧlq where unit uniformly contains little or no hornblende bearing rocks

Ꞧlh **Hornblende-biotite quartz monzonite**—Hornblende-biotite quartz monzonite. Locally subdivided from Ꞧlq where rock uniformly contains visible hornblende in addition to biotite

Ꞧlb **Equigranular leucocratic biotite quartz monzonite**—Biotite quartz monzonite, ranging to monzogranite. Generally medium grained and equigranular, lacking foliation typical of most other Mount Lowe Intrusive Suite units. Average color index between 4 and 7; contains no hornblende. Plagioclase ranges from oligoclase to albite, and is most abundant mineral in rock. Potassium feldspar is orthoclase; most occurs as small phenocrysts (Ehlig, 1981). Quartz is generally less than 20 percent of rock, but ranges from a few percent to about 25 percent. Unit grades into, and locally intrudes, porphyritic quartz monzonite and quartz monzodiorite unit (Ꞧlq). West of quadrangle, makes up volumetrically largest part of Mount Lowe Intrusive Suite. Part of rocks mapped as this unit could be Late Cretaceous, and may correlate with monzogranite and granodiorite unit (Kmg)

Ꞧdg **Diorite and gabbro of Bare Mountain (Triassic)**—Mixed mafic granitic rocks. Mostly diorite and gabbro, but includes minor, mafic granodiorite and tonalite. Nearly all rocks contain abundant hornblende, many intermediate composition granitic rocks have some biotite, and gabbroic rocks generally contain some pyroxene. Grain size ranges from fine to coarse. Some gabbroic and dioritic rocks show layering that may be primary. Development of secondary foliation progressively increases eastward. As mapped, unit probably represents more than one intrusive event, and may include small amounts of Cretaceous or Jurassic rocks, especially in eastern exposures (photo 38). Forms numerous small bodies south of San Andreas Fault from west edge of quadrangle, 22 km eastward to vicinity of Dorr Canyon. Cox and others (1983) report unit is intruded by Triassic Mount Lowe Intrusive Suite (Ꞧlu) in western part of quadrangle

Pzgs **Metasedimentary schist and gneiss (Paleozoic)**—Well foliated schist and gneiss exposed on Penstock Ridge and extensively in eastern San Gabriel Mountains. In Penstock Ridge area, composition of schist and gneiss is variable, but most is biotite-bearing and derived almost exclusively from pelitic sedimentary protoliths. Most common lithologies include biotite gneiss, garnet-biotite quartzofeldspathic gneiss, biotite quartzofeldspathic schist, and phyllite. Commonly displays well-developed millimeter- and centimeter-scale chevron and isoclinal folds. Intruded by leucocratic biotite monzogranite and pegmatite dikes, which are variably affected by ductile deformation. May be interfolded with marble or quartzite layers and medium grained (Proterozoic?) biotite augen gneiss of monzogranitic composition. In Potato Mountain and Ontario Ridge areas (fig. 1), unit consists of highly recrystallized quartzite, marble, biotite-sillimanite schist, and graphitic schist, all intruded by Cretaceous tonalite. Considered to be part of Placerita suite of Powell (1993). Degree of metamorphism and deformation in all parts of unit precludes stratigraphic subdivision or correlation with other Paleozoic sections

Pzmg **Marble, San Gabriel Mountains (Paleozoic)**—Coarse-grained calcite marble containing variable amounts of calc-silicate minerals including forsterite and diopside; phlogopite is minor, but widespread mineral. Locally mylonitic; gneissic in western part of quadrangle

Pzqg **Quartzite, San Gabriel Mountains (Paleozoic)**—White, gray, and tannish-gray quartzite; typically has orange-hued weathered surfaces. Massive to thickly layered; layering may or may not reflect primary bedding. Feldspathic in many places; highly feldspathic locally. Commonly biotite bearing. Unit found along ridges flanking San Antonio Canyon (fig. 1)

Ꝑa **Anorthosite (Proterozoic)**—Mylonitic anorthosite. Forms single 1.5-km-long dike-form mass on south flank of Copter Ridge between South and Iron Forks of San Gabriel River (fig. 1). Composed of plagioclase and minor mafic minerals, all highly mylonitized, showing extreme grainsize reduction. Surrounded by Cretaceous to Proterozoic mylonitic orthogneiss related to Vincent Thrust (KꝐm); pervasive mylonitic fabric precludes determination of relative age relations.

Ꝑgnd **Dioritic gneiss or amphibolite (Proterozoic)**—Relatively mafic gneiss ranging in composition from diorite to amphibolite. Presumed derived from dioritic and gabbroic intrusive rocks

Ꝑpv **Gneiss of Pleasant View Ridge (Proterozoic)**—Quartzofeldspathic biotite gneiss. Alternating leucocratic and biotite-rich layers. In northwestern part of quadrangle, forms moderate-size body east of Little Rock Creek (fig. 1) and smaller bodies west of creek. Moderately heterogeneous. Age assignment based on similarity to gneiss and augen gneiss in Soledad Basin area (Cox and others, 1983). Includes:

Ꝑpva **Gneiss of Pleasant View Ridge, augen gneiss**—Biotite augen gneiss; coarse-grained. Granodiorite composition. Contains large potassium feldspar megacrysts. Surrounded by gneiss of Pleasant View Ridge (Ꝑpv)

Ꝑgt **Pelitic gneiss of Troop Peak (Proterozoic)**—Pelitic gneiss containing irregularly scattered schist layers. Biotite gneiss locally containing sillimanite, garnet, and rarely staurolite. Heterogeneous; partly resulting from variable concentration of leucocratic intrusive rock in unit. Fine- to coarse-grained; intensity of foliation development variable. Contacts poorly established, partly due to gradational character, especially where bordered by mixed metamorphic and granitic rocks of Big Dalton Canyon (MzꝐb)

Ꝑm **Granulitic gneiss, mylonite, and cataclasite, retrograde (Proterozoic)**—Prograde granulitic gneiss that is largely retrograde to amphibolite and greenschist grade mylonite and cataclasite. Granulitic gneiss includes quartz-feldspar gneiss, garnet-quartz-feldspar gneiss, amphibolite, garnet-pyroxene rich rocks, and spinel-pyroxene rich rocks. Gneiss contains layers of coarse-grained marble (Pzmg) that are progressively more mylonitic southward in unit

Ꝑgu **Granulitic gneiss, mylonite, and cataclasite (Proterozoic)**—Same protolith as granulitic gneiss, mylonite, and cataclasite, retrograde unit (Ꝑm), but most of prograde mineralogy and texture is preserved. Unit is compositionally layered, but most is massive garnet-pyroxene-plagioclase rock. Includes irregularly distributed, small areas of mylonitized rocks

Ꝑgn **Layered gneiss, undifferentiated (Proterozoic)**—Thinly and thickly layered, fine-grained gneiss (photo 550); some layered on millimeter scale. Foliation has mylonitic appearance. Isoclinal folds are common; multiple generations of deformational fabrics preserved. Metamorphosed to upper amphibolite facies. Probably derived from texturally diverse volcanic, fine-grained intrusive, and immature sedimentary protoliths. Intruded by foliated to gneissic granodiorite unit (Ꝑgd) and gneissic quartz diorite of unknown age (Morton, 1973; J.A. Nourse, written commun., 2002). Uranium-lead ages of zircons suggest sedimentary protolith accumulated between 1.68 and 1.75 Ga (Silver, 1971). Includes (no relative age relations implied by order listed):

Ꝑgn$_6$ **Layered gneiss, Unit 6**—Mixed gneiss, marble, calc-silicate rocks, amphibolite, and leucocratic rocks. Gneissic rocks include biotite-quartz-feldspar gneiss, hornblende-biotite-quartz-feldspar gneiss, and hornblende-quartz-feldspar gneiss.

Ꝑgn$_5$ **Layered gneiss, Unit 5**—Gneissic granodiorite to monzogranite. Although included in layered gneiss unit (Ꝑgn), rocks of Ꝑgn$_5$ are not obviously layered.

Medium-grained, having weakly developed gneissic, and locally cataclastic, fabric. Generally more leucocratic than other Ᵽgn units

Ᵽgn$_4$ **Layered gneiss, Unit 4**—Heterogeneous mixture of highly deformed gneiss, layered gneiss, and gneissic granodiorite to monzogranite, all cut by locally abundant leucocratic granitic dikes. Layered gneiss is relatively undeformed, alternating layers of leucocratic and biotite-rich rocks; biotite-rich layers contain garnet. Other rocks are ductilely and brittlely deformed

Ᵽgn$_3$ **Layered gneiss, Unit 3**—Mixed gneissic quartz diorite and gneiss; much is cataclastic. Granitic rock is highly deformed, and much of gneiss is highly chloritic. Unit is characterized by dark green color resulting from abundance of chlorite in rocks. Gneiss is fine grained and contains lenses of leucocratic augen gneiss (Morton, 1973). Gneiss also contains partially chloritized biotite, some white mica, and structurally elongated, strained quartz grains; augen in leucocratic parts are pink potassium feldspar

Ᵽgn$_2$ **Layered gneiss, Unit 2**—Biotite-rich gneiss having variable amounts of quartz and feldspar. Contains moderate to large proportion of rocks probably derived from foliated to gneissic granodiorite unit (Ᵽgd) and foliated to gneissic monzogranite unit (Ᵽgm)

Ᵽgn$_1$ **Layered gneiss, Unit 1**—Quartzofeldspathic gneiss containing variable amounts of biotite

Ᵽgd **Foliated to gneissic granodiorite (Proterozoic)**—Porphyritic biotite granodiorite, medium grained; highly foliated to gneissic. Texturally resembles medium-grained biotite granite augen gneiss (Ᵽgm), but augen and gneissic texture are not as well developed, and rocks are more leucocratic. Biotite and potassium feldspar are recrystallized, and typically form multi-grain aggregates. Commonly grades into layered gneiss, unit 2 (Ᵽgn$_2$). Foliation may be tightly to isoclinally folded. Well exposed in San Gabriel Canyon near Morris and San Gabriel reservoirs (fig. 1). Extensively intruded by quartz diorite and diorite parts of Mesozoic and Proterozoic metamorphic and granitic rocks of Big Dalton Canyon unit (MzᵽPb) (J.A. Nourse, written commun., 2002). Uranium-lead ages of zircons suggest emplacement ages between 1.65 and 1.68 Ga (Silver, 1971)

Ᵽgm **Medium-grained biotite granite augen gneiss (Proterozoic)**—Medium-grained biotite-rich augen gneiss; approximately monzogranite composition. Differs from unit Ᵽgc mainly by grain size. Augen are potassium feldspar typically between 0.5 and 1 cm in length. Well developed foliation or gneissic texture is commonly folded isoclinally. Typically, very weathered; least weathered outcrops occur along lower West Fork San Gabriel River. Underlies large areas between San Gabriel and San Antonio canyons. Sample on western Glendora Ridge gave zircon Pb-Pb age of 1.67 Ga (Ehlig, 1981). Includes medium-grained, highly foliated to gneissic, leucocratic, biotite monzogranite that forms small bodies in San Dimas Canyon area (fig. 1) (J.A. Nourse, written commun., 2002)

Ᵽgc **Coarse-grained biotite granite augen gneiss (Proterozoic)**—Coarse-grained biotite augen gneiss; approximately monzogranite composition. Augen are potassium feldspar up to 8 cm in length that are flattened and locally isoclinally folded. Forms numerous, noncontiguous bodies within and around granodiorite and quartz monzonite of Fern Canyon (Jgf); shapes and orientations of bodies roughly mimic outer form of Jgf. Bodies in vicinity of upper Bell Canyon and upper West Fork San Dimas Canyon (fig. 1) form closed map-scale folds (J.A. Nourse, written commun., 2002)

grg **Granitic rocks, undifferentiated (age unknown)**—Tonalite to monzogranite; leucocratic biotite monzogranite and granodiorite most common. Mostly monzogranite to granodiorite south of San Andreas Fault. Unit includes variety of granitic rocks, nearly all in very small, restricted areas. Probably includes rocks from many different plutons. Near and within San Andreas Fault Zone, unit is highly brecciated and crushed (Barrows, 1985). Part of unit is described by Ross (1972) as being distinctive due to abundance of hornblende relative to biotite compared to other nearby granitic rocks of this approximate composition. Rocks assigned to this unit on opposite sides of San Andreas Fault are not correlative. Age is probably Mesozoic, but unit could be all or part Proterozoic

dgm **Diorite gneiss and migmatite (age unknown)**—Hornblende-diorite gneiss and migmatite. Dark gray to black. Foliated and complexly deformed. Migmatite is contorted and locally blastomylonitic. Unit also includes amphibolite, coarse-grained hornblendite, and uralitized ultramafic rocks (Barrows, 1985). Restricted mainly to Juniper Hills area (fig. 1) between San Andreas Fault Zone and Punchbowl Fault

gnm **Cataclastic gneiss (age unknown)**—Cataclastic and mylonitic biotite gneiss intruded by granitic rocks which are also mylonitized. Gneiss is layered, intensely slip folded, and contains amphibolite grade mineral assemblages. Restricted to Scotland area in Lytle Creek drainage, eastern San Gabriel Mountains. Gneiss contains scattered pods of white, coarse to very fine grained, massive and mylonitic marble (Pzmg). Includes:

cgm **Chloritized cataclastic granitic rocks (age unknown)**—Cataclastic biotite gneiss containing large proportion of cataclasized, chloritic granitic rocks. Restricted to Scotland area in Lytle Creek drainage, eastern San Gabriel Mountains, adjacent to cataclastic gneiss unit (gnm)

gnb **Gneiss of Blue Cut area (age unknown)**—Compositionally and texturally heterogeneous, chloritized biotite gneiss containing variable amounts of chloritized hornblende tonalite. Highly broken and fractured. Mappable unit limited to fault-bounded sliver within Punchbowl Fault Zone in Blue Cut area in Cajon Canyon (fig. 1)

cru **Crystalline rocks, undifferentiated (age unknown)**—Highly mixed granitic and metamorphic rocks. Partly reconnaissance mapped; partly unmapped. Probably contains elements of Mount Lowe Intrusive Suite, mixed metamorphic and granitic rocks of Big Dalton Canyon (MzPb), and Cretaceous granitic rocks. Contacts with mylonitic orthogneiss related to Vincent Thrust (KPm) and undifferentiated unit (Trlu) of Mount Lowe Intrusive Suite are highly gradational and poorly established

ROCKS BOUNDED BY THE MILL CREEK FAULT AND SAN ANDREAS FAULT

Mill Creek Formation of Gibson (1971) (Miocene)—Nonmarine claystone, mudstone, sandstone, and conglomerate; probably late Miocene (Woodburne, 1975). Nonconformably overlies gneissic granitiod rocks and gneiss unit (gg); upper contact is erosional. Gibson (1964, 1971) applied name Mill Creek Formation to outcrops Vaughan (1922) originally grouped within his Potato Sandstone. Here, Mill Creek Formation is restricted to beds between San Bernardino and Wilson Creek strands of San Andreas Fault. Five informal subunits are recognized based on overall lithologic character. Subunits intertongue with one another, but order of description approximates stratigraphic order from youngest to oldest. Includes:

Tmm **Mudstone unit**—Mudstone predominates over sandstone. Chiefly thin- to medium-bedded claystone, mudstone, and siltstone; sandstone distinctly subordinate. Has massive appearance, but contains flat to irregular laminations that range from faint to prominent. Fine-grained rocks are greenish-gray, greenish-brown, and brown. Locally contains mudcracks, flat-pebble conglomerate, and possibly mudchip-breccia. Unit is recessive

Tmcv **Volcanic-clast-bearing unit**—Sandstone and pebble-cobble-bearing sandstone; fine- to coarse-grained, moderately well to well sorted, pale-brown to light-gray, weathers pale tan. Contains clasts of aplite, granitoid rocks, and gneiss, but characterized by rounded to subrounded pebbles and small cobbles of volcanic rocks, including latite, quartz latite, basaltic andesite, and andesite. Medium to very thick bedded. Lenticular bedded; lenses range from tens to hundreds of meters long. Ledge forming

Tms **Sandstone unit**—Sandstone predominates over mudstone. Sandstone is yellowish-gray, gray, and pale brown. Bedding ranges from massive to laminated (photo 321); cross lamination and graded bedding common; convolute laminated and pillow-and-ball structure locally (photos 322 and 323)

Tma **Arkose unit**—Stratigraphic interval dominated by pale-brown to yellowish-tan weathering arkosic sandstone. Pebbly and cobbly sandstone and conglomerate lenses locally abundant; clasts are rounded to subangular, and consist mainly of leucocratic granitoid rocks and gneiss, some muscovite-bearing. Framework grains and conglomerate matrix are feldspar-rich and locally contain detrital muscovite. Medium to very thick bedded. Lenticular bedded; lenses range from tens to hundreds of meters long

Tmcp **Pelona Schist-bearing conglomerate unit**—Sandstone, pebbly sandstone, and pebble-cobble conglomerate characterized by clasts of bluish-gray, coarsely crystalline Pelona Schist (photo 325). Thick- to very thick-bedded, brownish-gray to greenish-gray weathering (photo 324). Moderately to poorly sorted. In addition to Pelona Schist, clasts include dark-green gneissic diorite, intermediate composition granitoids, milky vein quartz, aplite and alaskite, and rare volcanic rocks. Schist clasts are similar to bedrock of unit Kps that Mill Creek Formation depositionally overlies in east part of quadrangle. Ledge forming

Tw **Formation of Warm Springs Canyon (Miocene)**—Nonmarine sandstone and conglomerate. Heterogeneous; consists of sedimentary rocks dominated by well sorted to poorly sorted sandstone, conglomerate, and conglomeratic sandstone interlayered with mudrock in some stratigraphic intervals. Clasts range from pebbles to large cobbles; typically pebbles and small cobbles, and are subangular to subrounded, dominated by leucocratic to mesocratic gneissic rocks and leucocratic granitoid rocks. Hornblende diorite-gabbro clasts are minor but distinctive. Unit occupies same structural position as conglomerate, sandstone, and arkose unit (Tsg) to northwest, but probably does not contain some older elements included in that unit. Base of unit is faulted against Mesozoic orthogneiss of Alger Creek (Mzga), but equivalent deposits east of quadrangle rest depositionally on crystalline rocks of San Bernardino Mountains assemblage. Upper contact is erosional

Tsg **Conglomerate, sandstone, and arkose (Miocene)**—Conglomerate and lithic, conglomeratic arkose. Clasts range from 1 cm to about 20 cm, poorly sorted, subangular to well rounded. Matrix- and clast-supported. Most derived from granitic and gneissic rocks, but subordinate amount of quartzite, vein quartz, calc-silicate rock, and silicic volcanic rocks. Arkose is pale pink, gray, and greenish-brown. Most of unit lacks conspicuous bedding, but locally is well bedded where arkose lenses are abundant. From approximately City Creek (fig. 1) southeastward, unit contains fault-bounded wedges of well lithified, interbedded sandstone, shale, and conglomerate, which may be Paleocene San Francisquito Formation or more probably Cretaceous Sedimentary rocks of Cosy Dell area. Proportion of unit southeast of City Creek that is possible San Francisquito Formation or sedimentary rocks of Cosy Dell area is unknown. Because Tsg is fault-bounded and may be comprised of more than one unit, thickness is unknown. Restricted to zone bounded by Mill Creek and Mission Creek strands of San Andreas Fault

Mzir **Inclusion-rich granitoid rocks (Mesozoic)**—Narrow elongate zones of mafic inclusions enclosed by gneissic granitoid rocks and gneiss unit (gg). Restricted to very small exposures near area where Santa Ana River exits San Bernardino Mountains; probably more Mzir than shown on map. Most inclusions are diorite to quartz diorite, some gabbro, typically flattened and ovoid

Mzc **Diorite of Cram Peak (Mesozoic)**—Biotite-hornblende quartz-bearing diorite. Forms elongate, partly fault-bounded bodies east of Santa Ana River in southeastern part of San Bernardino quadrangle. Medium- to coarse-grained. Color index about 18; hornblende and biotite subequal. Some hornblende to 1.5 cm long. Plagioclase is sodic to intermediate andesine. Orthoclase is very sparse and interstitial to plagioclase and quartz. Quartz averages about 4 percent. Rock ranges from massive to having well developed foliation. Intrudes gneissic granitoid rock and gneiss unit (gg). Compositionally similar to Jurassic granitic rocks in region, but could be Cretaceous or Triassic

Mzgu **Granitoid rocks (Mesozoic)**—Light-gray to pinkish-gray, texturally massive to slightly foliated, medium- to coarse-grained, biotite-bearing, leucocratic granitoid rock that is monzogranite to granodiorite in composition. Rock locally has potassium feldspar phenocrysts as much as 1 cm long

Mzgy **Mesocratic granitoid rocks (Mesozoic)**—Fine- to coarse-grained granodiorite, tonalite, and quartz diorite; highly weathered. Has variable, but distinctly higher color index than granitoid rocks unit (Mzg). Forms small bodies in gneissic granitoid rocks and gneiss unit (gg)

Mzga **Orthogneiss of Alger Creek (Mesozoic)**—Light-gray, fine- to medium-grained biotite-hornblende granodiorite having well developed lenticular laminated fabric resulting from streaks of quartz, pink feldspar, and mafic aggregates. Locally encloses thin lenses of foliated amphibolite. Unit commonly is sheared and fractured, and weathers to dark brown color. Named for Alger Creek in quadrangle to east where unit crops out directly northeast of Mill Creek strand of San Andreas Fault

gg **Gneissic granitoid rocks and gneiss (age unknown)**—Crystalline rocks characterized by compositional and textural heterogeneity and well developed gneissic fabric resulting from alternating mafic-rich and mafic-poor layers. Compositional layering ranges from millimeter and centimeter laminations to layering tens of meters thick. Mafic layers are biotite-rich, typically internally foliated, and range in composition from granodiorite to tonalite. Mafic-poor layers are quartzofeldspathic, texturally massive to foliated, and generally are granodiorite, but include monzogranite, tonalite, and rarely quartz monzodiorite. Unit contains zones of concentrated inclusions and attenuated dikes of mafic granitoid rock; some mapped (Mzi), but most are only a few meters wide. Unit locally cut by low-angle shear zones (photo 320); rocks throughout unit are fractured. Age and protolith unknown. Unit probably is plutonic complex of heterogeneous mafic and intermediate rocks deformed during or subsequent to intrusion. Part of unit may be related to diorite of Cram Peak (Mzc)

SAN BERNARDINO MOUNTAINS ASSEMBLAGE

Qb **Sedimentary breccia of Meisling (1984) (Pleistocene)**—Well cemented, pale-gray to pale-tan sedimentary breccia. Restricted to small outcrops in northern San Bernardino Mountains, north of Juniper Flats. Clasts are mostly Paleozoic carbonate rocks. Relation to other Quaternary units is unknown, but appears to be older than Qvof

QTsb **Conglomerate, conglomeratic arkose, and clayey arkose (Pleistocene and Pliocene)**—Consolidated to poorly indurated conglomerate and conglomeratic arkose. Restricted to area west of White Mountain (fig. 1), near eastern edge of San Bernardino quadrangle. Upper 1 to 4 m of unit are highly pigmented (5YR 4/6 to 7.5YR 4/6), main body of unit much less so, grading to medium brown. Highly pigmented (5YR 4/6 to 7.5YR 4/6) sediment that appears to be stratigraphiclly lower than pigmented upper part of unit may represent buried soil horizons. Clasts range from small pebbles to 40 cm-wide boulders; subangular to moderately rounded. Matrix ranges from fine silt to coarse sand; poorly sorted. Clasts are marble, quartzite, and granitic rocks, all of which appear to be locally derived from identifiable San Bernardino Mountains sources; no clasts of volcanic rocks or metavolcanic rocks were found that would suggest northern source area

Qsh **Shoemaker Gravel (Pleistocene)**—Conglomerate, lithic arkosic conglomerate, and lithic arkosic sandstone. Pale grayish-brown; moderately well consolidated. Clasts range in size from pebbles to meter-wide boulders, and are typically subrounded to rounded. Numerous conglomerate and conglomeratic arkose lenses, commonly meters thick, define bedding, but overall, unit has massive appearance. Clast composition includes large variety of granitic types ranging from monzogranite to mafic tonalite and monzonitic rocks of Triassic Mount Lowe Intrusive Suite. Unit also contains clasts of Pelona Schist, volcanic rocks, and Tertiary sedimentary rocks. Contact with underlying Harold Formation (Qh) is gradational (photo 361); unconformably overlain by very old Quaternary fanglomerate deposits (Qvof). Unit is locally about 100 m thick, tapering to zero thickness southeastward and northwestward; extent beneath Qvof deposits is unknown. M.D. Kenney (written commun., 1999) considers Shoemaker Gravel to be time-transgressive, oldest to southeast and youngest to northwest

Qh **Harold Formation (Pleistocene)**—Sandstone, conglomeratic sandstone, and lesser conglomerate in relatively thin beds and lenses (photo 361). Tan to light-brown. Contains discontinuous carbonate-cemented layers. Moderately well consolidated, but very friable. Most clasts are subrounded to moderately rounded, and include Pelona Schist, rocks of Mount Lowe Intrusive Suite, and gneiss, all characteristic of basement rocks of northeastern San Gabriel Mountains. Ranges from about 150 m thick near Sheep Creek to about 75 m thick a few kilometers west of Cajon Pass (photo 351). East of Cajon Pass, Harold Formation is difficult to confidently distinguish from Shoemaker Gravel, so there, all sedimentary rocks above Phelan Peak deposits of Weldon (1984) (QTpp) or Crowder Formation (Tcr) and below very old alluvial fan deposits (Qvof) are mapped as Shoemaker Gravel

QTpp **Phelan Peak deposits of Weldon (1984), undifferentiated (Pleistocene and Pliocene)**—Interbedded siltstone, claystone, siliceous ash, sandstone and lesser conglomerate (photo 355) (Meisling and Weldon, 1989, Kenney, written commun., 1999). Conglomerate clasts are both derived from nearby basement and recycled from older sedimentary units. Clasts include marble, granitic, volcanic, and variety of metamorphic rocks. Unit contains paleosols, carbonate-cemented layers (photo 357), and fresh-water gastropod-bearing layers; thickness up to 500 m (Meisling and Weldon, 1989). Some rocks mapped as Crowder Formation (Tcr) east of Mojave River, probably include Phelan Peak deposits of Weldon (1984) and may include Harold Formation

$QTpp_3$ **Phelan Peak deposits of Weldon (1984), Unit 3 (Pleistocene and Pliocene)**—Claystone and siltstone containing lesser sandy zones in which sand is either disseminated or restricted to beds. Includes argillic paleosols and carbonate-cemented layers. Very similar to Unit 1 (Tpp_1). Bruhnes-Matayama polarity reversal is contained in this unit (Meisling and Weldon, 1989)

Tpp_2 **Phelan Peak deposits of Weldon (1984), Unit 2 (Pliocene)**—Sandstone, conglomeratic sandstone, and lesser conglomerate. Contains marble clasts considered by Foster (1980) to be derived from Table Mountain area, and by Weldon and others (1993) from Liebre Mountain area on southwest side of San Andreas Fault. Unit is noticeably coarser grained and more conglomeratic than Unit 1 (Tpp_1) or Unit 3 ($QTpp_3$) (Meisling and Weldon, 1989; Foster, 1980)

Tpp_1 **Phelan Peak deposits of Weldon (1984), Unit 1 (Pliocene)**—Claystone and siltstone containing lesser sand that is both disseminated and restricted to beds. Includes argillic paleosols, carbonate-cemented layers, and gastropod-bearing siltstone. Orangish-brown; moderately well to very well consolidated (M.D. Kenney, written commun., 1999). Contains 3.8 Ma ash bed found in Cajon Pass area and in Mescal Creek area (Weldon and others, 1993). Unit previously referred to as volcanogenic unit of Crowder Formation by Foster (1980). Other than ash bed, unit is very similar to Unit 3 ($QTpp_3$)

Tcc **Conglomerate of Crestline (Pliocene?)**—Conglomerate and conglomeratic arkose. Restricted to a few small areas west of Crestline. Clasts range from pebbles to small boulders, poorly sorted, subangular to rounded. Dominantly matrix-supported. Clasts appear to be derived from San Bernardino Mountains granitic units. Gray and greenish-gray. Bedding is indistinct, except where arkose lenses are abundant. Age and relation to other Tertiary units on south side of San Bernardino Mountains is unknown

Tcf **Conglomerate of Fredalba (Pliocene?)**—Conglomerate and lesser interbedded arkosic conglomerate; matrix is poorly sorted lithic arkose ranging in grain size from very fine to very coarse. Restricted mainly to area around Fredalba and Running Springs, and to few smaller areas south of Lake Arrowhead. Pale tan to nearly white. Poorly bedded, matrix- and clast-supported boulder conglomerate containing sparse arkosic lenses up to 40 cm thick and 50 m long (photo 342). Predominant clasts are slightly porphyritic biotite monzogranite probably derived from Cretaceous monzogranite of City Creek (Kcc). Many boulders are weathered, presumably in-place, because weathered boulders are too friable to survive stream transport. Other clast types include fine-grained, leucocratic, granitic rocks, pegmatite, and mafic, fine-grained dike rocks. Average clast size is about 40 cm across, ranging up to 1 m across. Age and relation to other Tertiary units on south side of San Bernardino Mountains is unknown

Tcu **Conglomerate and arkose, undifferentiated (Pliocene)**—Conglomerate and arkose. Pale tan and pale pinkish-tan. Bedding defined by conglomeratic lenses in arkose; channel and fill common. Restricted to several, mostly fault-bounded areas between City Creek and Waterman Canyon (fig. 1). Thickness unknown. Meisling and Weldon (1989) consider unit to be easternmost part of Crowder Formation. Also similar to Pliocene and Miocene Santa Ana Sandstone (Tsa)

Tav **Anaverde Formation, undifferentiated (Pliocene)**—Arkosic sandstone and lesser clayey shale and conglomerate. Coarse-grained, white to reddish-brown, massive to poorly bedded, weakly to fairly well consolidated (Barrows, 1979, 1987). Includes:

Tavc **Clay-shale unit**—Clayey shale interbedded with sandy siltstone, and locally, arkosic sandstone. Light to dark gray grading to brown, thin bedded, sandy, silty; locally contains abundant gypsum. Arkosic sandstone is pale tan and medium bedded. Leaf fragments present in some beds. Parts of unit develop expansive clay soils (Barrows, 1987)

Tavb **Pale-tan arkose unit**—Pebbly arkose; silty interbeds in upper part of unit. Pale tan to gray, medium bedded to massive, medium to very coarse grained. In eastern part, contains carbonaceous material and plant fragments in locally occurring, flaggy, micaceous siltstone layers. In places conglomeratic, containing subangular to subrounded granitic rocks of unknown provenance in arkosic matrix (Barrows, 1987)

Tavr **Red arkose unit**—Pebbly arkose, and in lower part, arkosic conglomerate. Pink to brownish red, coarse grained, medium to thick bedded. Very angular to subangular pebbles and cobbles of biotite-hornblende diorite in lower conglomeratic part (Barrows, 1987)

Tavw **White arkose unit**—Arkosic sandstone. Massive, coarse-grained; resembles weathered granitic rocks, because weathered casts look like matrix. Clasts are angular, equant grains of granitic rocks ranging in composition from granite to diorite. Locally, unit contains sparse, red-brown silty layers. Grades upward into red arkose member (Tavr) (Barrows, 1987)

Tss **Santa Ana Sandstone (Pliocene and Miocene)**—Arkosic sandstone and conglomeratic arkosic sandstone. Characterized by very abundant detrital biotite in almost all rocks. Pale gray to pale brownish- and pinkish-gray. Well consolidated to moderately well lithified; in places, supports 25-m-high nearly vertical cliff faces (photo 341). Most of unit is massive appearing, but bedding is relatively well defined by numerous, 5-cm-thick to 50-cm-thick lenses of conglomeratic arkose and by 5-cm-thick to 20-cm-thick lenses of sandy siltstone. Clasts range from pebbles to boulders that are angular to subrounded. Most are biotite monzogranite probably derived from monzogranite of City Creek (Kcc) and monzogranite of Keller Peak (Kk). Matrix is poorly sorted, angular to subrounded, medium to very coarse grained. Very fine-grained silty, argillaceous, and possibly calcareous material is interstitial to matrix grains. Irregularly bedded, greenish-gray and brownish-gray siltstone and mudstone near base of unit (photo 340). Up to 320 m thick in quadrangle, possibly thicker to east (Jacobs, 1982). Monzogranite locally thrust over upper part; elswhere, unit is unconformably overlain by Quaternary deposits. Contains basalt flow yielding 6.2 Ma whole-rock potassium-argon age (Woodburne, 1975)

Tcr **Crowder Formation, undifferentiated (Miocene)**—Arkosic sandstone, pebbly arkosic sandstone, and conglomerate. Formation is a generally, but very irregularly fining-upward sequence. Pale pinkish-tan, pale gray to near-white, and pale brown. Bedding characteristics range widely from non-parallel lensoidal beds characterized by large-scale trough cross-bedding and channel and fill, to parallel-planar and near-massive. Much of upper part of unit is indistinctly bedded, almost massive-appearing silty, arkosic sandstone containing sparse, matrix-supported pebbles and cobbles that do not define bedding. Locally subdivided into 5 subunits by Foster (1980). Differences between Crowder subdivisions are very subtle, and are not applicable formation-wide. Any particular subunit cannot be confidently identified in non-contiguous areas unless nearly complete bounding subunits are present. Combined color, induration, and bedding characteristics are used to distinguish Crowder Formation from other late Tertiary and early Quaternary units. Crowder contains no Pelona Schist or rocks of Mount Lowe Intrusive Suite. Some rocks mapped as Crowder Formation east of Mojave River, probably include Phelan Peak deposits of Weldon (1984) (QTpp). Local subdivisions includes:

Tcr_5 **Crowder Formation, Unit 5**—Pebbly arkose and arkosic conglomerate. Pale pink to pale tan, coarse-grained, medium to thick bedded, poorly bedded. Unit represents slight reversal to poorly defined fining-upward trend in formation

Tcr_4 **Crowder Formation, Unit 4**—Arkosic sandstone and pebbly arkosic sandstone. Most is medium to fine grained, and contains relatively large fraction of silt and possibly clay. Compared to older Crowder units, unit 4 has very little conglomerate in beds or lenses, and contains widely scattered, isolated pebbles to large cobbles. Tan to pale-brown. Some bedding similar to Unit 1 (Tcr_1), but much of unit is massive appearing

Tcr_3 **Crowder Formation, Unit 3**—Arkosic sandstone and pebbly arkosic sandstone. Pale pinkish-tan to pale grayish-white. Well consolidated to slightly indurated. Appears to have fewer and thinner conglomeratic lenses than unit 1 (Tcr_1), but contains some as thick as 2 m. Other bedding characteristics and clast composition similar to that in unit 1 (Tcr_1)

Tcr_2 **Crowder Formation, Unit 2**—Lithic arkose. Greenish-gray, grayish-orange, and pale pink. Noticably less consolidated than bounding units; forms badland topography. Restricted occurance east of Cajon Junction; pinches and loses definition eastward

Tcr_1 **Crowder Formation, Unit 1)**—Arkosic sandstone, pebbly arkosic sandstone, and minor conglomerate (photo 352). Most is pale pinkish-tan. Well consolidated to slightly indurated; supports high, steep road-cuts and high canyon walls of downcut streams (photos 351 and 353), but most natural exposures are rounded and covered with weathered or eroded debris. Contains widely scattered, matrix-supported, large cobble and small boulder clasts, and sparse, widely spaced, 2-cm-thick to 3-m-thick lenses of cobble to boulder conglomerate; most lenses less than 15 cm thick. Clasts are angular to well rounded, average is subrounded. Chief clast types are fine and coarse grained, relatively leucocratic biotite monzogranite, and lesser metavolcanic rock, quartzite, dark gray hornfelsic rock, epidote-quartz rock, and possibly aphanitic, non-vesicular basalt. Unit contains irregularly spaced, sparse, lensoidal beds of light brown, medium to fine grained arkosic, biotitic sandstone that may be slightly carbonaceous and ranges in thickness from 2 cm to about 1 m. Bedding is mainly non-parallel, discontinuous, lensoidal, and characterized by large-scale trough cross-bedding and channel and fill. In some road cuts, bedding is 70 cm to 1 m thick, and parallel-planar; lateral extent of individual beds is unknown

Cajon Valley Formation (Miocene)—Arkosic conglomerate and conglomeratic sandstone, interbedded with arkosic and biotitic sandstone and siltstone. Conglomerate content of formation decreases upward in section; upper part of formation contains minor lignite and limestone. About 2,400 m thick. Subdivided into 6 units and one subunit. Nearly all contacts are gradational. Bedding is discontinuous, nonparallel, and typically lensoidal. Large- and small-scale cross-bedding very common. Finer grained beds are more laterally continuous than coarser grained beds. Descriptions of formation and its subdivisions are taken largely from Woodburne and Golz (1972), although they referred to unit as Punchbowl Formation. For unit nomenclature, we follow later usage of Foster (1980). Consists of:

Tcv_6 **Cajon Valley Formation, Unit 6**—Conglomeratic sandstone and sandstone. Contains abundant clasts of dark-green and maroon porphyritic tuff and flow rock of latite composition. Interbedded with subordinate varicolored siltstone and fine-grained sandstone; also contains pale-green mudstone near middle of unit. Similar to unit 4 (Tcv_4), but differs in that metavolcanic rock clasts are much more uniformly colored than those in unit 4. Thickness is about 275 m, but upper contact is unconformity. Unfossiliferous (Woodburne and Golz, 1972)

Tcv_5 **Cajon Valley Formation, Unit 5**—Heterogeneous sequence of interbedded conglomerate and conglomeratic sandstone, pebbly fine- and coarse-grained sandstone, and siltstone. Near middle of unit, includes sparse thin beds of black mudstone, plant-bearing lignite, and pale-gray to tan, impure, fresh-water limestone. Conglomeratic rocks are mottled maroon and gray similar to those in unit 4. Fine-grained sandstone beds are purplish-green, greenish-brown, and maroon. Medium-grained sandstone is yellowish-tan and contain sparse cobbles of granodiorite. Lateral variation of relative proportions of sedimentary rock types varies greatly. Fresh-water limestone contains invertebrate fossils and clastic rocks contain vertebrate fossils, none of which are sufficient for precise dating. From stratigraphic position, unit is considered late Miocene (Woodburne and Golz, 1972). Includes:

Tcv_{5a} **Cajon Valley Formation, Unit 5a**—Conglomerate and conglomeratic sandstone. Reddish-brown; contains cobbles and pebbles noticeably more angular than elsewhere in Cajon Valley Formation. Clasts are chiefly gneiss, marble, and quartzite, and lesser granodiorite and fine-grained schist. Unit is at least 880 m thick, but is not differentiated from surrounding units everywhere on map. Appears to be wedge-shaped, interfingering with unit 5 (Tcv_5)

Tcv_4 **Cajon Valley Formation, Unit 4**—Arkosic conglomerate and conglomeratic sandstone. Includes abundant interbeds of arkosic, pebbly, fine- to medium-grained sandstone, and siltstone locally in uppermost part of unit. Mottled maroon and pale-grayish-tan, locally white. Well indurated; forms cliffs and hogbacks. Similar to unit 2 (Tcv_2), but differs by clast content that includes very abundant, multicolored metavolcanic rocks of latite to quartz latite composition, and by nearly total absence of fine-grained metamorphic rocks. Maximum thickness about 210 m. Unfossiliferous (Woodburne and Golz, 1972)

Tcv_3 **Cajon Valley Formation, Unit 3**—Arkosic conglomerate and conglomeratic sandstone interbedded with coarse- to fine-grained sandstone and siltstone. Most of unit is light-gray to pale-tan, except for most fine-grained sandstone and siltstone beds which are reddish-brown. Induration of coarse-grained rocks about same as in unit 2 (Tcv_2), but finer grained rocks are less resistant. Gradationally overlain by unit 5 (Tcv_5), and to south truncated by wedge of unit 4 (Tcv_4). Thickness varies from about 150 to about 275 m. Contains vertebrate fossils, including *Merychippus tehachapiensis* indicating probable middle Miocene age (Woodburne and Golz, 1972)

Tcv_2 **Cajon Valley Formation, Unit 2**—Conglomerate and conglomeratic sandstone. Contains interbeds of light gray to light tan, fine-grained sandstone which increase up section. Reddish-brown, fine-grained sandstone and siltstone beds common in upper part of unit. Well indurated, forms hogbacks (photo 348); surfaces characterized by weathered hollows up to 1 m in diameter. Differs from Unit 1 (Tcv_1) by much higher degree of induration, greater yellow to tan pigmentation, and higher proportion of reddish-brown, fine-grained sandstone beds. Ranges in thickness from 425 to 550 m. Contains *Merychippus tehachapiensis* indicating probable middle Miocene age (Woodburne and Golz, 1972)

Tcv_1 **Cajon Valley Formation, Unit 1**—Arkosic conglomerate and conglomeratic sandstone. Pale gray to white. Interbedded with fine-grained sandstone and siltstone. Nonresistant to moderately resistant. Vertically and possibly laterally gradational with unit 2 (Tcv_2). Thickness ranges from 210 to 300 m (Woodburne and Golz, 1972)

Tv **Vaqueros Formation (Miocene and Oligocene)**—Marine, arkosic sandstone, sandstone, and siltstone. White, coarse-grained, fossiliferous, arkosic sandstone and brown, flaggy, concretionary sandstone and siltstone in lower part. Alternating reddish-brown and light-gray, fine-grained sandstone and siltstone in upper part (Woodburne and Golz, 1972). About 150 m thick near Cajon Junction; thins to southeast and northwest. Contains *Turritella inezana* and cetacean vertebrae

TKmg **Mafic granodiorite (Tertiary or Cretaceous)**—Medium- to fine-grained hornblende-biotite granodiorite; highly seriate. Color index about 20. As mapped, restricted to two dikes, one in western Granite Mountains, other on east side of Lovelace Canyon (fig. 1) in northern San Bernardino Mountains; latter is highly porphyritic, containing abundant 2-cm-long potassium feldspar phenocrysts. Numerous other dikes too small to show at map scale found in and around San Bernardino Mountains. Age based on intrusive relations with Cretaceous plutons and similarity to both Tertiary and Cretaceous mafic dikes

Kcd **Sedimentary rocks of Cosy Dell area (Cretaceous)**—Thin- to medium-bedded arkosic sandstone and siltstone. Restricted to several small, noncontiguous areas on north side of San Andreas Fault near Cosy Dell (fig. 1) and in eastern part of Lone Pine Canyon (Woodburne and Golz, 1972). Sandstone is fine to coarse grained, tan, brown, and shades of tannish gray. Bedding is irregular, parallel planar, and lensoidal (photos 345 and 346); cross lamination fairly common. Contains conglomerate and conglomeratic layers (Kcdc), especially in lower part (photos 343 and 344). Unconformably deposited on granitic and gneissic rocks, and faulted against Cajon Valley Formation (photo 347); unknown amount of upper part not preserved. Age is based on occurrence of sparse *elasmosaurid* Pleisiosaur remains (Kooser, 1985; Lucas and Reynolds, 1991). Includes:

Kcdc **Sedimentary rocks of Cosy Dell area, conglomerate (Cretaceous)**—Coarse boulder and cobble conglomerate as thick as 60 m at base of sedimentary rocks of Cosy Dell area (Kcd), and thinner cobble and pebble conglomerate higher in unit. Basal conglomerate consists of angular and subrounded clasts (photos 343 and 344) of granodiorite and gneiss of unknown, but possibly local, provenance; both clast and matrix supported. Volcanic clasts common in early Tertiary conglomeratic units in region appear to be absent (Woodburne and Golz, 1972). Bedding is indistinct except where lenses or beds of sandstone are present

KJhs **Mixed granitic rocks of Hopi Spring (Cretaceous and Jurassic)**—Biotite quartz monzonite or quartz monzodiorite intruded by small to moderate amounts of monzogranite of Coxey Road (Kcr). Underlies irregular shaped area 12 km northeast of Lake Arrowhead (fig. 1). Contacts with monzogranite are highly gradational. Quartz monzonite or quartz monzodiorite is medium to coarse grained, except constituent biotite is medium to fine grained. Quartz averages 10 to 15 percent of rock. Plagioclase is sodic andesine; potassium feldspar is orthoclase. Color index ranges from 15 to 20; biotite is only mafic mineral, but opaque mineral(s) much more abundant than in other units of similar composition. Sphene is abundant, allanite and epidote present but sparse. Texture is seriate; no obvious directional fabric. Cretaceous and Jurassic age based on textural similarities with nearby Cretaceous granitic rocks, and of quartz monzonite or quartz monzodiorite composition with nearby Jurassic granitic rocks

KJos **Mixed granitic rocks of Oak Spring (Cretaceous and Jurassic)**—Predominantly biotite quartz monzodiorite, but includes abundant dikes, pods, and irregular masses of monzogranite of City Creek (Kcc). Underlies small, irregularly shaped area northeast of Luna Mountain (fig. 1), 13 km north-northeast of Lake Arrowhead. Quartz monzodiorite is medium grained, containing about 15 percent quartz. Plagioclase is intermediate to calcic oligoclase; potassium feldspar is microcline. Color index averages 18; biotite is only mafic mineral. Contains abundant sphene and opaque mineral(s), and trace epidote and allanite. Texture is even grained. Contacts with surrounding units are gradational over several tens of meters. Age based on compositional and textural similarities to nearby rocks of both Cretaceous and Jurassic age

KJsp **Mixed granitic rocks of South Peak (Cretaceous and Jurassic)**—Biotite quartz monzonite, ranging to quartz syenite, and containing abundant inclusions, and small screens of Cambrian and Late Proterozoic metasedimentary units. Also includes minor leucocratic monzogranite probably of Cretaceous age. Main mass of granitic rock is shown on map, but dikes, sills, and irregular masses are found over much of White Mountain area (fig. 1) and westward. Biotite quartz monzonite is medium to coarse grained and equigranular to seriate. Plagioclase is calcic oligoclase. Potassium feldspar is highly perthitic microcline, and very abundant; rocks have very high potassium feldspar to plagioclase ratio. Color index varies widely from about 3 to about 15; biotite is only mafic mineral. Texture ranges from equigranular to seriate. Unit has compositional and textural characteristics of both Cretaceous and Jurassic plutons in region

KTRmm **Mixed monzogranite and leucocratic monzonite (Cretaceous and Triassic)**—Leucocratic hornblende monzonite cut by dikes and small bodies of biotite monzogranite, and hornblende-biotite monzogranite that ranges to granodiorite and possibly quartz monzodiorite. Forms irregular shaped bodies in western Granite Mountains (fig. 1)

Mzgr **Biotite monzogranite of Big John Peak (Mesozoic)**—Biotite monzogranite. Forms small, partly fault-bounded pluton about 12 km northwest of Wrightwood (fig. 1). Except for sparse, localized hornblende, biotite is only mafic mineral; color index averages 5, but varies widely. Contains thin, lenticular inclusions of layered gneiss, schist, and marble. Medium- to fine-grained; has faintly developed foliation in parts of unit, especially near contacts with host rocks. Relatively homogeneous compared to nearby granitic units. Conventional potassium-argon biotite age is 69 Ma, but is considered cooling age, not emplacement age (Miller and Morton, 1980). Probably Cretaceous based on compositional and textural similarities to Cretaceous plutons in region, but could be Jurassic

Mzgd **Gneissic granodiorite of Holcomb Ridge (Mesozoic)**—Hornblende-biotite granodiorite. Forms noncontiguous bodies east and west of mouth of Mescal Creek, 13 km west of Phelan (fig. 1). Biotite dominant, hornblende minor; color index averages about 12. Medium-grained, irregularly porphyritic. Moderately to poorly developed foliation is defined by alternating fine- and coarse-grained layers, and by thin layers of segregated hornblende. Contains moderately abundant inclusions of marble, schist, and mafic gneiss oriented parallel to foliation. Intrudes MzPzm and Mzgn. Cut by numerous pegmatite, alaskite, and aplite dikes. Characterized by cuniform metallic mineral contained within large sphene crystals (Kenney, 1999). Considered correlative with granodiorite at Squaw Peak (Kenney, 1999) which yields uranium-lead zircon age of 75 to 81 Ma (Silver and others, 1988)

Mzog **Heterogeneous hornblende-biotite orthogneiss (Mesozoic)**—Hornblende-biotite orthogneiss; granodiorite ranging to monzogranite in composition. Forms numerous irregular shaped masses in mixed orthogneiss, paragneiss, and granitic rocks unit (Mzgn) about 10 km west-southwest of Phelan (fig. 1). Consists of thin layers containing 10 to 15 percent mafic minerals irregularly distributed in relatively leucocratic rock that in places contains small, pale pink potassium feldspar phenocrysts or porphyroblasts. Grain size ranges from fine to very coarse; mafic minerals generally finer grained than accompanying felsic minerals. Contains lenticular inclusions of gneiss and marble oriented parallel to foliation. Shows isoclinal folding on all scales. Texture and composition very heterogeneous, but not as much so as mixed orthogneiss, paragneiss, and granitic rocks unit (Mzgn), with which Mzog is intricately intermixed. Kenney (1999) considers Mzog to be younger than Mzgn

Mzh **Monzogranite and granodiorite of Holcomb Ridge (Mesozoic)**—Monzogranite and granodiorite. Monzogranite is medium to coarse grained, generally leucocratic, having biotite as only mafic mineral. Granodiorite is medium to coarse grained, moderately mafic, and typically contains hornblende and biotite. Moderately heterogeneous; probably represents more than one pluton. Unit is slightly gneissic, and contains marble, calc-silicate rocks, amphibolite, and gabbro inclusions

Mzug **Mesozoic granitic rocks, undivided (Mesozoic)**—Monzogranite to diorite, including small areas of monzonite. Underlies highly irregular area around White Mountain (fig. 1) in northeastern part of San Bernardino quadrangle. Includes heterogeneous, nondistinctive granitic rocks that cannot be assigned to larger granitic units in quadrangle. Fine- to coarse-grained; massive to foliate and lineate. Eastern part of unit is mixed monzogranite and granodiorite that resembles nearby Cretaceous rocks; color index generally less than 12. Most of unit is heterogeneous mix of monzogranite, monzodiorite, diorite, and monzonite that resembles nearby Cretaceous, Jurassic, and Triassic rocks, and has color indices ranging from 10 to 50

Mzsl **Mixed granitic rocks of Silverwood Lake (Mesozoic)**—Biotite granodiorite and monzogranite; hornblende-biotite quartz monzonite, quartz monzodiorite, and tonalite; hornblende monzonite. Very heterogeneous unit that includes numerous granitic rock types, and elements of several distinct intrusive events. Color index ranges from 10 to 35. Most constituent rock types contain abundant, but, in several cases, irregularly distributed sphene. Texture variable, but many parts of this composite unit are deformed, having flattened, recrystallized, sutured quartz, and bent and milled feldspars. Eastern part of unit is cut by abundant unmapped dikes and irregular shaped bodies of Cretaceous monzogranite of City Creek (Kcc), Cretaceous monzogranite of Kinley Creek (Kkc), pegmatite, and alaskite. Unit at most places is very deeply weathered Based on comparisons with other plutons in region, granodiorite and monzogranite are probably Cretaceous, hornblende-biotite rocks are probably Cretaceous and Jurassic, and monzonite is probably Triassic

Mzmx **Mixed mafic rocks and monzogranite (Mesozoic)**—Biotite-hornblende quartz monzodiorite and biotite monzogranite. Restricted to single, moderate-sized, partly fault-bounded body 7 km south of Lake Arrowhead (fig. 1). Compositionally and texturally heterogeneous unit. Monzogranite and associated dikes intrude quartz monzodiorite on all scales. Much of quartz monzodiorite is slightly foliated to gneissic, but is interlayered with rock having no apparent directional fabric. Quartz monzodiorite has color index of about 20; hornblende and biotite subequal. All hornblende contains very abundant round inclusions of quartz that gives grains swiss-cheese appearance in thin section. Very abundant sphene. Plagioclase averages an_{30} and sparse potassium feldspar is orthoclase. Monzogranite is even grained to subporphyritic, but typically exhibits some grain-size reduction and annealing, especially in quartz. Biotite is only mafic mineral; average color index is 10. Monzogranite is probably Cretaceous monzogranite of City Creek (Kcc). Unit Mzmx also contains numerous masses of hornblende gabbro that may be dikes, large included bodies, or both. Much of unit is internally deformed in that many constituent rock types appear to be fault-bounded and disaggregated. Monzogranite is probably Cretaceous, but precise age of other rock types is unknown, although probably Mesozoic

MzPzm **Mixed granitic and metasedimentary rocks, and gneiss (Mesozoic and Paleozoic)**—Mafic schist, leucocratic monzogranite, quartzite, marble, and calc-silicate rocks; intruded by gneissic granodiorite of Holcomb Ridge (Mzgd), which constitutes a volumetrically large proportion of unit. Mafic schist is dominantly plagioclase, amphibole, and clinopyroxene, but may include biotite or garnet. Leucocratic monzogranite contains distinctive reddish-brown biotite, large bluish-gray quartz porphyroblasts, and locally, garnet. Much quartzite is impure, containing plagioclase and biotite, and is tan or green. Quartzite ranges from fine grained to very coarse grained, and some may be conglomeratic. Protolith of metasedimentary rocks considered Paleozoic, but for some could be Late Proterozoic

MzPd **Gneiss of Devil Canyon (Mesozoic to Proterozoic)**—Gneiss, schist, migmatite, and granitic rock. Includes numerous pods of Paleozoic(?) marble too small to show at scale of map, especially in lower part of Devil Canyon (fig. 1); also may include larger, undetected marble bodies between Devil Canyon and Cable Canyon (fig. 1). Underlies extensive area on northeast side of San Andreas Fault from north of San Bernardino to Big John Peak area (fig. 1). Most of unit is layered biotite-quartz-microcline-plagioclase gneiss, but muscovite and garnet zones are present locally, and hornblende-rich zones are common. Large, irregularly shaped pods of foliated granitic rocks are also common. Schistose biotite-rich zones are relatively thin and sparse. Parts of unit lack prominent layering and resemble massive augen gneiss and metamorphosed pegmatite bodies. Discordant dikes, pods, and small bodies of granitic rocks are probably related to Cretaceous and Jurassic plutons. Age of gneissic part of unit is uncertain, but elements could range from late Mesozoic to Proterozoic. Appears to be intruded by Mesozoic mixed granitic rocks of Silverwood Lake (Mzsl) and Cretaceous or Jurassic quartz monzonite of Crestline (KJc). Intrusive relationship with Triassic monzonite of Cedarpines Park (Trcp) is uncertain

MzPm **Mixed granitic and metamorphic rocks (Mesozoic to Proterozoic)**—Extremely heterogeneous mixture of large and small igneous and metamorphic inclusions in leucocratic medium-grained monzogranite. Forms small body west of Lovelace Canyon (fig. 1). In much of unit, volume of inclusions exceeds volume of monzogranite containing them. Leucocratic monzogranite is composed of about equal parts intermediate oligoclase and microcline, and averages about 25 percent quartz. Color index variable, but does not exceed 5. Monzogranite is equigranular, has both medium and fine grained variants. Inclusions are derived from (1) Triassic monzonite of Fawnskin, (2) unnamed monzodiorite of probable Jurassic age, (3) fine-grained metamorphosed, leucocratic granitic rocks of unknown age, and (4) Paleozoic and (or) Late Proterozoic carbonate-bearing sedimentary rocks and fine-grained clastic rocks. Some inclusions are rounded; some are angular, especially larger ones. In addition to containing inclusions, monzogranite in small and large irregular shaped dikes cut inclusions. Unit appears to grade into Cretaceous heterogeneous leucocratic granitic rocks unit (Khl)

MzPl **Mixed granitic rocks, quartzite, and schist of Lizard Springs (Mesozoic to Proterozoic)**—Heterogeneous mixture of leucocratic biotite monzogranite, biotite quartz monzonite and quartz monzodiorite, fine- to medium-grained quartzite, and fine-grained feldspar-quartz-biotite schist. Locally, schist contains andalusite and (or) sillimanite, and very locally schist contains pods and small screens of calc-silicate rock. Leucocratic monzogranite resembles Cretaceous monzogranite of Coxey Road (Kcr), but is compositionally and texturally more heterogeneous. Quartz-deficient granitic rocks resemble Jurassic quartz monzonite of Crystal Creek (Jc), Cretaceous and Jurassic mixed rocks of South Peak (KJsp), and Jurassic quartz monzodiorite of Dry Canyon (Jd). Quartzite in unit is probably from Cambrian Zabriskie Quartzite (Єz), Cambrian Wood Canyon Formation (Єw), and Late Proterozoic Stirling Quartzite (Psu). Schist in unit probably derived from Wood Canyon Formation and calc-silicate from carbonate-bearing parts of Stirling Quartzite. Internal and bounding contacts highly gradational

Klu **Leucocratic granitic rocks (Cretaceous)**—Fine- to coarse-grained leucocratic granitic rocks, chiefly monzogranite composition; color index typically less than 3. Forms dikes, sills, pods, and small bodies in many parts of western San Bernardino Mountains, most too small to map. Typically more resistant to weathering than host rocks. Includes alaskite, pegmatite, aplite, and heterogeneous monzogranite. Large mass south of Little Shay Mountain (fig. 1) is composite body of sheet-like masses of pegmatite, micropegmatite, and monzogranite. Rocks are generally nonfoliate, nonlineate, and spatially associated with Cretaceous plutons

Krl **Leucocratic rocks of Rattlesnake Mountain pluton of MacColl (1964) (Cretaceous)**—Fine- to coarse-grained leucocratic granitic rocks, chiefly monzogranite. Spatially restricted to Cretaceous Rattlesnake Mountain pluton of MacColl (1964), but genetic association is uncertain; forms several noncontiguous bodies that mimic form of large mafic bodies in pluton. Appears to be much more uniform with respect to texture and composition than leucocratic granitic rocks unit (Kl). Distinguished by low color index and by fine-grained margins in outer 2 m of bodies. Color index rarely more than 2; unevenly distributed biotite is only mafic mineral in rock. Nonfoliate, but locally has intergranular, cataclastic grain-size reduction texture

Khl **Heterogeneous leucocratic granitic rocks (Cretaceous)**—Fine-, medium-, and coarse-grained leucocratic monzogranite, possibly ranging to quartz monzonite; fine-grained rocks vastly predominate. Irregularly mixed on scales from hand-sample to hillside. Nearly all rocks are monzogranite composition; possible quartz monzonite may represent inclusions derived from leucocratic Jurassic rocks. Plagioclase is intermediate oligoclase and potassium feldspar is microcline. Quartz averages about 20 percent of rock. Fine-grained rocks typically have color index less than 3; coarse-grained rocks, some of which contain sphene, have color index between 3 and 8. Biotite is only mafic mineral in unit regardless of grain size. Granitic texture, but locally has subtle lineation and foliation. Forms irregularly shaped body west of Lovelace Canyon (fig. 1)

Kaw **Alaskite of western Granite Mountains (Cretaceous)**—Very leucocratic monzogranite. Restricted to single pluton in western Granite Mountains, east of Apple Valley in northeastern part of quadrangle. Color index ranges from 0 to 1. Biotite is only mafic mineral; occurs as sub-millimeter grains that are partly altered. Contains 25 to 30 percent quartz. Plagioclase is intermediate albite; potassium feldspar is microcline and is more abundant than plagioclase. Contains secondary muscovite and up to 0.3 percent opaque minerals. Medium-grained, equigranular, has no foliation. Minor, localized intergranular grain-size reduction. Unit is relatively homogeneous with respect to composition, grain-size, and texture. Paucity of biotite and relatively large amount of opaque minerals may indicate unit has undergone selective alteration. Distinguished from alaskite of Sunset Cove (T̄ra) by texture, sparse biotite, and absence of fluorite and garnet. Cretaceous age assignment based on compositional and textural similarities to nearby Cretaceous granitic rocks

Kmbb **Biotite monzogranite (Cretaceous)**—Coarse- and medium-grained leucocratic monzogranite, grading to gneiss and gneissic granite. Restricted to several fault-bounded exposures in San Andreas Fault zone, 5 km southeast of Blue Cut (fig. 1), on east side of Cajon Canyon. Sub-porphyritic, containing small, poorly formed, pink potassium feldspar phenocrysts. Intensely fractured, but relatively resistant to erosion, forming smooth, rounded exposures; fractures commonly contain epidote. Cretaceous age based on similarity to nearby granitic rocks of Cretaceous age

Khr **Hybrid rocks (Cretaceous)**—Biotite monzogranite containing high proportion of evenly and unevenly mixed, partially resorbed quartzite and schist; rocks have near-granitic texture, but non-granitic compositions. Also contains irregular pods of older monzonite that have poorly defined, gradational borders

Kdp **Monzogranite of Deadman Point (Cretaceous)**—Biotite monzogranite, very quartz-rich. Restricted to single pluton in western Granite Mountains, east of Apple Valley (fig. 1) in northeastern part of San Bernardino quadrangle (photos 551, 552, and 553). Plagioclase is calcic oligoclase; potassium feldspar is microcline, which is more abundant than plagioclase. Biotite is only mafic mineral; typically occurs as 1 mm grains, much smaller than felsic minerals. Color index averages about 5. Medium- to coarse-grained. Monzogranite is relatively homogeneous, leucocratic, non-foliated, and non-porphyritic, hypidomorphic granular. Forms highly irregular body and numerous dikes. Contains numerous small pods of heterogeneous medium-to fine-grained alaskitic rock that grade into typical Deadman Point biotite monzogranite. Cretaceous age assignment based on compositional and textural similarities to nearby Cretaceous granitic rocks

Kms **Monzogranite of Muddy Spring (Cretaceous)**—Medium- to coarse-grained muscovite-biotite monzogranite. Forms very elongate, highly irregular body that intrudes Cretaceous monzogranite of Keller Peak (Kk) and Proterozoic quartzite and gneiss units west of Shay Mountain (fig. 1). Distinguished by muscovite, uniform grain size, abundant potassium feldspar (microcline), low color index, and potassium feldspar much more abundant than plagioclase (calcic oligoclase). Color index averages about 5; biotite is only mafic mineral. Muscovite is sparse and fine grained, but probably primary. Hypidiomorphic-granular; has no directional or penetrative fabric. Resembles and may be related to monzogranite of Coxey Road (Kcr)

Kkc **Monzogranite of Kinley Creek (Cretaceous)**—Muscovite-biotite monzogranite. Forms large body northwest of Lake Arrowhead. Medium-grained; locally subporphyritic. Plagioclase is intermediate oligoclase. Potassium feldspar is orthoclase and microcline, and in much of unit has slight pink tint. Biotite is only mafic mineral. Color index averages 8. Muscovite generally less than 0.5 percent of rock; some is probably secondary. Contains abundant zircon, some having much larger grain size than typical in granitic rocks. No sphene in unit. Very quartz-rich, averages 30 percent, is as high as 35 percent in some rocks. In much of unit quartz is highly strained, flattened, has sutured borders, and shows incipient grain-size reduction. Deformation not reflected in megascopic fabric.

Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

Kmc **Monzogranite of Malony Creek (Cretaceous)**—Biotite monzogranite. Forms small, elongate body 2 km north of Lake Arrowhead. Medium-grained; even-grained. Plagioclase is calcic oligoclase. Potassium feldspar is orthoclase, microperthitic orthoclase, and microcline. Potassium feldspar much more abundant than plagioclase. Biotite is only mafic mineral; color index averages 8. Trace amounts of muscovite appear to be secondary. Similar to monzogranite of Kinley Creek, but contains no primary muscovite and nearly everywhere has trace amount of sphene; unusual in this region for leucocratic, biotite-only monzogranite. In places, biotite defines crude, incipient foliation. Typically very deeply weathered. Contacts with monzogranite of City Creek (Kcc) are gradational over 10 m to 300 m and mapped locations at many places are highly subjective. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

Kbm **Heterogeneous, leucocratic biotite monzogranite (Cretaceous)**—Biotite monzogranite, ranging to granodiorite. Characterized by average color index below 3, and extreme textural inhomogeniety. Forms three small bodies south of Juniper Flat essentially graphic and myrmekitics (fig. 1), northwestern San Bernardino Mountains. Plagioclase averages intermediate oligoclase, potassium feldspar is microcline. Biotite is generally only mafic mineral, but in at least one place contains 2 percent hornblende as only mafic mineral. Locally contains up to 2 percent muscovite. Except for muscovite-bearing rocks, contains very sparse, anhedral sphene that has granular or spongy character; in region, sphene in rocks of this composition is uncommon. Textural variations include (1) even-grained, fine-grained rocks, (2) rocks that are intergrowths, and (3) rocks that are essentially the latter that contain centimeter-sized inclusions of the former. Textures are mixed on all scales, and have both gradational and sharp boundaries between textural regimes. Considered Cretaceous based on compositional similarities with nearby Cretaceous rocks, but hornblende-bearing rocks may represent inclusions of Jurassic granitic rocks

Kcc **Monzogranite of City Creek (Cretaceous)**—Biotite monzogranite, muscovite-biotite monzogranite, pegmatite, and alaskite. Very heterogeneous, containing included masses of older monzogranite, granodiorite, diorite, and gabbro ranging in length from centimeters to hundreds of meters. Most included masses are probably Cretaceous, but some could be as old as Jurassic. Biotite monzogranite and muscovite-biotite monzogranite are probably different parts of same intrusion, and make up at least 70 percent of unit by surface outcrop. Southern part of unit is relatively uniform, even-grained to subporphyritic, medium- to coarse-grained monzogranite, some of which contains muscovite and some of which does not. Most monzogranite is quartz-rich, but quartz is deformed and sutured. Biotite is only mafic mineral, and in much of unit is intergranular to felsic minerals and slightly disaggregated. In some monzogranite muscovite is primary; rarely exceeds one percent of rock. Plagioclase averages an_{20}, and is subordinate to potassium feldspar; potassium feldspar is both orthoclase and microcline. Beginning about 4 km south of Lake Arrowhead, unit becomes increasingly heterogeneous northward by increase in dike rocks and included masses of older granitic rocks. Grades into mixed granitic rocks of Heaps Peak (Kmx), in which included material constitutes up to 70 percent of rocks. Unit is typically very deeply weathered, and in southern part, highly fractured. Contact with monzogranite of Keller Peak (Kk) is poorly defined as phenocrysts in that unit decrease in size and concentration westward, and rocks are difficult to distinguish from monzogranite of City Creek. Similarity of two units suggest they could be related. Conventional potassium-argon age of biotite from muscovite-biotite monzogranite from southern part of unit is 66 Ma, but is considered cooling age by Miller and Morton (1980)

Kpbm **Porphyritic biotite monzogranite (Cretaceous)**—Coarse-grained biotite monzogranite ranging almost to syenogranite. Forms small irregular shaped body about 4 km west of Rattlesnake Mountain (fig. 1). Texturally and mineralogically uniform. Contains microcline phenocrysts to several centimeters long. Biotite is only mafic mineral; color index about 10. Plagioclase averages an_{20}; distinctly subordinate to potassium feldspar, which is all microcline. Abundant quartz, none of which is deformed. Groundmass texture is even grained to seriate, no directional fabric. Ranges from medium to coarse grained. Contains no sphene, but has moderately large, anhedral allanite. Cretaceous age assignment based on compositional and mineralogical similarity to nearby Cretaceous granitic rocks

Kk **Monzogranite of Keller Peak (Cretaceous)**—Medium- to very coarse-grained biotite monzogranite. Forms very large body southeast of Lake Arrowhead, that extends at least 5 km east of quadrangle. Grain size is coarse to very coarse in eastern part of unit, grading nonuniformly to medium grained in western part. As mapped, coarse-grained, highly prophyritic easternmost part may represent a separate intrusion. In western part, is similar to monzogranite of City Creek (Kcc). Irregularly porphyritic; has sparse, 2-cm-long, well-formed microcline phenocrysts, especially in eastern part; some are pink. Plagioclase is calcic oligoclase to sodic andesine. Contains sparse sphene in eastern part of unit, largely absent in western part. Average color index 9; relatively uniform throughout unit. Biotite is only mafic mineral. In western part, rock contains trace amounts of muscovite, which may or may not be primary. Texture is hypidiomorphic-granular; rock has no directional fabric. Conventional K-Ar age on biotite is 71 Ma; considered cooling age (Miller and Morton, 1980)

Kbp **Monzogranite of Butler Peak (Cretaceous)**—Fine- to medium-grained muscovite-biotite monzogranite. Forms north-south irregularly elongate body near eastern edge of quadrangle. Distinguished by even-grained texture and presence of muscovite. Color index averages 6; biotite is only mafic mineral. Biotite:muscovite ratio averages 3:1 but varies widely, grading southward into rocks containing only trace muscovite. Texture is hypidiomorphic-granular; rock has no directional fabric. In northern and western parts, highly broken and cut by numerous subhorizontal fractures and gouge zones probably related to landsliding. Completely surrounded by, grades into, and probably related to monzogranite of Keller Peak

Kh **Granodiorite of Hanna Flat (Cretaceous)**—Coarse-grained hornblende-biotite granodiorite. Forms 0.5-km-wide to 1-km-wide body around northeastern part of monzogranite of Keller Peak (Kk). Irregularly porphyritic; has 2-cm-long, poorly formed, scattered phenocrysts of orthoclase containing patches of microcline. Plagioclase composition averages intermediate andesine. Average color index 10 near contact with monzogranite of Keller Peak, grading outward to about 15; concentration of hornblende and sphene also increases outward from monzogranite of Keller Peak. Body may represent outer part of monzogranite of Keller Peak that was contaminated by intrusion into relatively mafic Triassic monzonite of Fawnskin (T̄Rf). Conventional K-Ar ages on hornblende and biotite, respectively, are 70.5 Ma and 71.5 Ma (Miller and Morton, 1980; considered by them to be cooling age); $^{40}Ar/^{39}Ar$ incremental age on same hornblende sample is 76.5 Ma (R.J. Fleck, written commun., 1996)

Rattlesnake Mountain pluton of MacColl (1964) (Cretaceous)—Biotite monzogranite and hornblende-biotite monzogranite. Forms large irregular shaped body in northern San Bernardino Mountains, centering about 14 km northeast of Lake Arrowhead (fig. 1). Pluton contains large bodies of leucocratic and highly mafic rocks. Coarse-grained, locally ranging to very coarse-grained and medium-grained. Generally porphyritic, but includes large bodies of even-grained, nonporphyritic rock. Microcline phenocrysts typically form up to 20 percent of porphyritic rock, but in places, are sparse and irregularly distributed. Plagioclase composition is intermediate to calcic oligoclase. Average color index is 10, but ranges up to 18; less than half of rocks in pluton contain hornblende. Very abundant sphene, and trace amounts of allanite and muscovite, latter probably secondary. Most rocks have hypidiomorphic-granular groundmass texture, but in places phenocrysts show crude alignment. Primary flow structure is poorly to moderately well defined in much of pluton by wispy streaks of concentrated mafic minerals and by aligned flat inclusions; fabric is not reflected by preferred alignment of groundmass minerals. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons. Divided into:

Krp **Porphyritic monzogranite**—Coarse-grained porphyritic biotite monzogranite and hornblende-biotite monzogranite. Contains scattered, pale pink to white, 2 to 3 cm-long phenocrysts of mixed microcline and perthitic orthoclase. Plagioclase is white, intermediate to calcic oligoclase, and is noticeably more abundant than potassium feldspar. Quartz averages about 25 percent of rock. Biotite is only mafic mineral in more than half of unit; where present, hornblende grains are small. Color index averages about 10, increasing to as much as 18 where pluton intrudes mafic country rocks; hornblende and sphene content increase with color index. Texture is granitic and rocks lack penetrative fabric, however, primary flow structure is defined in some parts of pluton by streaks of concentrated mafic minerals and in much of pluton by aligned flat inclusions. Except for streaks of mafic minerals and near contacts with mafic plutons, rocks are relatively homogeneous with respect to composition and texture. Similar to and may be related to monzogranite of Keller Peak (Kk)

Kr **Even-grained monzogranite**—Medium- to coarse-grained biotite monzogranite. Similar in most respects to porphyritic monzogranite of Rattlesnake Mountain pluton of MacColl (1964), except that it contains few or no phenocrysts, rarely contains hornblende, and is moderately variable with respect to grain-size, and composition. Specifically, parts of unit are medium to fine grained and limits of biotite variation is noticeably greater than in porphyritic parts of pluton. Appears to grade into, and may be related to part of monzogranite of Luna Mountain

Kdh **Monzogranite of Devils Hole (Cretaceous)**—Biotite monzogranite. Restricted to small body along Deep Creek (fig. 1), 4 km northeast of Lake Arrowhead. Coarse-grained; very porphyritic. Pale pink, slightly perthitic orthoclase phenocrysts make up as much as 25 percent of some rocks. Phenocrysts average 2.5 cm, are as long as 4 cm, and contain 20 to 50 percent included plagioclase (intermediate oligoclase). Some orthoclase phenocrysts appear to be tectonically shaped. Color index averages 13; biotite is only mafic mineral. Texture is porphyritic, but groundmass grain size is distinctly bimodal. Groundmass contains irregular shaped masses of fine-grained felsic minerals between coarse grains of same minerals. Rock is cut by thin shear zones containing broken and rehealed minerals. Some quartz is highly strained and tectonically shaped, and some biotite is disaggregated and strung out along thin shear zones. Deformation is apparent in thin section only, not in outcrop. Rock is considered Cretaceous based on similarity of composition and primary igneous texture to that of nearby Cretaceous granitic rocks. However, deformation seen in monzogranite of Devils Hole is not found in adjacent Cretaceous rocks

Kgdb **Biotite granodiorite (Cretaceous)**—Coarse- and medium-grained biotite granodiorite. Sub-porphyritic, containing small, poorly formed, pink potassium feldspar phenocrysts. Intensely fractured, but relatively resistant to erosion, forming smooth, rounded exposures; fractures commonly contain epidote. Cretaceous age based on similarity to nearby granitic rocks of Cretaceous age

Kgdc **Biotite granodiorite, Cajon area (Cretaceous)**—Granodiorite, ranging to monzogranite. Most is massive, tan weathering biotite granodiorite, locally gneissoid. Medium- to coarse-grained. Color index generally less than 12. Cut by numerous leucocratic granitic and pegmatitic dikes. Restricted to a few square kilometers of highly faulted rocks west of Cajon Junction area (fig. 1)

Kml **Mixed mafic and leucocratic granitic rocks (Cretaceous)**—Heterogeneous fine-grained hornblende-biotite monzogranite. Forms small, irregularly shaped bodies southeast of Lovelace Canyon (fig. 1) in northern San Bernardino Mountains, 16 km northeast of Lake Arrowhead. Prominently zoned plagioclase is intermediate oligoclase; potassium feldspar is microcline. Quartz averages about 20 percent of rock, and is strained. Hornblende concentrated in fine-grained centimeter-long ovoids that have color index of about 60 and hornblende:biotite ratio of about 10:1. Ovoids grade over 1 mm into rock typical of unit in which color index ranges from 8 to 20, and hornblende:biotite ratio averages about 1:10. Heterogeneity is due to irregular variation in color index and concentration of ovoids. Sphene is abundant, anhedral to subhedral, and concentrated near mafic ovoids. Texture is granitic to seriate; no penetrative directional fabric. Unit appears to be fine-grained component of Cretaceous heterogeneous leucocratic granitic rocks unit (Khl) that is contaminated by partially resorbed rocks from Cretaceous or Jurassic mixed diorite and gabbro unit (KJdg)

Kcr **Monzogranite of Coxey Road (Cretaceous)**—Biotite monzogranite. Forms very irregular body that intrudes Cretaceous and Jurassic mixed rocks of Hopi Springs (KJhs) north of Little Pine Flat (fig. 1), 3 km southwest of White Mountain. Distinguished by very abundant quartz, low color index, and potassium feldspar (microcline) more abundant than plagioclase (calcic oligoclase). Has sparse, irregularly distributed, 1.5-cm-long, highly perthitic microcline phenocrysts. Color index ranges from 3 to 5. Biotite is only mafic mineral. Looks heterogeneous near contacts with mixed granitic rocks of Hopi Springs (KJhs), due to incomplete ingestion of that rock. Texture is hypidiomorphic-granular; rock has no directional fabric. Resembles and may be related to monzogranite of Muddy Spring, but contains no muscovite

Kcm **Tonalite of Circle Mountain (Cretaceous)**—Biotite-hornblende tonalite. Heterogeneous, intensely fractured, typically foliated. Restricted to several small exposures on and around Circle Mountain (fig. 1), 4 km west of Cajon Junction. Contains varying amounts of included gneissic rock and coarse-grained marble. Locally contains calc-silicate rocks resulting from reaction of tonalite and marble

Kmx **Mixed granitic rocks of Heaps Peak (Cretaceous)**—Similar to monzogranite of City Creek (Kcc), but proportion of biotite monzogranite and muscovite-biotite monzogranite is much smaller. Very heterogeneous, generally consisting of more than 70 percent included masses of older monzogranite, granodiorite, diorite, gabbro, and large irregular pegmatite masses. Proportion of highly mafic rocks is much greater than in Kcc. Most included masses are probably Cretaceous, but some could be as old as Jurassic. Grades into monzogranite of City Creek over zone at least 200 m wide; placement of contacts is highly subjective

Kbf **Monzogranite of Burnt Flats (Cretaceous)**—Biotite monzogranite. Forms small body 7 km north of Lake Arrowhead. Fine- to medium-grained; texture is highly seriate. Noticeably finer grained and more resistant to weathering than surrounding rocks. Color index ranges from 12 to 15. Contains sphene. Inclusions and screens of mixed rock abundant near borders and locally in other parts of body. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

Kwcy **Monzogranite of Willow Canyon (Cretaceous)**—Biotite monzogranite. Forms small body north of Redonda Ridge (fig. 1), 13 km northeast of Lake Arrowhead. Coarse- to very coarse-grained; slightly porphyritic. Phenocrysts are 1-cm-long, poorly formed, pale-pink microcline. Plagioclase is calcic andesine. Biotite is only mafic mineral; color index averages 12. Sphene moderately abundant. Except for sparse, poorly formed phenocrysts, texture is hypidiomorphic-granular. Unit is fairly uniform with respect to composition and texture. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

Kao **Granodiorite of Angeles Oaks (Cretaceous)**—Hornblende-biotite granodiorite. Forms large, elongate, partly fault-bounded pluton in eastern part of San Bernardino quadrangle just north of Mill Creek strand of San Andreas Fault. Most of pluton lies east of quadrangle. Coarse-grained, nonfoliate, and nonporphyritic hypidiomorphic granular. Color index averages 15; biotite forms centimeter-wide grains in places. Hornblende and biotite subequal in eastern part of body, but central and western parts range from subequal to having only minor hornblende. Difference may reflect hornblende-rich Triassic host rocks in eastern part, or could indicate two separate plutons. Plagioclase averages an_{35}; potassium feldspar is microperthitic orthoclase. Quartz forms large, multi-grain masses that show moderate deformation and suturing. Deeply weathered most places (photo 338). Hornblende and biotite from sample 5 km east of quadrangle yielded conventional potassium-argon ages of 71 Ma and 72 Ma, respectively (Miller and Morton, 1980); considered cooling ages, not emplacement ages

Khc **Granodiorite of Hook Creek (Cretaceous)**—Hornblende-biotite granodiorite, ranging almost to tonalite. Forms moderate sized pluton east of Lake Arrowhead. Coarse- to very coarse-grained. Plagioclase is sodic and intermediate andesine. Potassium feldspar is orthoclase containing minor patches of microcline. Hornblende and biotite about subequal. Average color index 18. In parts of unit, biotite forms centimeter-wide grains. Contains very abundant sphene. Very similar in appearance to Cretaceous granodiorite of Willow Creek (Kwc), but typically has much higher plagioclase:potassium feldspar ratio. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

Kwc **Granodiorite of Willow Creek (Cretaceous)**—Hornblende-biotite granodiorite. Forms well-defined pluton 3 km north of Lake Arrowhead. Medium- to coarse-grained. Plagioclase is sodic and intermediate andesine. Potassium feldspar is slightly perthitic orthoclase containing minor patches of poorly twinned microcline. Most potassium feldspar is interstitial to other minerals. Average color index 15. Hornblende:biotite ratio averages 1:4; most hornblende distinctly smaller than biotite. Abundant euhedral sphene, some as wide as 4 mm. Minor opaque minerals, epidote, and allanite, trace zircon and apatite. Granitic texture, no directional fabric, no intergranular cataclasis. Considered Cretaceous on basis of textural and compositional similarity to nearby Cretaceous plutons

KJta **Tonalite of Ord Mountains (Cretaceous or Jurassic)**—Hornblende-biotite and biotite-hornblende tonalite. Forms single, partly fault-bounded, irregularly shaped pluton east of Mojave River, southern part of Ord Mountains (fig. 1). Coarse grained, non-foliate, non-porphyritic hypidiomorphic granular texture; has no directional fabric. Hornblende:biotite averages about 1:2; color index averages 17. Potassium feldspar nearly absent. Plagioclase ranges from calcic oligoclase to sodic andesine. Quartz averages about 25 percent, and is undeformed. Sphene fairly abundant, but paler tan than in most other hornblende-biotite rocks in region. Unit is uniform with respect to texture and composition except around margins and in southern part. Margins are about 50 percent more mafic, and grain size highly variable. Southern part of unit contains inclusions and septa of more mafic and more leucocratic rocks having gradational borders with tonalite. Probably Cretaceous, but all or part could be Jurassic; age assignment based on textural and compositional similarities to plutons of those ages in region

KJgm **Mixed granitic rocks, gneiss, and quartzite (Cretaceous or Jurassic)**—Heterogeneous mixture of (1) diverse granitic rocks, (2) leucocratic, fine-grained rocks probably part of Jurassic fine-grained rocks of Silver Canyon (Jsc), (3) white and gray vitreous quartzite, (4) calc-silicate rocks, and (5) medium- to coarse-grained quartz-feldspar-biotite gneiss and locally andalusite-sillimanite-biotite schist. Unit forms several large and small bodies west of Rattlesnake Mountain (fig. 1). Relative amounts of constituents are highly variable, both on local and unit-wide scale, but granitic component accounts for approximately 80 percent of unit overall. Biotite and hornblende-biotite granodiorite, quartz monzonite, and quartz monzodiorite make up bulk of granitic rocks. Most are medium to coarse grained, non-porphyritic, and have color index ranging from 10 to 20; probably more than one intrusive event represented. One-meter-long to 100-m-long pods, dikes, and sills of leucocratic granitic rocks ranging from biotite monzogranite to quartz diorite are very abundant in western and northern parts of unit; also found irregularly throughout unit. Probably associated with nearby Cretaceous plutons, but some granitic rock appears to be result of localized partial melting of gneiss protolith during metamorphism. Rocks considered part of fine-grained rocks of Silver Canyon (Jsc) are identical to those described for that unit. Age and provenance of included metamorphic rocks imprecisely known, but probably Paleozoic and Late Proterozoic

KJdd **Quartz monzonite of Dawn O'Day Canyon (Cretaceous or Jurassic)**—Biotite quartz monzonite; averages about 15 percent quartz. Fairly heterogeneous with respect to included material, containing variable amounts of metasedimentary schist, and inclusions and dikes of other granitic rocks. Color index ranges from 5 to 18, commonly within single large outcrop. Biotite is only mafic mineral; rock typically has trace amounts of very fine grained muscovite, probably not primary. Potassium feldspar is microcline, plagioclase is calcic andesine. Has compositional and textural characteristics of both Cretaceous and Jurassic plutons in region

KJqd **Quartz-bearing diorite (Cretaceous or Jurassic)**—Hornblende-biotite diorite; typically contains 2 to 4 percent quartz; up to 15 percent quartz near contact with monzogranite of Devils Hole (Kdh). Restricted to small area 6 km northeast of Lake Arrowhead. Medium- to fine-grained; slight foliation, but too indistinct to measure. Plagioclase is calcic oligoclase to sodic andesine; potassium feldspar is orthoclase. Color index averages 20, but varies widely; hornblende and biotite occur in subequal amounts. Age based on overlapping compositional and textural similarities to Cretaceous and Jurassic granitic rocks

KJhb **Hornblende-biotite granodiorite (Cretaceous or Jurassic)**—Compositionally and texturally heterogeneous hornblende-biotite granodiorite. Ranges to, or includes pods of, biotite granodiorite and biotite monzogranite. Fine to coarse grained; seriate. Grain size, texture, and composition irregularly variable throughout unit; could represent more than one intrusive event. Forms irregular shaped masses in western Granite Mountains (fig. 1) (photo 553), in northeastern part of quadrangle

KJdg **Mixed diorite and gabbro (Cretaceous or Jurassic)**—Biotite-hornblende diorite and quartz diorite, hornblende-biotite diorite and quartz diorite, pyroxene-hornblende gabbro, and hornblende gabbro. Fine- to coarse-grained. Dioritic rocks appear to have possible spatial relation to contact zones between Paleozoic carbonate rocks and intermediate composition Mesozoic plutons. Rocks of this unit have wide compositional and textural range, but are distinguished from rocks of other units by very high color index, which averages 45. All rocks consist of plagioclase (intermediate andesine) and hornblende ±quartz; most contain biotite; some contain clinopyroxene and orthopyroxene. Rarely rocks contain enough potassium feldspar to be monzodiorite, but most contain almost none. Accessory minerals include sphene, apatite, epidote, allanite, and opaque mineral(s). Typically, rocks are even grained hypidiomorphic-granular, but textures include porphyritic, glomeroporphyritic, and pegmatitic. Compositions of large mafic bodies within Rattlesnake Pluton of MacColl (1964) (Kr) are particularly variable, partly due to contamination by monzogranite of Rattlesnake Pluton. Unit probably includes rocks of more than one period of intrusion, possibly during both Cretaceous and Jurassic. In northwestern part of San Bernardino quadrangle, unit is coarse-grained gabbro, ranging to hornblende diorite. There, it includes layered gabbro, orbicular gabbro, and pegmatitic gabbro, and is intruded by abundant leucocratic pegmatite dikes of probable Mesozoic age (Barrows, 1985)

KJsc **Quartz diorite of Sand Canyon (Cretaceous or Jurassic)**—Hornblende-biotite quartz diorite, ranging to quartz monzodiorite and tonalite. Forms single, elongate pluton between City Creek and Waterman Canyon (fig. 1), 2 km north of San Andreas Fault Zone. Plagioclase averages an_{40}; sparse potassium feldspar is orthoclase. Hornblende: biotite ratio is variable, but averages 1:3; color index averages 20, and is relatively uniform. Quartz averages about 18 percent. Medium to coarse grained, characterized by mafic minerals wrapping around, and seemingly forming a matrix for felsic minerals. Quartz is highly deformed and sutured; feldspars show variable grain-size reduction and tectonic rounding. Despite mineral deformation, however, rocks are not foliated or lineated. Texture and composition relatively uniform throughout pluton. Appears to intrude gneiss of Devil Canyon (MzPd), but does not have obvious foliation or gneissosity of that unit. Considered Cretaceous or Jurassic based on textural and compositional similarities to Cretaceous and Jurassic granitic rocks in region

KJc **Quartz monzodiorite of Crestline (Cretaceous or Jurassic)**—Medium- to coarse-grained biotite-hornblende quartz monzodiorite, ranging to quartz diorite and granodiorite. Color index averages 20, and hornblende is more abundant than biotite. Characterized by very abundant sphene. Rock is typically foliated and in places lineated. Nonporphyritic. Appears to intrude Mesozoic to Proterozoic gneiss of Devil Canyon (MzPd), and is intruded by Cretaceous monzogranite of City Creek (Kcc); relation to Jurassic granodiorite of Arrowhead Peak (Ja) unknown. Considered Cretaceous or Jurassic based on textural and compositional similarities to Cretaceous and Jurassic granitic rocks in region; mineral composition suggests Jurassic may be more likely

Jcr **Cataclastic rocks (Jurassic)**—Fine-grained to aphanitic cataclastic rocks. Medium- to dark-gray, commonly having green tint. Derived primarily from extreme deformation of granitic units and Jurassic fine-grained rocks of Silver Canyon (Jsc). In central part of cataclastic zone, most rocks are highly comminuted, nearly aphanitic, and relatively uniform. Uniform rocks in central part of zone grade outward by appearance of grains and grain-aggregates that are tectonically reduced in size, but are distinctly larger than near-aphanitic groundmass. Progressive gradation outward continues into rocks retaining some pre-deformation primary texture, but are cut by close spaced, anastomosing seams of cataclastic rock. These rocks grade progressively into granitic rocks that show intergranular milling and are cut by widely spaced zones of microbreccia, and hence pass into essentially undeformed rocks. Gradational zone from noticeably deformed to apparently undeformed rock varies from few meters to over 100 m wide, so placement of contacts is fairly subjective in some places. Restricted to small areas bounded by younger faults in northeastern part of San Bernardino quadrangle; but very extensive east of quadrangle

Js **Leucocratic hornblende syenite (Jurassic)**—Syenite to quartz-bearing syenite. Uniformly pale gray. Contains sparse hornblende, and locally, scattered grains of arfvedsonite that appear to be partly replaced by hornblende; color index averages about 3. Medium to coarse grained; even grained. Does not have foliation or other directional fabric contained in other nearby granitic or metamorphic rocks. Lack of fabric may be due to near absence of quartz in rocks. Restricted to numerous, small, irregularly shaped bodies intruding highly recrystallized metasedimentary rocks in northwesternmost San Bernardino Mountains (photo 330). In places grades into rocks having color index of 8 to 10, and containing about 12 percent quartz. These rocks are probably not related to syenite, but are older or younger than syenite. Barth and others (1997) report zircon uranium-lead ages for this rock ranging from 149 Ma to 158 Ma, clustering at 152 Ma

Jc **Leucocratic quartz monzonite of Crystal Creek (Jurassic)**—Hornblende-biotite quartz monzonite and biotite quartz monzonite, ranging to monzonite. Restricted to small area at eastern edge of quadrangle, 1.5 km northeast of White Mountain (fig. 1), but is very extensive in Fawnskin 7.5' quadrangle to east. Leucocratic. Coarse-grained. Distinguished by low quartz content, low color index, and presence of hornblende and sphene in most samples. Plagioclase is calcic oligoclase; potassium feldspar is highly perthitic microcline and orthoclase. Average color index is 5, locally as high as 12. Uranium-lead age on sphene from quartz monzonite is 151 Ma (J.L. Wooden, written commun., 1997)

Jwm **Monzodiorite of White Mountain (Jurassic)**—Biotite monzodiorite, ranging to quartz monzodiorite and microcline-bearing quartz diorite. Medium- to coarse-grained. Quartz content ranges from 2 to 10 percent. Plagioclase is calcic oligoclase; potassium feldspar, very subordinate to plagioclase, is microcline. Color index is about 17; biotite is only mafic mineral. Contains sphene and abundant allanite. Strongly resembles Jurassic quartz monzodiorite of Dry Canyon (Jd), and may be noncontiguous part of same intrusion. Considered Jurassic based on compositional similarities to nearby Jurassic plutons

Ja **Granodiorite of Arrowhead Peak (Jurassic)**—Porphyritic, medium- to coarse-grained biotite-hornblende granodiorite. Characterized by potassium feldspar phenocrysts averaging 3 cm in length and as large as 5 cm. Color index between 15 and 20; hornblende generally more abundant than biotite, but not in all rocks. Rock has irregular foliation and commonly contains lineation similar to that in quartz monzodiorite of Crestline (KJc). Irregular foliation imparts swirled appearance to rocks at some places. Unit is very similar to widespread porphyritic biotite-hornblende rocks in Mojave Desert that yield concordant hornblende and biotite potassium-argon ages between 165 Ma and 170 Ma (Miller and Morton, 1980)

Jrr **Biotite quartz monzodiorite of Redonda Ridge (Jurassic)**—Medium- to coarse-grained biotite quartz monzodiorite, ranging to monzodiorite. Restricted to one large and several small bodies at west end of Redonda Ridge (fig. 1) in east-central part of San Bernardino quadrangle. Rocks average about 6 percent quartz, but some have less than 5 percent. Plagioclase is intermediate andesine, and potassium feldspar, averaging 12 percent, is orthoclase. Color index is about 18 and varies little; biotite is only mafic mineral. Contains abundant sphene. Even-grained to seriate, having no directional fabric, but locally contains abundant aligned, elongate inclusions. Strongly resembles quartz monzodiorite of Dry Canyon (Jd), and may be noncontiguous part of same intrusion. Considered Jurassic based on compositional similarities to nearby Jurassic plutons

Jd **Quartz monzodiorite of Dry Canyon (Jurassic)**—Biotite quartz monzodiorite, ranging to monzodiorite. Restricted to small area at east edge of San Bernardino quadrangle in White Mountain area; unit is extensively exposed in quadrangle to east. Medium- to coarse-grained. Distinguished by relatively low quartz content and relatively high color index in rock having biotite as its only mafic mineral. Quartz content ranges from 3 to 8 percent. Plagioclase is sodic andesine; potassium feldspar, very subordinate to plagioclase, is microcline. Color index averages 15. Contains sparse sphene, even where intruding sphene-rich Triassic monzonite of Fawnskin (Ŧf). Has wide gradational contact with fine grained rocks of Silver Canyon (Jsc). Considered Jurassic based on compositional similarities to nearby Jurassic plutons

Jsc **Fine-grained rocks of Silver Canyon (Jurassic)**—Pale-gray to medium-gray, very fine-grained porphyroblastic rock made up predominantly of quartz, plagioclase, and potassium feldspar. Typically contains bands of very fine-grained quartz up to 2 mm thick, commonly separated by bands of concentrated feldspar. Contains variable amounts of biotite, up to 5 percent, and trace muscovite. Inferred to be metamorphosed mylonitic or cataclastic rocks of possible monzogranite to quartz monzodiorite composition, but could be very fine grained, slightly metamorphosed, leucocratic granitic rocks, or leucocratic metavolcanic rocks. Distinct and not derived from Jurassic cataclastic rock unit (Jcr); differs in that recrystallization has erased nearly all traces of penetrative fabric. Protolith and age very uncertain. In adjacent Fawnskin 7.5' quadrangle, Miller and others (2001) considered unit to be older than Jurassic quartz monzodiorite of Dry Canyon (Jd); unit now thought to be younger, based on ubiquitous presence of 0.2- to 1-m-long, wispy, inclusion-like masses of Dry Canyon rock in Silver Canyon rock. Restricted to very small areas in northeastern part of San Bernardino quadrangle; very extensive east of quadrangle

Ŧm **Monzogranite of Manzanita Springs (Triassic)**—Biotite-hornblende monzogranite and hornblende monzogranite, ranging to quartz monzodiorite and quartz monzonite. Forms three relatively large masses between Running Springs (fig. 1) and east edge of San Bernardino quadrangle, one completely fault bounded. Also one small body at north end of Ord Mountains (photo 336). Rocks are characterized by pale-pink potassium feldspar phenocrysts averaging about 2.5 cm in length, but ranging from 1 to 5 cm. High concentrations of leucocratic and mafic dike rocks and mafic inclusions are also characteristic of unit, in places making up more than 50 percent of rocks. Plagioclase averages sodic andesine. Potassium feldspar is microcline and orthoclase, and is confined almost exclusively to phenocrysts. Locally, rocks containing only sparse phenocrysts are almost quartz diorite composition. Quartz is interstitial to most other minerals. Color index ranges from 12 to 18; hornblende:biotite ratio ranges from about 2:1 to rocks containing only hornblende. Sphene is abundant and allanite is found in most rocks. Some rocks have no directional fabric, but primary and secondary foliations are common, though irregularly developed (photo 337). Frizzell and others (1986) report uranium-lead age on zircon of 215 Ma; Miller and Morton (1980) report potassium-argon ages of 70 Ma on biotite and 75 Ma on hornblende, but consider both to be cooling ages, not emplacement ages

Ŧcp **Monzonite of Cedarpines Park (Triassic)**—Medium-grained biotite-hornblende monzonite and hornblende monzonite; locally porphyritic. Contains sparse quartz. Average color index 20; hornblende:biotite ratio everywhere greater than 10:1. Hornblende commonly has cores of pyroxene. Most of body has poorly developed, highly irregular foliation and lineation, probably primary, that gives rocks swirled or folded appearance. Deformed and moderately to highly foliated in northwestern part of body. Structurally elongated pods of Ŧcp meters to tens of meters long are found in Mesozoic to Proterozoic gneiss of Devil Canyon (MzPd) and Mesozoic mixed granitic rocks of Silverwood Lake (Mzsl) units. Unit is very similar to Triassic monzonite of Fawnskin (Ŧf) 27 km to east, which yields zircon uranium-lead age of 231 Ma (Barth and others, 1997)

Ŧf **Monzonite of Fawnskin (Triassic)**—Hornblende monzonite, ranging to quartz monzonite and monzodiorite. Medium- to coarse-grained, locally porphyritic. Distinguished by very low quartz content and abundance of hornblende and sphene. Quartz generally less than 5 percent; where monzonite intrudes quartzite units, is as high as 12 percent, but most quartz is exotic. Hornblende commonly has altered pyroxene cores. Plagioclase is intermediate to calcic oligoclase; potassium feldspar is microcline. Ratio of microcline to plagioclase is highly variable, but generally greater than 3:2. Color index averages 18; hornblende, pyroxene, and less commonly biotite are mafic minerals. Texture is hypidiomorphic-granular to seriate, locally porphyritic. Flow aligned feldspar and hornblende impart foliated or lineated appearance to rock in places, but fabric is highly variable in orientation even on outcrop scale. Zircon uranium-lead age is 231 Ma (Barth and others, 1997)

Ƚfl **Leucocratic monzonite of Fawnskin (Triassic)**—Identical to monzonite of Fawnskin, except color index is between 10 and 15, and microcline is generally much more abundant than plagioclase; unit ranges to syenite in places. Underlies two small areas in northeastern part of San Bernardino quadrangle, and larger area in northwestern part of Fawnskin 7.5'quadrangle to east (Miller and others, 1998)

Ƚlm **Fine-grained leucocratic monzonite (Triassic)**—Augite-hornblende monzonite, monzodiorite, and quartz monzodiorite. Fine-grained, equigranular to slightly and irregularly porphyritic. Quartz ranges from about 4 percent to 12 percent, but relatively high-quartz rocks of this unit have obviously acquired some quartz from quartzite host rocks. Plagioclase is sodic andesine, and potassium feldspar is orthoclase. Ratio of orthoclase to plagioclase is less than 1:2 in all rocks, unlike typical monzonite of Fawnskin (Ƚf). Color index averages about 8, but is misleading in outcrop, because hornblende is fine grained, pale and does not look like mafic mineral. Considered Triassic on basis of mineralogical and compositional similarities to monzonite of Fawnskin (Ƚf), but high quartz content and relatively low potassium feldspar content are similar to some Jurassic granitic rocks in region

Ƚa **Alaskite of Sunset Cove (Triassic)**—Medium- to fine-grained, leucocratic, garnet- and fluorite-bearing alaskite (photo 554). Contains no mafic minerals other than very sparse opaque minerals. Plagioclase is albite; potassium feldspar is perthitic orthoclase and minor microcline. Some potassium feldspar appears to have partially replaced plagioclase. Quartz content about 25 percent. Garnet is pale gold and forms small, typically very fine-grained, spongy masses. Very sparse fluorite forms 1 mm and sub-millimeter grains; some is purple and at a few places is visible in hand specimen. Texture is characterized by variable bimodal grain size. One to 3 mm-long grains of quartz, plagioclase, and orthoclase are irregularly distributed in groundmass composed mostly of 0.1- to 0.01-mm-long grains of same minerals. Plagioclase replaced by potassium feldspar, presence of fluorite, and absence of mafic minerals indicate unit may have undergone severe late-stage-emplacement alteration. Triassic age assignment based on compositional and alteration features that, in this region, are found only in Triassic granitic rocks

Ƚsp **Quartz monzonite of Strawberry Peak (Triassic)**—Monzonite and quartz monzonite (photos 555, 556, and 557), latter probably resulting from introduction of quartz after (or late-stage) emplacement. Rock contains abundant, finely granular, yellow-orange garnet and pale green epidote that replaces hornblende and pyroxene. Very sparse purple fluorite scattered irregularly through unit. Small unaltered shreds of hornblende are rare. No other mafic minerals in rock. Texture ranges from even-grained to seriate; much of rock is subporphyritic similar to monzonite of Fifteenmile Point (Ƚfp). Garnet appears to be alteration or late-stage reaction product derived from pyroxene and probably hornblende. Rocks may have undergone recrystallization subsequent to alteration. Unit may represent highly altered part of monzonite of Fifteenmile Point (Ƚfp), or may be separate intrusion

Ƚrl **Monzonite of Rabbit Lake (Triassic)**—Hornblende monzonite and quartz monzonite. Medium- to coarse-grained. Very similar to both monzonite of Fifteenmile Point (Ƚfp) and monzonite of Strawberry Peak (Ƚsp), but texture is more uniformally even-grained. Some of unit altered similar to monzonite of

Strawberry Peak, but alteration not as thorough. Probably textural variation of monzonite of Fifteenmile Point pluton

Trfp **Monzonite of Fifteenmile Point (Triassic)**—Pyroxene-hornblende monzonite (photo 558). Medium- to coarse-grained. Texture ranges from even-grained to seriate; much of rock is subporphyritic. One or both feldspars commonly are lath-shaped, and in combination with hornblende, define poorly to moderately well developed primary foliation. Potassium feldspar is orthoclase, and plagioclase is intermediate oligoclase. Quartz sparse, but ubiquitous, varying from 1 to 4 percent. Average color index 12; relatively constant, but locally as high as 22 and as low as 5. Most of unit contains clinopyroxene, both as cores in hornblende, and as stand-alone grains. Sphene and epidote are very abundant, and allanite is sporadically abundant

Trh **Monzonite of Hill 4001 (Triassic)**—Hornblende monzonite. Forms elongate, dike-form body in Granite Mountains northwest of Rabbit Lake (dry) in northwestern part of quadrangle. Medium-grained. Texture is seriate, locally even-grained. Most of unit has distinct, but poorly developed primary flow foliation. Unlike other monzonite units in region, hornblende forms large equant grains imparting spotted appearance to rock (photo 559). Size of hornblende decreases eastward in unit. Contains very abundant sphene and large, sparsely scattered allanite. Average color index is 8. Barth and others (1997) report uranium-lead age of 235 Ma

Pzmb **Marble, San Bernardino Mountains (Paleozoic)**—Coarse- to medium-grained marble and dolomitic marble. Most is thickly layered to massive; color ranges from white to gray. Has few recognizable sedimentary structures that survived metamorphism, unless some layering represents primary bedding. Highly deformed, and tectonically intermixed with Mesozoic to Proterozoic gneiss of Devil Canyon (MzPd) and other units. Typically shows little development of contact metamorphic minerals adjacent to Mesozoic granitic rocks, but locally, especially in Devil Canyon and Bailey Canyon areas, and around some bodies in Mescal Creek area (fig. 1), diopside-actinolite-quartz-plagioclase-calcite hornfels is present. Probably derived from Paleozoic carbonate units, but some could be from carbonate-bearing parts of Late Proterozoic Stirling Quartzite (Psu)

IPbs **Bird Spring Formation (Pennsylvanian)**—Upper part of Furnace Limestone of Vaughan (1922) as mapped by Guillou (1953), and Richmond (1960); correlated with Bird Spring Formation of southern Great Basin by Cameron (1981) and Brown (1991). Generally light-colored, medium- to thick-layered, medium to coarsely crystalline calcite marble. Degree of recrystallization in San Bernardino quadrangle precludes confident subdivision of formation, but in Fawnskin 7.5' quadrangle to east, typical lithologies include white, gray, or mottled marble and cherty, silicified marble. Some chert-bearing calcite marble contains lenses and thin layers of quartz silt and fine sand. Intermittent layers of minor brown-weathering dolomite marble, siliceous marble horizons, and dark-gray calcite marble. Locally includes yellowish- to brownish-gray phyllite (or schist), white quartzite, schistose metasiltstone, and interlayered chert and marble. In San Bernardino quadrangle, due to extreme recrystallization and deformation, layering in much of formation may or may not be bedding

Mm **Monte Cristo Limestone (Mississippian)**—Upper part of Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960). Correlated with Monte Cristo Limestone of southern Great Basin by Cameron (1981), and mapped by Brown (1991) who recognized several formal stratigraphic members named originally by Hewett (1931). Degree of recrystallization in San Bernardino quadrangle precludes recognition of detailed subdivisions, but includes heterogeneous, interlayered, light- and dark-gray, calcite and dolomite marble characteristic of Yellowpine Member, and thick-layered, light-gray to white, texturally massive, very pure calcite marble characteristic of Bullion Member (Brown 1991)

Ds **Sultan Limestone (Devonian)**—Middle part of Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960); Brown (1991) correlated rocks in this interval with members of Sultan Limestone of Hewett (1931) in southern Great Basin. Includes: (1) thin- to thick-layered, white calcite marble containing sparse thin layers of dark-gray calcite and dolomite marble characteristic of Crystal Pass Member; in part irregularly dolomitized, and (2) laminated to massive, light-gray, brown, and white, finely crystalline, locally chert-bearing metadolomite characteristic of Valentine Limestone Member

Ꞓbk **Bonanza King Formation (Cambrian)**—Lower part of Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960). Originally named by Hazzard and Mason (1936) from exposures in Providence Mountains. In type area, Hazzard and Mason (1936) recognized five informal subdivisions of Bonanza King Formation. In San Bernardino quadrangle, Bonanza King is metamorphosed, and unlike in adjacent Fawnskin 7.5' quadrangle (Miller and others, 1998) is not divisible into informal members. Consists mainly of dolomite and limestone marble. Exhibits thin to thick layering, which at most places in quadrangle probably does not reflect bedding. White to medium-gray, commonly striped, texturally massive to mottled, fine- to coarse-grained. Probably includes some or all of Cambrian Nopah Formation in some sequences. Contains intervals, meters to tens of meters thick, consisting of greenish-brown and grayish-brown metasiltstone, argillite, and hornfels

Ꞓc **Carrara Formation (Cambrian)**—Heterogeneous mixture of interlayered calcite marble, phyllite, calc-silicate rock, schist, and minor quartzite. In general, upper part dominated by carbonate rock; lower part dominated by phyllite, calc-silicate rock and quartzite. Due to extreme metamorphism and deformation in San Bernardino quadrangle, it is not certain if even gross lithologic layering reflects primary bedding. Carrara is equivalent to lower part of Furnace Limestone of Vaughan (1922) as mapped by Richmond (1960). Correlated with Carrara Formation of southern Great Basin by Stewart and Poole (1975, fig. 3), but name first used in map area by Tyler (1975). Latham Shale, Chambless Limestone, and Cadiz Formation of Marble and Providence Mountains (Hazzard and Mason, 1936) occupy same approximate stratigraphic interval as Carrara, but it is not possible to map these three distinct formations in quadrangle

Ꞓz **Zabriskie Quartzite (Cambrian)**—Tough, quartz-cemented, thoroughly recrystallized quartzite. Uniformly white, but some fracture surfaces are stained yellow, orange or hematite-red by iron oxides. Very pure; quartz is almost only mineral in rock. Medium- to fine-grained, but contains scattered grains up to 5 mm across which are not aligned to define bedding; within San Bernardino quadrangle, no original grain shapes survive recrystallization. Massive; bedding, if it survived metamorphism, is unrecognizable in quadrangle. Locally, unit contains partings of phyllitic argillaceous rock, which may or may not reflect bedding, and may or may not be restricted to particular part of formation. Distinguished from quartzites of Cambrian Wood Canyon Formation (Ꞓw) and Late Proterozoic Stirling Quartzite (Ᵽsu) by purity, lack of feldspar grains, whiteness, and massive structure. Correlated with Zabriskie Quartzite of southern Great Basin by Stewart and Poole (1975). In Fawnskin 7.5' quadrangle to east, average thickness as calculated from outcrop width is 400 m (Miller and others, 1998). Variation in thickness in quadrangle is probably due to folding and faulting and does not represent changes in stratigraphic thickness

Ꞓwc **Wood Canyon Formation (Cambrian)**—Quartzite, quartzose phyllite, biotite schist, and minor calc-silicate rock. East of San Bernardino quadrangle, in Big Bear City 7.5' quadrangle, formation consists of five subunits. Elements of these five subunits are recognized in the map area, but due to degree of deformation and metamorphism, could not be mapped. Although parts of these subunits may not be present and their relative stratigraphic positions are not preserved in San Bernardino quadrangle, brief descriptions are listed here for reference. (1)

Lower 15-20 m of formation is black, biotite-rich, quartz-bearing phyllite containing sparse but ubiquitous metamorphic tourmaline and locally abundant *Scolithus* and flaser-laminated zones. (2) Phyllite grades upward into 20-25 m of interbedded coarse-grained, cross-bedded, feldspathic quartzite, pebbly quartzite, and quartzose phyllite. (3) Relatively uniform lavender-gray, fine- to coarse-grained, trough-cross-bedded quartzite. (4) Black, quartzose phyllite of uncertain thickness. (5) About 20 m of medium-gray and brownish-gray, finely interbedded quartzite, phyllite and siltite. In San Bernardino quadrangle, color and nearly all sedimentary structures are destroyed by metamorphism, and faulting and folding obscure internal stratigraphy

Shay Mountain metamorphic complex of MacColl (1964) (Cambrian? And Late Proterozoic?)—Name, Shay Mountain complex, used by MacColl (1964), is informally adopted here for highly recrystallized metamorphic rocks surrounded by younger granitic rocks in Shay Mountain-Coxey Creek area (fig. 1). Here subdivided into five units based on dominant lithology. Five units are probably derived mostly from Late Proterozoic Stirling Quartzite (Ꝑsu), Cambrian Wood Canyon Formation (Ꞓw), and possibly Cambrian Zabriskie Quartzite (Ꞓz) and Cambrian Carrara Formation (Ꞓc). All contacts between units are highly gradational, ranging in width from 50 to 500 m; placement of contacts in many places is inherently subjective. Consists of:

ꞒꝐgsq **Mixed gneiss, schist and quartzite**—Heterogeneous mixture of (1) white and gray vitreous quartzite, (2) medium- to coarse-grained quartzofeldspathic biotite gneiss and locally andalusite-sillimanite-biotite schist, and (3) variable amounts of granitic rocks. Relative amounts of constituents differ greatly, both on local and unit-wide scale. Leucocratic granitic rocks ranging from biotite monzogranite to quartz diorite are very abundant in western and northern parts of unit; 1-m-long to 100-m-long pods, dikes, and sills are found irregularly throughout unit. Probably associated with nearby Cretaceous plutons, but some granitic rock appears to be result of localized partial melting of gneiss protolith during metamorphism

ꞒꝐqc **Quartzite and cataclastic rocks of Little Pine Flat**—Interlayered white and gray vitreous quartzite, gray and white dolomitic marble, and calcite-epidote-tremolite-diopside hornfels. Irregularly developed zones of highly cataclastic rocks developed in all constituent rock types. Very recrystallized; all sedimentary structures destroyed by metamorphism. Metamorphic grain size ranges from fine to very coarse. In contact with quartzite of Little Shay Moutain, but due to extreme deformation and recrystallization in both units, stratigraphic relations are unknown

ꞒꝐcc **Biotite schist of Cox Creek**—Dark gray to nearly black, fine-grained plagioclase-muscovite-quartz-biotite schist. Locally contains andalusite or andalusite and sillimanite; andalusite is commonly retrograde to quartz and muscovite. Andalusite porphyroblasts are up to 1.5 cm long

ꞒꝐlsm **Quartzite of Little Shay Mountain**—Massive to indistinctly layered, white and gray, recrystallized vitreous quartzite. Irregularly micaceous and foliate. Layering is probably transposed bedding, but some could be primary bedding. No primary sedimentary structures appear to have survived metamorphism

ꞒꝐsm **Gneiss of Shay Mountain**—Well layered, medium- to coarse-grained quartzofeldspathic biotite gneiss containing thin, discontinuous zones of plagioclase-quartz-muscovite-biotite schist, and pods and layers of medium-grained leucocratic granitic rocks ranging from biotite monzogranite to quartz diorite. Although unit strongly resembles dominantly metaigneous Proterozoic Baldwin Gneiss, extensively exposed east of San Bernardino quadrangle, relatively high quartz content of most Shay Mountain gneiss and thin bands of fine-grained quartz suggests much of Shay Mountain unit is metasedimentary. Contains some discreet quartzite layers, particularly where gradational into quartzite of Little Shay Mountain (Ꝑlsm)

Ꝑsu **Stirling Quartzite, undifferentiated (Late Proterozoic)**—Part of Saragossa Quartzite of Vaughan (1922) as mapped by Dibblee (1964b). Lower part of Chicopee Formation as mapped by Guillou (1953); lower member of Chicopee Canyon Formation as mapped by Richmond (1960). Correlated with Stirling Quartzite and Johnnie Formation of southern Great Basin by Stewart and Poole (1975). In San Bernardino quadrangle, unit is highly deformed, and very recrystallized; layering in most cases probably does not represent bedding. Unit is locally subdivided into three informal members; upper member of metaquartzite is separated by mixed carbonate and quartzite member from lower member of metacarbonate rock. Includes:

Ꝑsq **Quartzite member**—Light-gray, yellow-gray, and white feldspathic metaquartzite and conglomeratic metaquartzite. Approximately lower two-thirds of member is medium- to thick-bedded, poorly sorted, fine- to coarse-grained feldspathic quartzite containing sparse matrix-supported pebbles up to 1 cm across. Upper third is medium to thin bedded, poorly to moderately well sorted, fine to medium grained feldspathic quartzite. In relatively unmetamorphosed section in Fawnskin 7.5' quadrangle to east, bedding in this part of member is parallel-planar, weathers slabby, and shows current and oscillation ripple-marked surfaces. Thickness there, as calculated from outcrop width, is approximately 230 m

Ꝑscq **Carbonate and quartzite member**—Wavy bedded, light-gray to light-tan-weathering dolomitic limestone interbedded with medium and thick bedded, medium grained quartzite, laminated to texturally massive calcite marble, quartz-sand-bearing marble, and calc-silicate rock. Poorly and incompletely exposed, but dolomitic limestone and quartzite appear to predominate. Base not exposed in San Bernardino quadrangle; unit is about 120 m thick in Jacoby Canyon in Big Bear City 7.5' quadrangle to east

Ꝑsc **Carbonate-rich rocks**—Relatively pure carbonate rock similar to carbonate rock in carbonate and quartzite member (Ꝑscq); contains only minor thin beds of quartzite. Appears to be below carbonate and quartzite member (Ꝑscq), but extreme deformation precludes positive determination of stratigraphic relations

grb **Granitic rocks, undifferentiated (age unknown)**—Tonalite to monzogranite; leucocratic biotite monzogranite and granodiorite most common. Unit includes variety of granitic rocks, nearly all in very small, restricted areas. Most occurences are fault bounded or surrounded by Quaternary alluvium, and many, near or within major fault zones, are highly fractured, brecciated, or gougy. Includes rocks from many different plutons. Most rocks are probably Mesozoic, but could include Tertiary or Proterozoic rocks

Mixed metamorphic rocks of Ord Mountains area (age unknown)—Heterogeneous mixture of metasedimentary and granitic rocks restricted to Ord Mountains area (fig. 1) in northwestern San Bernardino Mountains. Metamorphic rocks include schist, marble, hornfels, and calc-silicate rocks, probably derived from Paleozoic and Late Proterozoic sedimentary units. Granitic rocks are mostly arfvedsonite-hornblende syenite and quartz syenite, but includes fine-grained, leucocratic biotite quartz monzonite and monzogranite. Rocks of this unit are deformed by extremely tight isoclinal folding accompanied by multiple faults roughly parallel to fold axes and fold limbs, and by transposition of bedding. Preexisting formations are disaggregated into kilometer-long pods, which show no consistant stratigraphic order. In many cases, identifiable parts of one unit are closely intermixed and interlayered with other units. Consists of:

ms **Metamorphic rocks, schist dominant**—Albite-quartz-muscovite-biotite schist. At many places contains porphyroblasts of andalusite and sillimanite, some to 4 cm in length; aluminosilicates commonly retrograded to fine-grained white mica and quartz. Fine to very coarse grained, highly recrystallized. In places, intricately intruded by heterogeneous granitic rocks, some of which may have derived from partial melting of schist (photo 333). No sedimentary structures preserved; banding or large-scale layering probably is not related to primary bedding, but to transposed bedding developed prior to, or during, latest metamorphism. Probably related to Shay Mountain metamorphic complex of MacColl (1964) or possibly Cambrian and Late Proterozoic sequence in White Mountain area, specifically Wood Canyon Formation. Recrystallization, folding, and disaggregation and tectonic mixing due to repeated failures along fold axes (photo 332) preclude association with specific Shay Mountain units or to formational units. Includes moderate component of heterogeneous granitic rocks in places

mm **Metamorphic rocks, marble dominant**—Predominantly dolomitic marble, but includes limestone marble, and minor calc-silicate rock schist and quartzite. Underlies fairly extensive area in northern Ord Mountains (fig. 1). Medium- to coarse-grained, but coarse grain size not apparent on weathered surfaces. Color of marble is pale grayish-tan; calc-silicate rocks, schist, and quartzite are generally pale green and dark gray, and white, respectively, but their colors are more variable than marble. Marble typically contains sparse, scattered, anhedral grains of diopside, olivine, or tremolite and is locally graphitic. Unit contains dikes, sills and isolated small masses of biotite monzogranite, hornblende and biotite-hornblende quartz monzonite, and leucocratic, hornblende syenite, none of which exceeds 15 percent of exposed rocks. Probably derived from Paleozoic carbonate units, and carbonate-bearing parts of Stirling Quartzite; large areas strongly resemble parts of Cambrian Bonanza King Formation (€bk)

mmc **Metamorphic rocks, marble and calc-silicate rock dominant**—Calc-silicate rock and minor schist, quartzite, and marble (photos 334, 571, and 573). Underlies fairly extensive area in northern Ord Mountains. Typical assemblages include: diopside-olivine-calcite, sphene-labradorite-tremolite, sphene-labradorite-diopside-garnet (photos 560 and 561), sphene-tremolite-diopside-labradorite. Compared to metamorphic rocks, marble dominant unit (mm), calc-silicate minerals in mmc unit are generally more abundant than carbonate minerals. Fine- to coarse-grained. Color variable, ranging from white to pale gray; commonly having pale-green tint. Contains dikes, sills and isolated small masses of monzogranite, quartz monzonite, and monzonite, but rarely exceeds 15 percent of exposed rocks. Probably derived from Paleozoic carbonate units, especially Carrara Formation, and carbonate-bearing parts of Stirling Quartzite

mms **Metamorphic rocks, marble and schist dominant**—Predominantly dolomitic marble and schist; minor calc-silicate rocks and quartzite. Bedding is strongly transposed and in many places rocks are intruded on fine scale by Mesozoic granitic rocks (photo 328). Underlies fairly extensive area in northern Ord Mountains (fig. 1), structurally interlayered or interfolded with metamorphic rocks, marble dominant unit (mm) (photo 332). Marble and schist are both segregated into thick bands and interlayered on fine scale. Eastern part of unit consists of thick band averaging about 100 m thick that contains only limited marble, calc-silicate, rocks, and quartzite. Western part of unit consists of about equal numbers of marble and schist layers, and scattered layers of calc-silicate, rocks, and quartzite Marble is essentially same as marble in mm unit. Schist parts contain dikes, sills and isolated small masses of biotite monzogranite, hornblende and biotite-hornblende quartz monzonite, and leucocratic hornblende syenite, which rarely exceeds 15 percent of exposed rocks. Probably derived from Wood Canyon Formation, Paleozoic carbonate units, and carbonate-bearing parts of Stirling Quartzite

mq **Metamorphic rocks, quartzite dominant**—Predominently white, vitreous quartzite (photo 335). Most likely parts of Late Proterozoic or early Paleozoic units. In most places, mixed with schist or gneiss

mx **Metamorphic rocks, mixed**—Quartzite, marble, calc-silicate rocks, schist, and gneiss. Proportion of each rock type highly variable. Typically cut by dikes and small bodies of alkalic granitic rocks gn **Gneiss**—Quartz-rich, medium to coarse grained, moderately well foliated, typically not notably layered. Some contains muscovite, garnet, and aluminosilicate minerals. Probably derived from parts of Late Proterozoic or early Paleozoic units; probably not part of Middle Proterozoic Baldwin Gneiss found east of quadrangle

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