



## **Preliminary Geologic Map of the El Cajon 30' x 60' Quadrangle, Southern California, Version 1.0**

Compiled by V.R. Todd

Open-File Report 2004-1361  
**Detailed Description of Map Units, version 1.0**

<http://pubs.usgs.gov/of/2004/1361>



U.S. Department of the Interior  
U.S. Geological Survey

*Prepared in cooperation with*  
CALIFORNIA GEOLOGICAL SURVEY

A product of the *Southern California Areal Mapping Project*  
A geologic-mapping project sponsored jointly by the U.S.  
Geological Survey and the California Geological Survey

Any use of trade, product, or firm names is for descriptive purposes only  
and does not imply endorsement by the U.S. Geological Survey.

# **Preliminary Geologic Map of the El Cajon 30' x 60' Quadrangle, Southern California, Version 1.0**

**Compiled by  
Victoria R. Todd**

## **INTRODUCTION**

The El Cajon quadrangle is one of about 20 1:100,000-scale topographic quadrangles in southwestern California being mapped and compiled by geologists of the U.S. Geological Survey and California Geological Survey as part of the Southern California Areal Mapping Project (SCAMP) and STATEMAP. Sources used for compilation of the El Cajon quadrangle include unpublished mapping at 1:24,000 scale, and unpublished reconnaissance mapping.

This report consists of a geologic map, a brief regional synthesis, and descriptions of map units. Geologic interpretations were aided by U-Pb ages for plutonic and volcanic rocks determined by D.L. Kimbrough, G.H. Girty, and C.T. Herzig at San Diego State University. Plutonic rock names were assigned based upon modal analyses and the International Union of Geological Sciences rock classification (Streckeisen, 1973).

## **REGIONAL GEOLOGIC SETTING**

The El Cajon 30' x 60' quadrangle includes parts of two physiographic provinces: the Peninsular Ranges Province on the west underlies the major part of the quadrangle; the western Colorado Desert (locally called the Anza-Borrego Desert) underlies the northeastern part. The approximate boundary between these two provinces is the Neogene Elsinore Fault Zone, the westernmost on-land fault related to the San Andreas Fault System. Movements on the Elsinore Fault Zone are believed to have resulted in uplift and westward rotation of the Peninsular Ranges block relative to the western Colorado Desert (Gastil and others, 1975). As a result, elevations in the El Cajon quadrangle increase from less than 100 m in the westernmost part of the quadrangle to about 2000 m along the irregular mountainous spine of the Peninsular Ranges (Cuyamaca, Laguna, Tierra Blanca, and Jacumba Mountains). From this spine, elevations decrease steeply eastward to less than 100 m in the Anza-Borrego Desert.

Southwest of the Elsinore Fault Zone, the El Cajon quadrangle is underlain by Jurassic and Cretaceous plutonic rocks of the composite Peninsular Ranges Batholith, which contains screens of variably metamorphosed Mesozoic supracrustal rocks. Late Jurassic and Early Cretaceous volcanic and volcaniclastic rocks that are exposed in the western part of the quadrangle represent an older, superjacent part of the Peninsular Ranges magmatic arc. Upper Cretaceous and Eocene marine and nonmarine strata were deposited widely upon the eroded batholith but are preserved only in the westernmost part of the quadrangle (San Diego embayment). Pliocene and Pleistocene coastal terrace deposits rest unconformably upon these early Tertiary rocks in the southwestern corner of the quadrangle.

Northeast of the Elsinore Fault Zone, the El Cajon quadrangle is underlain by extensive Neogene nonmarine and marine sedimentary and volcanic rocks of the Fish Creek-Vallecito Basin. Basement uplifts in this region are composed of crystalline rocks of the eastern Peninsular Ranges Batholith (Vallecito, Fish Creek and Coyote Mountains).

## **PENINSULAR RANGES BATHOLITH**

### **Prebatholithic rocks**

Prebatholithic rocks in the El Cajon quadrangle are present as steeply dipping tabular bodies, or screens, measuring as much as 4 km wide and 40 km long, between, and within, plutons. The oldest rocks in the quadrangle are amphibolite-facies metasedimentary and metavolcanic rocks in the central and eastern parts. They are divided into three map units: 1) the Julian Schist of Hudson (1922), a sequence of metamorphosed Triassic and Jurassic submarine fan deposits containing minor intercalated volcanic rocks, in the central part of the quadrangle; 2) a sequence of undated marine metasedimentary and minor metavolcanic rocks informally named the Rocks of Jacumba Mountains in the southeastern part; and 3) metamorphosed miogeoclinal rocks of probable Paleozoic age in the northeastern part. The nature of the original contacts between these units is unknown; it is possible that each sequence contains rocks of more than one age and depositional setting.

### **Plutonic rocks**

In the El Cajon quadrangle, prebatholithic rocks were intruded by Middle (?) and Late Jurassic, Early Cretaceous, and Late Cretaceous plutons. Jurassic S-type (Chappell and White, 1974; White and Chappell, 1977) granitoid plutons intruded the Julian Schist and the Rocks of Jacumba Mountains to form an axial belt of metaplutonic rocks within the Peninsular Ranges Batholith. The western limit of Jurassic plutons (I-S line) coincides with a steep magnetic gradient in the northern batholith (Jachens and others, 1991; Jachens, 1992), a gradient that is considered to mark the location of a latest Jurassic to earliest Cretaceous crustal-scale fault (Todd and others, 1994a). Cretaceous I-type felsic to mafic plutons intruded these prebatholithic and Jurassic rocks during two major episodes as the Cretaceous magmatic arc swept eastward across the Late Jurassic continental margin. Plutons of both intrusive episodes, Early Cretaceous to Late Cretaceous, are present in the El Cajon quadrangle.

On the west side of the Peninsular Ranges Batholith, Early Cretaceous plutons intruded a Late Jurassic and Early Cretaceous island-arc assemblage; isotopic ages of the Early Cretaceous Santiago Peak Volcanics (Larsen, 1948) range from slightly older than, to coeval with these Early Cretaceous plutons. Early Cretaceous plutons also intruded the western part of the axial belt of Jurassic plutons and their Triassic-Jurassic wallrocks. In the central-eastern part of the batholith, large mid- to Late Cretaceous plutons of trondhjemitic and granodioritic composition (La Posta-type) intruded the Triassic-Jurassic belt, and farther to the east they intruded the Rocks of Jacumba Mountains and miogeoclinal Paleozoic rocks. Small, satellitic mid-Cretaceous trondhjemitic plutons in the southwestern part of the El Cajon quadrangle were apparently precursors of the voluminous eastern-zone La Posta plutons.

Descriptions of the pre-Cenozoic basement rocks of the Peninsular Ranges Batholith are divided into western and eastern zones (see Description of Map Units and Correlation of Map Units). These zones are separated approximately by the I-S line, which represents the Late Jurassic western margin of North America and coincides with other prominent axis-parallel geophysical and geochemical boundaries within the batholith (Todd and others, 1988b).

### **Batholithic structure**

Evidence from the El Cajon quadrangle suggests that intrusion, regional (intra-arc) deformation, and metamorphism were closely linked in the northern Peninsular Ranges Batholith. Batholithic structural trends change from west to east across the batholithic rocks in the quadrangle (Todd and others, 1988b). In the western zone, Early Cretaceous plutons have sheeted to diapiric shapes with variable structural trends. These western plutons intruded metavolcanic wallrocks concordantly, and foliation in both is parallel to steep contacts. Amphibolite-facies metamorphism of the volcanic rocks was predominantly of regional type. Steeply inclined magmatic foliation and lineation are well developed near pluton margins, and thin-section views show that magmatic foliation was variably overprinted by subsolidus recrystallization. These features suggest that the Early Cretaceous plutons were emplaced during intra-arc ductile deformation that continued after intrusion, at least into the late Early Cretaceous, the age of the youngest plutons that bear the western-zone fabric.

In the central part of the quadrangle, the Jurassic plutons and most of the Early Cretaceous plutons that intruded them have north-northwest-elongate shapes and strongly foliated, gneissic, or mylonitic textures (Cuyamaca-Laguna Mountains Shear Zone, Todd and others, 1988b; Thomson and Girty, 1994). Contacts and foliation within plutons and screens in the central Peninsular Ranges Batholith display steep eastward dips and a penetrative down-dip lineation, a fabric that is present in plutons as young as about 118 Ma (Todd and others, 1994b) but only weakly developed in a pluton dated as about 104 Ma by L.T. Silver (oral commun., 1979).

In contrast to Jurassic and Early Cretaceous bodies, plutons of Late Cretaceous age in the south-central and eastern parts of the quadrangle show both concordant and discordant contact relations with older plutons suggesting that they were emplaced during the waning stages of, and after, regional deformation. Grove (1987) reported that fold axes in strongly foliated to mylonitic, mid-Cretaceous tonalite of Granite Mountain just north of the quadrangle plunge subhorizontally to the north-northwest; he interpreted this fabric to have formed during intrusion. In contrast, plutons of the Late Cretaceous tonalite of La Posta have moderately to weakly foliated margins and massive interiors. Satellitic plutons of both units in the central and western parts of quadrangle exhibit weak to moderate foliation that is concordant with the fabric of the surrounding plutons. Shallow linear fabric elements in the Granite Mountain unit north of the study area may reflect a change from Early Cretaceous subduction perpendicular to the continental margin to Late Cretaceous subduction oblique to, and with a component of slip parallel to, the continental margin (Engebretson and others, 1985; Murchey and Blake, Jr., 1993).

### **Uplift and unroofing**

Unroofing of the westernmost part of the Peninsular Ranges Batholith in San Diego County had occurred by about 84 Ma, the age of fossiliferous marine strata that nonconformably overlie batholithic rocks west of the El Cajon quadrangle (Kennedy, 1975). Fission-track and  $^{40}\text{Ar}$   $^{39}\text{Ar}$  ages of plutonic rocks in the western part of the quadrangle indicate that this area cooled rapidly at about 112Ma, whereas episodes of rapid cooling occurred at about 82 and about 62 Ma in the west-central part (Snee and others, 1994; Naeser and others, 1996). In the eastern part of the quadrangle, rapid cooling took place from about 60-40 Ma. Uplift and cooling of the eastern Peninsular Ranges Batholith was associated with episodes of Late Cretaceous and early Tertiary (?), ductile-to-brittle low-angle faulting (Erskine, 1986; Todd and others, 1988b; George and Dokka, 1994). During this interval, plutonic rocks that originated in a distal eastern part of the batholith were apparently thrust westward over high-grade mylonitic plutonic rocks and metasedimentary anatexites of the present northeastern region (Erskine, 1986). Continued uplift produced brittle listric normal faults that cut these high-grade rocks (Sharp, 1979; Erskine, 1986). The southern termination of this system of low-angle faults extends into the quadrangle in the southern Vallecito Mountains and northern Tierra Blanca Mountains, where four low-angle fault plates consisting of the tonalites of Granite Mountain and La Posta are preserved in a graben within the Elsinore Fault Zone.

## **SAN DIEGO EMBAYMENT**

By Late Cretaceous time, the westernmost part of the Peninsular Ranges Batholith had undergone uplift, erosion to a surface of low relief, and marine inundation forming the San Diego embayment (Kennedy, 1975). The oldest strata of the embayment, which are assigned to the Upper Cretaceous Rosario Group of Kennedy (1975), are present in the eastern part of the San Diego 30' x 60' quadrangle (Kennedy, in press) and the westernmost part of the El Cajon quadrangle. The Rosario Group consists of 1) basal nonmarine fanglomerate of batholithic derivation assigned to the Lusardi Formation of Nordstrom (1970) unconformably overlain by 2) Campanian-Maestrichtian marine strata assigned to the Point Loma and Cabrillo Formations (Kennedy, 1975), neither of which occur in the El Cajon quadrangle. No stratigraphic record is present for the Paleocene and early Eocene in the region, but the Upper Cretaceous strata were apparently uplifted and eroded prior to deposition of the middle and upper Eocene La Jolla and Poway Groups (Kennedy, 1975).

Biostratigraphic relations among the Eocene formations record gradual subsidence of the northwest-trending San Diego embayment and, despite fluctuations in sea level, an overall east-to-west progression from nonmarine near-shore and shoreline deposits to marine shelf deposits (Kennedy, 1975). The Eocene strata in the easternmost part of the embayment were deposited by a system of west-flowing rivers (Minch, 1972). The Eocene strata in the coastal zone are unconformably overlain by Pliocene and Pleistocene marine and nonmarine strata that were laid down upon a broad wavecut coastal terrace.

Patchy remnants of Late Cretaceous and Eocene strata in the westernmost part of the El Cajon quadrangle indicate that the San Diego embayment may originally have extended at least as far east as 116°45' W. long. Conglomerates of the Poway Group contain distinctive silicic volcanic and quartzite clasts that are believed to be exotic to the Peninsular Ranges Batholith (Abbott and Smith, 1978; 1989). Provenance of the Poway clasts is considered to have originally lain east of the Peninsular Ranges and is now located across the San Andreas Fault several hundred kilometers to the southeast in Sonora, Mexico (Abbott and Smith, 1978; 1989). Patches of lag gravel that contain Poway clasts are present at elevations as high as 1,000 m in the El Cajon quadrangle, and reworked Poway clasts may also be present in the western Colorado Desert (Kerr and Kidwell, 1991). Thus, Eocene strata that once blanketed much or all of the quadrangle apparently were stripped from batholithic basement prior to, or at an early stage in Neogene tectonics.

### **FISH CREEK-VALLECITO BASIN**

The Neogene sedimentary and volcanic rocks that are exposed along the western margin of the Salton Trough comprise the most complete stratigraphic record of the northern Gulf of California in southern California (Winker, 1987; Kerr and Kidwell, 1991). As a result of the Neogene transition from a subduction plate boundary to the Gulf of California-San Andreas rift-transform system (Kerr and Kidwell, 1991; Atwater, 1992), the Salton Trough had become the site of rifting, extensional faulting, basaltic volcanism, and marine transgression by Miocene time.

During Miocene through Pleistocene time, a thick (5-6 km) section of continental and marine clastic rocks characterized by complex facies changes and local unconformities accumulated in subsiding basins such as the Fish Creek-Vallecito Basin, a major part of which is exposed in the eastern part of the El Cajon quadrangle. The oldest strata in the Fish Creek-Vallecito Basin are early and middle Miocene fluvial, alluvial-fan, and rock-avalanche deposits mainly of local derivation that were deposited nonconformably upon crystalline basement of the Peninsular Ranges Batholith (Kerr, 1984). Volcanic rocks that range in age from 22 to 14 Ma (Hawkins, 1970; Minch and Abbott, 1973; Hoggatt, 1979; Ruisaard, 1979) are interstratified with these continental strata at several horizons and also occur as clasts within them.

In late Miocene and early Pliocene, the Fish Creek-Vallecito Basin underwent rapid subsidence and was invaded by a northward transgression of the Gulf of California (Johnson and others, 1983). Basin-marginal alluvial fan deposits grade laterally to shallow-marine evaporites (Dean, 1988), sandstone, and conglomerate, and, as subsidence continued, to deeper-marine turbidites (Winker, 1987; Kerr and Kidwell, 1991). Early Pliocene marine strata record gradual shoaling as the basin was rapidly filled by the influx of large volumes of fine-grained sand and silt supplied by the Colorado River. The initiation of the Colorado River as a major sediment source for the Salton Trough was soon followed by widespread deposition of thick (about 3.5 km) Pliocene progradational deltaic deposits (Kerr and Kidwell, 1991).

Pliocene through Quaternary strata record a transition from deltaic deposition to largely nonmarine fluvial and basin-marginal alluvial fan deposits whose clasts were derived from local basement uplifts. The Late Pleistocene and Holocene were marked by widespread erosion of folded Pliocene to middle Pleistocene strata and the formation of extensive alluvial fans and terraces (Woodard, 1963).

### **TECTONIC HISTORY OF WESTERN SALTON TROUGH**

In early to middle Miocene, continental rifting and extensional faulting produced half-graben basins and basement horsts in the western Salton Trough (Winker, 1987; Kerr and Kidwell, 1991). The

onset of strike slip tectonism, which produced major northwest-southeast dextral strike-slip faults and antithetic northeast-southwest sinistral strike-slip faults (Winker, 1987), has not been dated precisely, but is estimated to have begun between the late Miocene (about 10 Ma) and early Pliocene (about 5 Ma) (Kerr and Kidwell, 1991). Late Pliocene or Pleistocene uplift, tilting, and about 35° clockwise rotation of the basin fill in the western Salton Trough (Johnson and others, 1983) was accompanied by folding on east-west axes and listric-normal and detachment faulting (Winker, 1987).

All of the above tectonic elements are present in the El Cajon quadrangle. Evidence that the Fish Creek-Vallecito Basin was initiated in early to middle Miocene includes sedimentary and volcanic rocks of this age that were deposited upon, and subsequently deformed along the flanks of basement horsts such as the Vallecito and Fish Creek Mountains. West of the Salton Trough, the Peninsular Ranges block apparently began to rise at about the same time, elevating Miocene volcanic rocks about 500 m above the desert floor in the Jacumba area. Smaller half-graben basins in the northwestern part of the Elsinore Fault Zone (Mason and Vallecito Valleys and the northern part of Carrizo Valley) are probably younger than the Fish Creek basin because the oldest strata in these basins, assigned to the Pliocene and Pleistocene Palm Spring Formation, are confined to basin floors and faulted along their margins.

No single strike-slip fault of large-magnitude displacement has been recognized within the quadrangle. Contacts between Mesozoic basement-rock units are essentially continuous from the Tierra Blanca Mountains through the Campbell Grade area into the Vallecito Mountains, and Late Cretaceous-early Tertiary low-angle faults are continuous across Vallecito Valley from the Tierra Blanca to the Vallecito Mountains. High-angle faults that bound the northeastern and northern margins of Mason and Vallecito Valleys show small (about 1 km), right-lateral, oblique offsets of basement contacts. Where granitic rock contacts cross the Elsinore Fault Zone immediately north of the quadrangle in the Julian 7.5' quadrangle, offsets suggest as much as 2.5 km right-oblique slip (V. Todd, unpublished mapping). Cumulative right-lateral slip in the region is greater if similar offsets exist on other northwest-trending faults in the complexly broken zone between the Elsinore and San Jacinto fault zones.

Within the quadrangle, late Pliocene and Pleistocene uplift of the Fish Creek-Vallecito Basin is recorded by large folds on east-west axes in basin fill, and by basement-cored folds on northwest axes in the western Coyote Mountains. Both sets of folds involve rocks as young as the Palm Spring Formation. In the western Coyote Mountains, the prominent fault that bounds the southwest flank of the range is a reverse fault that dips from 47° to 55° NE and carried crystalline rocks southwestward over a late Pleistocene to Holocene alluvial fan (Hoggatt, 1979).

Kerr and Kidwell (1991) cited the persistence of coarse basin-marginal deposits throughout the Neogene history of the region as suggesting continuous rejuvenation of local source areas. This is indicated in the quadrangle by the occurrence of Miocene to early Pliocene megabreccia, or landslide deposits in the Vallecito Mountains and by similar deposits that involve the Palm Spring Formation in the northeast wall of Mason Valley and in Sandstone Canyon. Quaternary landslides are mapped along the northeastern margin of Mason Valley and the northern margin of Vallecito Valley (Hart, 1991).

Extensional faulting continued into Holocene time in the southern part of the Elsinore Fault Zone. Predominantly high-angle normal faults cut late Pleistocene to Holocene alluvial fans and terraces and locally cut older and younger alluvium (e.g., Mason and Vallecito Valleys; frontal fault zone of the Tierra Blanca Mountains; northern Jacumba Mountains). Along the Laguna Salada Fault, which is the extension of the Elsinore Fault Zone into Baja California, Mexico, Isaac and others (1986) described Plio-Pleistocene detachment faulting that is associated with low- and high-angle extensional faults. The authors proposed that these extensional structures were exposed by left-stepping of recent dextral faults.

## DESCRIPTION OF MAP UNITS

### *El Cajon quadrangle*

Qya      **Young alluvium (Holocene)**—In Peninsular Ranges, includes sand, silt, and gravel in modern streambeds, and thin veneers of fine-grained sediment formed in situ by chemical weathering in upland meadows. In Anza-Borrego Desert, consists of sand and gravel in narrow modern washes as well as material that is transported

- intermittently by seasonal floods on alluvial fans or has accumulated as cone-shaped fans at mouths of canyons
- Qc **Colluvium (Holocene and Pleistocene)**—Sand and gravel of slopewash, debris-flow, and talus deposits. Grades locally into older and younger alluvium
- Qu **Alluvium and colluvium, undivided (Holocene and Pleistocene)**—Deposits in which younger and older alluvium and colluvium have not been mapped separately
- Qls **Landslide deposits (Quaternary)**—Localized deposits of unconsolidated to consolidated earth and rock materials that moved down slope as landslides
- Qoa **Older alluvium (Holocene and Pleistocene)**—Well to poorly bedded, unconsolidated deposits of sand, silt, and gravel that occur as moderately dissected terraces in stream valleys within the Peninsular Ranges (western and central El Cajon quadrangle) and on the higher parts of alluvial fans in the Anza-Borrego Desert. Modern streams have cut older alluvium to depths of as much as 15 m. A preliminary radiocarbon age of  $920 \pm 60$  years B.P. was determined for charcoal from older alluvium in Pine Valley (S.W. Robinson, U.S. Geological Survey). In some areas, older alluvium grades into younger alluvium
- QTf **Fanglomerate (Pleistocene and Tertiary?)**—Patchy deposits that consist of thick (>10 m) lenses of poorly sorted, weakly indurated conglomeratic sands and fanglomerate of local derivation (gabbro, leucocratic monzogranite and granodiorite, and minor prebatholithic rocks) occur in the El Cajon quadrangle at elevations ranging from 425 to 1200 m. As mapped, these deposits include debris-flow deposits and small landslides. Fanglomerate lies on ridgetops and spills into adjacent valleys, or forms a broad fill, now largely dissected and eroded, in the larger valleys. The deposits grade locally into older and younger alluvium possibly because of reworking of material by slopewash. Sparse rounded cobbles of the above resistant lithologies and scattered small sand lenses suggest that similar deposits were once more widespread on erosion surfaces in the north-central part of the quadrangle. Tonalite beneath the deposits is deeply weathered and has a soil profile. If the fanglomerate deposits represent more than one cycle of erosion and deposition, then they may include materials of Tertiary age

### *San Diego Embayment*

- Ql **Lindavista Formation (Pleistocene or Pliocene)**—Reddish-brown interbedded sandstone and conglomerate. The Lindavista Formation was named by Hanna (1926) for exposures in the La Jolla 7.5-minute quadrangle west of the quadrangle. The formation consists of near-shore marine and nonmarine sediments deposited on a 10-km-wide wavecut platform following deposition of the middle or late Pliocene San Diego Formation and prior to deposition of fossiliferous late Pleistocene strata (Kennedy, 1975). A molluscan fauna suggests it is early Pleistocene or late Pliocene. Ferruginous cement, mainly hematite, gives the formation its characteristic color and resistance to erosion
- Tsd **San Diego Formation (Pliocene)**—Marine sandstone and subaerial conglomerate (Kennedy, 1975). Sandstone lies east of, and generally below, the conglomerate facies. Sandstone is typically fine- to medium-grained, yellowish-brown, poorly indurated, in places having limy cement. Locally rich fossiliferous sections contain fauna that suggest a middle and late Pliocene age (Milow and Ennis, 1961). Sandstone beds are weakly resistant to erosion and underlie a subdued terrain. Conglomerate of the San Diego Formation lies above, and interfingers with the sandstone. The conglomeratic part of the formation consists of pebbles, cobbles, and boulders in a coarse-grained sandstone matrix. These rocks attain a maximum thickness of 75 m and are poorly sorted, well indurated, and cemented with ferruginous cement. Siliceous metavolcanic tuff locally constitutes 75% of

the clasts. Clasts of granitic and low-grade metavolcanic rocks derived from local basement are abundant in some exposures. The conglomeratic part of the formation is resistant to erosion and weathers reddish-brown as a result of the oxidation of iron-bearing cement

- Tf **Fanglomerate (Pliocene and Miocene)**—An unnamed boulder-fanglomerate unit crops out near Lower Otay Reservoir. The fanglomerate rests nonconformably upon low-grade metavolcanic rocks. Clasts are fresh and angular and have compositions identical to the basement rocks exposed nearby. The matrix of the fanglomerate consists of medium- and coarse-grained, light-brown sandstone and waxy light-brown bentonite. Fanglomerate interfingers with strata of the Otay Formation to the west
- To **Otay Formation (Oligocene)**—The Otay Formation of Artim and Pinckney (1973) is composed of light-gray and light-brown, moderately well sorted, poorly indurated massive sandstone and claystone. Claystone is waxy and is composed almost exclusively of bentonite. The topographic expression of the unit is gently rolling and subdued
- Poway Group (Eocene)**—Conglomerate, marine sandstone, and brackish water claystone. Subdivided into:
- Tp **Pomerado Conglomerate (Eocene)**—The Pomerado Conglomerate, which is the uppermost formation of the Poway Group, has a maximum thickness of 55 m. It was named for exposures west of the quadrangle in the Poway 7.5-minute quadrangle (Peterson and Kennedy, 1974). The Middle Eocene Pomerado Conglomerate is a massive cobble conglomerate that is lithologically identical to the Stadium Conglomerate with occasional thin beds, lenses, and tongues of light-brown, medium-grained sandstone. The contact between the Mission Valley Formation and the Pomerado Conglomerate is conformable and gradational
- Tmv **Mission Valley Formation (Eocene)**—The Mission Valley Formation, a predominantly marine sandstone unit, rests conformably upon the Stadium Conglomerate and is in turn conformably overlain by the Pomerado Conglomerate. The Mission Valley Formation has a maximum thickness of 60 m and was named for exposures in the La Jolla 7.5-minute quadrangle west of the quadrangle (Kennedy, 1975). Sandstone is soft and friable, light-olive-gray in color, fine- to medium-grained, and composed mostly of quartz and K-feldspar with less than 2% plagioclase and biotite. Tongues of cobble conglomerate that is similar to the Stadium Conglomerate comprise as much as 30% of the easternmost exposures of the formation. Interbeds and tongues of claystone of brackish water origin locally compose 20% of the section. The Mission Valley Formation contains a molluscan fauna in its western and central exposures and a land-mammal fauna in eastern exposures that together indicate a Middle Eocene age
- Tst **Stadium Conglomerate (Eocene)**—Three partly intertonguing and partly time-equivalent formations- the Stadium Conglomerate, the Mission Valley Formation, and the Pomerado Conglomerate- comprise the late Eocene Poway Group (Poway Conglomerate of Hanna, 1926; Kennedy, 1975). These rocks, which are mainly nonmarine in their easternmost exposures and nearshore marine and lagoonal in their westernmost exposures, crop out in the westernmost part of the El Cajon quadrangle. The type section of the Stadium Conglomerate lies outside the quadrangle near the boundary between the La Jolla and La Mesa 7.5-minute quadrangles (Kennedy, 1975). The formation consists of massive cobble conglomerate with a dark-yellowish-brown, coarse-grained sandstone matrix. Conglomerate is moderately well sorted with an average clast size in the cobble size range. In some sections, sandstone beds and lenses make up 50% of the rock. The distinctive "Poway clasts" that typify the Stadium Conglomerate consist predominantly (as much as 85 percent) of weakly metamorphosed rhyolitic to dacitic volcanic and volcanoclastic rocks and as



much as 20% quartzite. The Stadium Conglomerate overlies the Friars Formation conformably and is conformably overlain by the Mission Valley Formation. Lenses of crossbedded sandstone within the conglomerate contain Middle Eocene fossils

**Tfr Friars Formation (Eocene)**—The Friars Formation is the uppermost unit of the La Jolla Group (La Jolla Formation of Hanna, 1926), which is a lower and middle Eocene marine and nonmarine unit that occurs west of the quadrangle (Kennedy, 1975). The formation includes nonmarine and lagoonal sandstone and claystone named for exposures in the La Jolla 7.5-minute quadrangle (Kennedy, 1975). The Friars Formation is predominantly a nonmarine and nearshore marine facies that reaches a maximum thickness of 50 m west of the El Cajon quadrangle. Sandstone is typically massive, yellowish-gray, medium-grained, and poorly indurated. Sand grains are composed entirely of plutonic rock detritus. Cobble-conglomerate lenses and tongues of fluvial origin are characteristic of the easternmost exposures. The Friars Formation rests unconformably on basement rocks within the quadrangle, and is in turn overlain by younger sedimentary deposits of Eocene, Pleistocene, and Holocene age. Marine and land-mammal fossils indicate a middle Eocene age for the formation

**Kl Lusardi Formation (Late Cretaceous)**—The Lusardi Formation was named by Nordstrom (1970) for exposures of boulder conglomerate in the Rancho Santa Fe 7.5-minute quadrangle west of the quadrangle. In its type area the formation is unconformably overlain by Eocene rocks, but 16 km to the north, it is overlain conformably by siltstone and sandstone of the Late Cretaceous Point Loma Formation (Kennedy and Moore, 1971). The Lusardi Formation is exposed in the northwest corner of the El Cajon quadrangle in scarce thin deposits that overlie batholithic rocks and locally are capped by the Eocene Pomerado Conglomerate. At the type locality, the formation consists of cobble and boulder conglomerate with occasional thin lenses of medium-grained sandstone (Kennedy, 1975). Here, clasts are as much as 10 m in diameter and the Lusardi Formation has a maximum thickness of 125 m. Its thickness is much less within the El Cajon quadrangle where erosion has removed much of the fine-grained matrix of the conglomerate and the formation is recognizable chiefly by the presence of scattered boulders and cobbles of resistant gabbro and Corte Madera-type monzogranite. Roadcuts into probable Lusardi Formation in the Alpine area reveal pale-gray-weathering, crudely bedded and poorly indurated pebbly and cobbly sands overlying a pluton of the Tonalite of Las Bancas. The Lusardi Formation is considered to be Late Cretaceous in age because it contains boulders eroded from the Early to Late Cretaceous Peninsular Ranges Batholith and is overlain by the Point Loma Formation, which contains fossils of Late Cretaceous (Campanian) age (Kennedy, 1975)

### *Western Colorado Desert*

**Qm Mesa Conglomerate (Pleistocene)**—The Mesa Conglomerate was defined by Woodard (1967) as pediment fan and alluvial outwash deposits consisting of massive conglomerate, arenite, and gravel that cap the folded Imperial and Palm Spring Formations in the Carrizo Badlands. The Mesa Conglomerate is characterized by nearly flat-lying beds and broad, gently sloping surfaces that are paved with cobbles and small boulders having well developed desert varnish. In the El Cajon quadrangle, the formation includes 1) massive or torrentially bedded, coarse boulder-conglomerate near mountain fronts; 2) flat-lying poorly bedded sandstone and conglomerate alluvial outwash deposits that filled and capped a gentle topography; and 3) well bedded siltstone and sandstone deposits whose source was the Palm Spring Formation. Near mountain fronts, the Mesa

Conglomerate consists of unstratified, poorly sorted angular clasts that accumulated at the apices of alluvial fans. Away from the fan-heads, the deposits become finer-grained, thinner, and similar to the Mesa Conglomerate as described by Woodard (1963). The latter consists of tan- or buff-colored, poorly sorted pebbly arenite with conglomeratic lenses that define indistinct bedding. The uppermost 1 to 2 m of arenite are commonly cemented by calcium carbonate and resemble concrete aggregate. Flat-lying Mesa Conglomerate overlies folded Palm Spring Formation with angular unconformity. In places where the Palm Spring Formation was the only source for the Mesa Conglomerate, it is difficult to distinguish the two units unless the unconformity is exposed. Prior to deposition of the Mesa Conglomerate, the eroded Palm Spring topography was apparently relatively flat, with small rounded hills and gentle valleys. The broad Mesa surfaces appear to be eroded along their edges but show little downcutting in the interiors. These surfaces are considered to be remnants of an original widespread pediment surface (Hoggatt, 1979). Mesa Conglomerate is unfossiliferous, but from regional relations, Woodard (1963) considered it to be of late Pleistocene to Holocene age

**Qt Terrace deposits (Pleistocene)**—Patchy deposits of dissected, flat-lying alluvium are present near the eastern border of the quadrangle on the lower flanks of the Fish Creek Mountains and near the crest of the central Coyote Mountains. These deposits consist of poorly consolidated silt, sand, and gravel that form desert pavement terraces coated with desert varnish. The alluvium is poorly sorted and its angular clasts were derived largely from the surrounding mountain ranges. Terrace deposits in the Fish Creek Mountains are essentially continuous with the upper Pleistocene to Holocene Mesa Conglomerate, but those in the Coyote Mountains lie at elevations that range from about 75 to 300 m higher than those of the Mesa Conglomerate (Christiansen, 1957; Hoggatt, 1979). In the latter case, terrace deposits that are equivalent to the Mesa Conglomerate may have been uplifted to their present position by normal faulting on the north and south sides of the Coyote Mountains. Terrace deposits are considered to be of Holocene and Pleistocene age

**QTps Palm Spring Formation (Pleistocene and Pliocene)**—The Palm Spring Formation was named by Woodring (1932) for nonmarine sediments overlying the Imperial Formation on the north side of the Coyote Mountains. The unit was studied comprehensively by Woodard (1963, 1974) in the Arroyo Tapiado 7.5-minute quadrangle, where badlands provide excellent exposures. Since then, the Neogene stratigraphy, sedimentation, and tectonics of the western margin of the Salton Trough have been restudied extensively (Kerr, 1984; Winker, 1987; Kerr and Kidwell, 1991). Woodard (1963) described more than 3,000 m of interbedded siltstone, claystone, arkosic sandstone, pebble conglomerate, and fresh-water limestone representing alluvial floodplain deposits marginal to the retreating Gulf of California. Marine interbeds containing impoverished marine fauna indicate intermittent marine transgressions as late as middle Pleistocene, and vertebrate fossils throughout the section provide evidence of continuous deposition from Irvingtonian to Blancan time (late Pliocene to early middle Pleistocene). Winker (1987) followed Woodard's subdivision of the Palm Spring Formation into four informal members and added a fifth member. He described the formation as consisting predominantly of fluvial and alluvial-fan deposits and minor lacustrine deposits representing interfingering, laterally gradational deltaic and basin-marginal alluvial sedimentary facies. The Palm Spring Formation becomes coarser and grades laterally into the Canebrake Conglomerate of Dibblee (1954) closer to the surrounding mountain ranges. Woodard (1963) described the Canebrake Conglomerate as locally derived, terrestrial pediment boulder- to cobble-fanglomerate and subordinate pebbly arenite that represents the marginal equivalent of the Palm Spring and Imperial Formations. The Palm Spring Formation grades downward into the underlying

Imperial Formation with the appearance of abundant gypsum platelets, irregularly shaped beds and blebs of bluish-gray claystone and green sandy silt, and interbeds of fossiliferous marine olive-green sandstone (Hoggatt, 1979). Surfaces of hills underlain by the Palm Spring Formation commonly are covered by a lag deposit of well-rounded cobbles and boulders derived from the Mesa Conglomerate

- Ti **Imperial Formation (Pliocene and Miocene)**—Marine strata within the Salton Trough were assigned by Woodring (1932) to the Imperial Formation. Tarbet (1951) subdivided the formation into three members: a lower member 60 m thick consisting of massive and poorly bedded gray feldspathic arenite; a middle member 750 m thick consisting of rhythmically bedded gray silty mudstone and very fine quartz arenite; and an upper member 390 m thick consisting of alternating siltstone and sandstone interbedded with massive biostromal limestone and calcereous arenite. The two lower members contain marine fossils, whereas the uppermost member contains vertebrate fossils that indicate a Blancan provincial age (Woodard, 1974). Winker (1987) recognized ten informal members within the Imperial Formation, and included upper, marine subunits of the Split Mountain Formation within the Imperial Formation. Winker characterized these ten members as representing two facies sequences: an older, pre-deltaic sequence and a younger deltaic sequence. The pre-deltaic sequence consists (in stratigraphic order) of fossiliferous shallow-marine facies (fan-deltas), "turbiditoid" facies (subaqueous sediment gravity flows and debris flows), and submarine fan facies (turbidites); whereas the deltaic sequence consists of prodelta facies (clay and silt), upward-shoaling marine delta front facies (sandstone and coquina), transitional marine-to-nonmarine facies (lagoons, brackish marshes, tidal flats), and delta plain facies (nonmarine fluvial deposits) (Winker, 1987). The Imperial Formation grades downward into, and interfingers with, the Fish Creek Gypsum and the Split Mountain Formation
- Tfc **Fish Creek Gypsum (Pliocene and Miocene)**—The Fish Creek Gypsum, named by Dibblee (1954), is a thick (as much as 60 m), exceptionally pure gypsum and anhydrite deposit that is exposed in the Fish Creek Mountains. The evaporites either rest unconformably on basement or else conformably overlie transitional marine mudstones; evaporites intertongue laterally with alluvial fan deposits of the Split Mountain Formation (Kerr and Kidwell, 1991). The Fish Creek Gypsum is overlain in sharp contact by locally derived turbidites or by the upper fanglomerate member of the Split Mountain Formation. The Fish Creek evaporites are of marginal marine origin and thus provide the first record of marine incursion in the Salton Trough (Dean, 1988). Microfossils from thin claystone beds within the evaporites date the deposit as late Miocene to early Pliocene in age (Dean, 1988)
- Tsm **Split Mountain Formation (Miocene)**—The Split Mountain Formation was named by Tarbet and Holman (1944) for exposures in the Fish Creek Mountains. Woodard (1974) recognized four members, which in part are laterally gradational lithofacies. In stratigraphic order upward, these are 1) a lower member of dark-gray, very coarse boulder and cobble fanglomerate composed of angular blocks of granitic and metamorphic rocks, 2) the Fish Creek Gypsum, which is interbedded locally with sandstone and shale of the overlying marine arenite member, 3) intercalated, lensing quartz arenite and olive-green micaceous shale containing middle or late Miocene (or younger) marine fossils, and 4) massive gray fanglomerate or megabreccia that is lithologically similar to the basal gray fanglomerate. The Split Mountain Formation overlies basement nonconformably, or unconformably overlies older, red alluvial fan deposits (the Miocene Anza Formation). The contact between the Split Mountain Formation and the overlying Imperial Formation is gradational
- Tal **Alverson Andesite (Miocene)**—The Alverson Andesite was named by Dibblee (1954) for as much as 120 m of volcanic flows in Alverson Canyon in the Carrizo

Mountain 7.5-minute quadrangle, near the eastern border of the El Cajon quadrangle. Volcanic rocks correlated with the Alverson Andesite also occur in the Fish Creek Mountains (Dibblee, 1954; Woodard, 1974), where they overlie granitic basement and the Anza Formation unconformably. Flows, consisting of dark-mauve-gray plagioclase-hornblende andesite, are interbedded with gray andesite tuff. In the northern Jacumba Mountains, volcanic rocks were extruded onto an eroded batholithic surface overlain locally by the Anza Formation. Upper Miocene and younger deposits unconformably overlie the volcanic rocks, locally with marked angular discordance (Kerr and Kidwell, 1991). The volcanic rocks of the northern Jacumba Mountains consist of as much as 150 m of massive flows, breccia, intercalated volcanoclastic deposits, and minor air-fall cinder deposits (Hoggatt, 1979). Individual flows average 4 to 6 m in thickness, and locally are up to 15 m thick. Flows vary widely in color and joint pattern, but typical fresh rock has a dark-gray aphanitic groundmass containing scattered greenish-brown mafic phenocrysts. Rock is olivine basalt composition. Beds of arkosic sandstone and oxidized volcanoclastic debris fill irregularities in flow surfaces as though the surfaces were washed by streams. Flows were generally preceded by an eruption of cinders and lapilli that thinly blanketed the area (up to 3 cm). Olivine basalt from the northern Jacumba Mountains yielded a K-Ar whole-rock age of  $16.9 \pm 0.5$  Ma (Hoggatt, 1979). This age is in accord with isotopic ages of volcanic rocks elsewhere in the quadrangle that range from about 14 to 22 Ma (Kerr and Kidwell, 1991)

Tj **Jacumba Volcanics (Miocene)**—Lower to middle Miocene alkalic and tholeiitic basalt flows, breccias, and pyroclastic rocks, and rare basaltic andesite differentiate (Hawkins, 1970; Ruisaard, 1979; Gjerde, 1982) are widely exposed in the eastern part of the quadrangle. Volcanic rocks in the southern Jacumba Mountains are assigned to the Jacumba Volcanics of Minch and Abbott (1973), whereas those in the northern Jacumba Mountains, Coyote Mountains, and Fish Creek Mountains are assigned to the Alverson Andesite. Minch and Abbott (1973) subdivided the volcanic rocks of Jacumba Valley into three units: 1) basalt flows and cinder cone deposits, 2) basaltic andesite plugs, and 3) andesite breccia, lahar deposits, conglomerate, and volcanoclastic sandstone. Flows comprise as much as 40 m of gray to dark-gray, platy to massive vesicular olivine basalt and basaltic andesite. Remnants of at least five cinder cones and two prominent hypersthene andesite plugs are exposed in the valley (Minch and Abbott, 1973). Basalt dike systems associated with the cinder cones appear to have partly followed northwest-trending fracture systems. A heterogeneous sequence of andesitic lahar deposits, breccia, conglomerate, and sandstone forms a conspicuous part of the Jacumba Volcanics. Andesite breccias grade into lahars. A tholeiitic basalt from the Jacumba Volcanics dated by Hawkins (1970) yielded a K-Ar whole-rock age of  $18.7 \pm 1.3$  Ma ( $19.2$  Ma recalculated using revised constants, Hoggatt, 1979). Minch and Abbott (1973) obtained concordant hornblende and plagioclase ages of  $18.5 \pm 0.9$  Ma and  $18.6 \pm 0.8$  Ma, respectively (recalculated ages  $19.0$  Ma and  $19.1$  Ma, Hoggatt, 1979) from a clast in andesite breccia near Jacumba. Tuff-breccia collected in lower Davies Canyon about 1 km east of the El Cajon quadrangle yielded two conventional K-Ar ages:  $11.1 \pm 0.4$  Ma on a dacitic bomb and  $13.7 \pm 0.4$  Ma on biotite from the tuffaceous matrix (J. Nakata, written commun., 1988). The Jacumba Volcanics rest nonconformably on lower and middle Miocene braided stream and alluvial fan deposits and are overlain by Quaternary alluvial deposits

Ta **Anza Formation (Miocene)**—The oldest postbatholithic sedimentary rock unit in the eastern part of the El Cajon quadrangle consists of coarse conglomeratic sandstone assigned to the Miocene Anza Formation. Defined by Woodard (1974), the Anza Formation was formerly considered to be the basal conglomerate member of the Split Mountain Formation of Tarbet and Holman (1944). At its type locality in the Fish Creek Mountains, the Anza Formation is

540 m thick, but in the northern Jacumba Mountains, its maximum exposed thickness is only about 5 m, and it is preserved only where covered by flows of the Alverson Andesite. The Anza Formation is unfossiliferous, and its age is estimated to be early Miocene because it was deposited on the eroded surface of the Peninsular Ranges Batholith. In the Jacumba Mountains, the formation grades upward into increasingly volcaniclastic beds whose deposition must have immediately preceded the first flows of the Miocene Alverson Andesite. At the type locality, the Anza Formation consists of reddish-brown arkosic sandstone and interbedded fanglomerate composed of granitic clasts (Woodard, 1974). Arkosic sandstone is coarse to very coarse, massive and crossbedded, and moderately to well indurated. Clasts are composed of quartz, feldspar, biotite, and granitic rock fragments. Weathering of iron-bearing minerals and abundant reddish-brown silty matrix imparts a distinctive reddish cast to the rock. Cobble- and boulder-fanglomerate beds composed chiefly of granitic and metamorphic rocks from local source areas increase markedly in the upper part of the section. Locally, boulders of dark-mauve-gray plagioclase-hornblende andesite porphyry are embedded in coarse arkosic sandstone of the Anza Formation. These boulders are petrographically similar to volcanic rocks of the Alverson Andesite exposed 8 km to the SE in the Fish Creek Mountains

### **Peninsular Ranges Batholith**

#### *Western sequence*

K1b **Tonalite of Las Bancas (Early Cretaceous)**—Plutons of the tonalite of Las Bancas (Hoggatt and Todd, 1977) are present throughout the El Cajon quadrangle, but are larger and more voluminous in the western zone. The unit forms large, homogeneous inclusion-free plutons that weather to dark-reddish-gray and buff-gray residual boulders. At elevations lower than about 500 meters, the tonalite of Las Bancas has a light-bluish-gray weathered color, and in some places can be distinguished from the adjacent mafic inclusion-bearing Alpine and Japatal Valley tonalites by this color and by its more resistant, uniformly jointed character. The most abundant rock types of the tonalite of Las Bancas are medium-grained, equigranular hypersthene-biotite tonalite, quartz diorite, and granodiorite, but include lesser diorite, quartz monzodiorite, and quartz norite. Potassium feldspar oikocrysts ranging from 0 to 15% of the rocks are especially present in eastern Las Bancas plutons. Clinopyroxene rims hypersthene and minor hornblende is present as narrow reaction rims around pyroxenes in many Las Bancas rocks. In dark-gray to black freshly broken rocks, mafic minerals show through clear, glassy plagioclase grains giving the impression of a higher color index than that determined from modal counts of stained slabs (color index 22 to 32). Large (0.5 to 2.5 cm), evenly distributed biotite oikocrysts that enclose earlier-crystallized mafic grains appear as reflective grains on weathered rock faces. Locally, tonalite displays cumulate layering and contains scarce, small ovoid basaltic inclusions. Most plutons of the tonalite of Las Bancas have magmatic microtextures and weak foliation, but in marginal parts of some plutons, foliation is protomylonitic. Contact relations suggest that the tonalite of Las Bancas may be partly coeval with the tonalite of Alpine; fine-grained hypersthene granodiorite dikes of Las Bancas-type thread through adjacent Alpine plutons parallel to foliation. The Las Bancas unit was intruded by the Corte Madera Monzogranite and the monzogranite of Pine Valley. In a few places, Las Bancas plutons have fine-grained (quenched?) margins against the Cuyamaca Gabbro, where in other places contacts suggest mingling of coeval

Las Bancas and gabbroic magmas. As described above, in the eastern part of the quadrangle, the Las Bancas and Granite Mountain units appear to be coeval, and both were intruded by the La Posta. Anderson (1991) reported an U-Pb zircon age of  $109 \pm 2$  Ma for the Las Bancas unit in the type locality, and L.T. Silver (oral comm., 1979) reported an U-Pb zircon age of about 104 Ma for the pluton south of the town of Mount Laguna. This age span likely reflects the general eastward younging of U-Pb ages noted by Silver and others (1979) for plutons in the northern 600 km of the Peninsular Ranges Batholith

Kc **Cuyamaca Gabbro (Early Cretaceous)**—Mafic to ultramafic plutons in the El Cajon quadrangle are assigned to the Cuyamaca Gabbro of Everhart (1951). Gabbroic rocks are distributed asymmetrically with respect to the NW-trending axis of the northern Peninsular Ranges Batholith (Todd and others, 1988b). Plutons in the western part of the quadrangle are typically large (up to about 50 km<sup>2</sup> in area), are approximately elliptical in shape, have steep contacts, and, in many plutons, gabbro is intersheeted with granitic rocks that include most of the Early Cretaceous granitoid units. Large gabbro plutons are surrounded by smaller, satellitic gabbro bodies and gabbroic dike swarms. The satellitic bodies have fine-grained textures similar to those of marginal parts of the larger plutons and, in many cases, are continuous with the larger gabbro plutons. In the eastern part of the quadrangle, gabbro is relatively scarce and is present mainly in small plutons and dike swarms. The gabbro line (Todd and others, 1988b) separating these two areas, lies about 8 km east of the I-S line. All gabbro plutons display similar rock types, textures, and chemical compositions (Everhart, 1951; Nishimori, 1976; Walawender, 1979). The more resistant interior parts of large gabbro plutons consist of hornblende-bearing troctolite; anorthositic gabbro  $\pm$  amphibole  $\pm$  orthopyroxene  $\pm$  olivine; and amphibole-olivine gabbro. Internal contacts are gradational, and cumulate layering and pegmatite are common. The marginal parts of large plutons and the smaller, satellitic gabbro bodies consist mainly of fine- to medium-grained hornblende gabbro  $\pm$  orthopyroxene  $\pm$  clinopyroxene  $\pm$  biotite. The largest of these satellitic bodies have medium- to coarse-grained cores made up of the same olivine- and pyroxene-bearing lithologies as the interiors of the larger gabbro plutons. Minor lithologies of both large and small plutons are hornblende diorite and leucodiorite  $\pm$  pyroxene  $\pm$  biotite. Most gabbro plutons have steeply inclined, moderate to strong foliation defined by the alignment of magmatic and variably recrystallized mineral grains (subsolidus recrystallization). This mineral foliation may or may not be parallel to cumulate layering, and is commonly also expressed by aligned hornblende oikocrysts and (or) bands of oikocrysts. Thin-sections show a range of microtextures from magmatic to subsolidus. Virtually all of the gabbro plutons within the quadrangle display ambiguous contact relations with surrounding Cretaceous granitoid plutons, i.e., granitic dikes are present in gabbro and gabbroic dikes in granite. Contacts between gabbro and granitoid plutons are intricate and suggest mingling of coexisting mafic and felsic magmas. Uranium-lead zircon ages of several gabbro plutons in the northern Peninsular Ranges Batholith indicate that mafic magmas were emplaced nearly simultaneously with nearby Cretaceous granitoid magmas (D.L. Kimbrough, oral commun., 1992). Within the quadrangle, the gabbro pluton at Poser Mountain yielded an U-Pb zircon age of  $107 \pm 2$  Ma (D.L. Kimbrough, oral commun., 1993), whereas the Los Pinos pluton gave a preliminary U-Pb age of about 99 Ma (M. Taylor, oral commun., 1990)

Kmgp **Monzogranite of Mother Grundy Peak (Early Cretaceous)**—The monzogranite of Mother Grundy Peak forms a large WNW- to NW-trending pluton in the west-central part of the El Cajon quadrangle and several smaller bodies just north of the border with Mexico. The unit consists of medium- to coarse-grained (locally very coarse-grained), strongly foliated hornblende-biotite leucomonzogranite, leucogranodiorite, and tonalite. Characteristic of the Mother Grundy Peak rocks

are subhedral K-feldspar phenocrysts as much as 4 cm long and slender hornblende prisms from 0.5 to 1 cm in length. Thin-sections show moderate to strong subsolidus recrystallization. Plutons of the monzogranite of Mother Grundy Peak are notably homogeneous and generally inclusion-free except for marginal parts of plutons adjacent to gabbro plutons; these carry abundant, small (up to 5 cm) ragged inclusions of fine-grained gabbro that appear to be fragments of disrupted synplutonic gabbroic dikes. Basaltic and gabbroic dikes are abundant at and near contacts between plutons of the Mother Grundy Peak unit and gabbro plutons. The monzogranite of Mother Grundy Peak intrudes the Japatul Valley Tonalite and is coeval with the Cuyamaca Gabbro. Contact relations between the unit and granitoid units of the western zone are similar to those of the Corte Madera Monzogranite. In the single area where these two units are in contact, leucocratic Corte Madera dikes appear to intrude a Mother Grundy Peak pluton. Pending isotopic age determination, the Mother Grundy Peak unit is considered to be Early Cretaceous in age

Kcm **Corte Madera Monzogranite (Early Cretaceous)**—The Corte Madera Monzogranite (Hoggatt and Todd, 1977) forms lensoid plutons and fringing dikes that are more resistant to weathering than any other granitoid unit; together with the Cuyamaca Gabbro, the Corte Madera formed peaks with the greatest relief on the late Mesozoic-early Tertiary erosion surface. Plutons of the Corte Madera unit are typically centrally located within western zoned plutons composed of the Las Bancas, Alpine, Japatul Valley, and Chiquito Peak units. Together, these five granitoid units compose irregularly zoned plutonic complexes that exhibit both normal and reverse zoning. In the westernmost complexes, gradations were observed between the Corte Madera Monzogranite and silicic metavolcanic wallrocks. Silicic metavolcanics form discontinuous shells partly surrounding, and concordant ring-like screens within, the central Corte Madera plutons; fringing Corte Madera dikes interfinger with surrounding metavolcanic wallrocks. These relations suggest that the westernmost Corte Madera magma chambers were shallow and vented to the surface. The Corte Madera Monzogranite consists of medium- to coarse-grained biotite leucomonzogranite, leucogranodiorite, and syenogranite; voluminous dikes of the unit are composed of leucogranite, alaskite, pegmatite, and aplite. Because of the unit's low color index (1 to 11), outcrops weather white with a distinct light pinkish-orange hue. Biotite is the chief mafic mineral, and small anhedral hornblende relics are scarce. Corte Madera plutons are weakly to strongly foliated, locally protomylonitic, due mainly to the alignment of lenticular 2-cm-long grains and aggregates of light-gray quartz and 1-cm-long scaly mafic aggregates. Mafic aggregates form widely spaced (0.5 to 2 cm) lenses that impart a spotted appearance to rock surfaces oriented perpendicular to foliation. Mafic inclusions are rare, and where present, are spatially associated with synplutonic mafic dikes, some of gabbroic composition. The Corte Madera Monzogranite has chilled margins against, and occurs as dikes in, the Las Bancas and Japatul Valley Tonalites, the Granodiorite of Cuyamaca Reservoir, and the Cuyamaca Gabbro. Mingling contacts between Corte Madera plutons and gabbro plutons/dikes are widespread. Dikes of the Corte Madera unit with sharp to indistinct margins intruded the migmatitic contact zones between the Japatul Valley Tonalite and its metavolcanic wallrocks. The Corte Madera unit intrudes the Chiquito Peak Monzogranite and is cut by synplutonic dikes of the quartz diorite of East Mesa. A U-Pb zircon age of  $111 \pm 2$  Ma was reported for a pluton of the Corte Madera unit in the northwest part of the quadrangle (D.L. Kimbrough, oral commun., 1993)

Kcp **Chiquito Peak Monzogranite (Early Cretaceous)**—The Chiquito Peak Monzogranite (Todd, 1977a) forms lenticular plutons and narrow, sheet-like bodies that underlie peaks and ridges. The unit consists of grayish-white-weathering, medium-grained hornblende-biotite monzogranite and granodiorite (color index

2 to 16) and lesser tonalite, leucogranite, alaskite, and pegmatite. Leucomonzogranite in the Stonewall Peak area having a color index of 2 to 3 contains abundant white, 1- to 2.5-cm-long subhedral K-feldspar phenocrysts. Moderate to strong foliation (ranging to porphyroclastic gneiss) in Chiquito Peak monzogranite-granodiorite is marked chiefly by evenly spaced, 2- to 5-mm-long, scaly recrystallized mafic aggregates. The Chiquito Peak unit consists of two major phases: 1) granodiorite and tonalite with abundant mafic inclusions and synplutonic mafic dikes, and 2) relatively inclusion-free monzogranite and granodiorite. Although contacts between the two are gradational and (or) mixed, in general the more silicic phase intrudes the more mafic phase. Marginal zones of some Chiquito Peak plutons and sheet-like bodies of the unit commonly consist of fine- to medium-grained, subporphyritic granodiorite and tonalite containing 1-cm, white subhedral K-feldspar phenocrysts. The textures of these rocks are heterogeneous due to uneven distribution of K-feldspar and mafic minerals, particularly of hornblende in stout prisms and clots of subhedral grains. Assimilation-contamination reactions between the marginal, sheeted Chiquito Peak rocks and adjacent prebatholithic and plutonic wallrocks gave rise to hybrid zones, mixtures of granitic rocks and stoped, partly assimilated metamorphic inclusions. The Chiquito Peak Monzogranite intrudes, and locally has mutually intrusive contacts with the tonalite of Las Bancas. Strip-like Chiquito Peak bodies in the Cuyamaca-Laguna Mountains Shear Zone display synplutonic and mingling contacts with the Quartz Diorite of East Mesa and the Granodiorite of Cuyamaca Reservoir (in the latter case, representing remobilization of Late Jurassic plutonic rocks?). The Chiquito Peak unit was intruded by the Corte Madera and Pine Valley monzogranite units (see below). Contacts that indicate magma mingling are observed between the Cuyamaca Gabbro and the Chiquito Peak unit. Uranium-lead zircon dating of a Chiquito Peak pluton within the Cuyamaca-Laguna Mountains Shear Zone gave an age of about 113 Ma (L.T. Silver, oral commun., 1979)

Kjv

**Japatul Valley Tonalite (Early Cretaceous)**—The Japatul Valley Tonalite (V. Todd, 1978b) forms a partial envelope around plutons of the tonalite of Alpine. Although the two units are gradational, the Japatul Valley rocks are generally less mafic (average color index about 22) and include significantly more tonalite. The Japatul Valley unit consists of light-gray to grayish-white-weathering, medium- to coarse-grained equigranular biotite-hornblende tonalite containing relict pyroxene; hornblende-biotite tonalite; and lesser hornblende-biotite granodiorite. The unit carries abundant mafic inclusions as well as scattered, small (1 to 2 cm) inclusions of more silicic granitoid rocks. Mafic inclusions are typically more resistant to weathering than the surrounding tonalite and therefore weather out several cm in relief compared to the surrounding tonalite. The Japatul Valley Tonalite underlies gently rolling erosion surfaces whose outcrops are more prominent and ridge-forming than those of the adjacent tonalite of Alpine. Japatul Valley Tonalite is spatially associated with screens of metavolcanic rocks and with the Chiquito Peak and Corte Madera Monzogranites. The spatial distribution of Japatul Valley plutons is similar to that of the Chiquito Peak unit, both units extend about 10 to 12 km east of the I-S line (and therefore further east than either the Alpine or Corte Madera units). Granodiorite of the Japatul Valley unit is lithologically similar to, locally grades to, and(or) was intruded by, the Chiquito Peak Monzogranite. In areas where the Japatul Valley, Chiquito Peak, and Corte Madera units form zoned plutons, the Japatul Valley unit underlies valleys and mesas ringed by ridges of the more resistant granodiorite, monzogranite, and metavolcanic screens. Although much of the Japatul Valley unit is moderately to strongly foliated, the rocks typically have a more igneous-appearing texture than the tonalite of Alpine because plagioclase, and to a lesser extent hornblende and biotite, are subhedral. However, in thin-section these igneous-appearing



plagioclase grains have undergone some degree of subsolidus strain and recrystallization. Both subhedral and recrystallized grains are aligned parallel to regional foliation. As stated above, the Japatul Valley Tonalite grades to the tonalite of Alpine; in some places, the two units are separated by screens of metavolcanic rocks  $\pm$  gabbro. Contacts between the Japatul Valley unit and metavolcanic screens are marked by compositionally and texturally heterogeneous, 0.5-km-wide zones of migmatitic rocks that apparently originated as 1) intrusion breccia between tonalite magma and wallrocks plus 2) local mingling between tonalite and mafic magmas. The Japatul Valley unit grades to, and is intruded by, the Chiquito Peak Monzogranite. Fine- to medium-grained Chiquito Peak dikes cut granodiorite and tonalite in the gradational zone between the two units. Some of these dikes have sharp, well defined margins, but most grade to, or interfinger with, the host rocks. The Japatul Valley Tonalite is undated but is considered to be Early Cretaceous in age based upon field relations with nearby Early Cretaceous units

- Ka      **Tonalite of Alpine (Early Cretaceous)**—Tonalite of Alpine weathers to subdued, reddish-tan and tannish-gray outcrops on broad erosion surfaces west of the I-S line. In hand specimen, the contrast between white-weathering plagioclase phenocrysts and the abundant mafic minerals and aggregates give the rock a "salt and pepper" appearance. The Alpine unit consists of medium- to coarse-grained biotite-hornblende tonalite with lesser quartz diorite and scarce borderline granodiorite (average color index about 30). In addition to 2 to 3 cm, diffuse concentrations of mafic minerals, the rocks contain abundant mafic inclusions. The smaller mafic aggregates are intergrowths of partly recrystallized mafic minerals and may represent relics of disrupted and partly assimilated mafic inclusions. Locally, tonalite carries 1 to 2 cm long biotite  $\pm$  hornblende oikocrysts. The alignment of lenticular mafic inclusions and aggregates imparts a moderate to strong foliation to the rock, and, as a result of these variably sized mafic constituents, the Alpine tonalite is heterogeneous in outcrop and hand specimen. In many places, mafic inclusions of the Alpine unit are composed of fine-grained and porphyritic gabbro or metagabbro. Bodies of partly reacted gabbroic rocks, some several meters to tens of meters long, occur in semi-continuous, 0.5- to 1-km-wide zones that parallel magmatic foliation in the tonalite. These "mixed" zones resemble the zones of tonalite-gabbro intrusion breccia that partly surround large gabbro plutons within the quadrangle; they apparently represent places where thin tongues of gabbroic magma reacted with, and were disrupted by, coeval tonalite magma (magma mingling). The tonalite of Alpine grades to mafic tonalite of the Japatul Valley unit. Contacts between the Alpine unit and the tonalite of Las Bancas are sharp, gradational, or interfingering, suggesting overlap in time of emplacement. Dikes and rounded inclusions of the tonalite of Las Bancas occur in the tonalite of Alpine, and in some places, a narrow zone of variable mafic and (or) metavolcanic inclusions separates the two units. A pluton of the Alpine unit yielded a U-Pb zircon age of  $108 \pm 2$  Ma (Anderson, 1991)
- Kgr      **Granitoid rocks (Early Cretaceous)**—Undivided tonalite and granodiorite comprising several Early Cretaceous units including the tonalite of Alpine, the Japatul Valley Tonalite, and the Corte Madera Monzogranite; includes lesser gabbro and metavolcanic rocks
- KJtg      **Tonalite and gabbro (Early Cretaceous and Jurassic)**—Three plutons in the Jacumba Mountains are composed of intersheeted, in part gradational, tonalite of Las Bancas and Cuyamaca Gabbro. These sheeted complexes intrude the migmatitic schist and gneiss of Stephenson Peak and are intruded by the tonalite of Granite Mountain and tonalite of La Posta. In the westernmost complex, the tonalite of Granite Mountain is intersheeted with the Las Bancas unit and the Cuyamaca Gabbro and have contact relations that indicate the three were approximately coeval. Ages of the tonalite of Las Bancas and the Cuyamaca

Gabbro in the Jacumba Mountains are considered to be about equivalent to that of the Granite Mountain unit, and hence younger than their pluton ages in the western part of the quadrangle

- KJld **Leucocratic dikes (Late Cretaceous and Late Jurassic)**—Dikes composed of leucogranite, granophyre, alaskite, pegmatite, and aplite cut all of the plutonic units in the quadrangle. In cases where these dikes are not clearly associated with a particular granitoid pluton/unit, they are assigned to the leucocratic dikes unit. The unit includes dikes of at least three ages: a large dike that cuts the Harper Creek and Cuyamaca Reservoir units yielded a Late Jurassic U-Pb zircon age (G.H. Girty, oral commun., 1992), whereas many dikes in the western and central parts of the quadrangle probably represent silicic differentiates of the Chiquito Peak, Corte Madera, Pine Valley, or Mother Grundy Peak units. Leucocratic dikes that cut the eastern, mid- to Late Cretaceous units are probably related to the Late Cretaceous La Posta and Early Cretaceous Granite Mountain bodies

#### *Eastern sequence*

- Kih **Indian Hill granodiorite of Parrish and others (1986) (Late Cretaceous)**—Fine- to medium-grained, garnetiferous muscovite-biotite leucogranodiorite and leucomonzogranite occur north and east of the town of Jacumba in an area where the La Posta pluton intrudes a large screen composed of metasedimentary rocks and Jurassic S-type granitoids (Todd and others, 1987b). The unit is named for a small body of garnet-muscovite-biotite granodiorite that underlies Indian Hill in the Jacumba Mountains (Parrish and others, 1986). A larger body, which crops out north and east of Jacumba, intrudes, and grades(?) southward and westward to, medium-grained tonalite of La Posta and thus may be a late differentiate of the La Posta magma. Leucomonzogranite carries well-crystallized muscovite grains up to 1 mm across, has a color index less than 7, and is weakly foliated parallel to pluton walls. The southern body is associated with numerous large, fine-grained muscovitic leucocratic dikes, most containing pegmatite, that extend for tens of kilometers into the country rocks adjacent to the La Posta pluton. Some of these dikes are complexly folded with the country rocks. The two-mica phase of the La Posta unit is similar lithologically to two-mica peraluminous granitoids of the inner Cordilleran belt (Miller and Bradfish, 1980). The Indian Hill granodiorite body yielded U-Pb and Rb-Sr ages that suggest an age of about 89 Ma, while the larger body near Jacumba was dated by U-Pb zircon method as  $93 \pm 1$  Ma (Walawender and others, 1990)
- Klp **Tonalite of La Posta (Early and Late Cretaceous)**—The tonalite of La Posta (V. Todd, 1978a) comprises several plutons in the El Cajon quadrangle: a batholith-sized pluton in the east-central part of the quadrangle (the La Posta pluton, Walawender and others, 1990), a smaller pluton in the southeastern part, and two small satellitic plutons in the west-central part. The unit is in part equivalent to the La Posta Quartz Diorite of Miller (1935). However, an informal name is used in this report because rocks in and near the town of La Posta are not typical of the unit as a whole. Plutons of the tonalite of La Posta are leucocratic, homogeneous, largely undeformed, and inclusion-free. The unit consists of idiomorphic hornblende-biotite trondhjemite in the western part of the quadrangle, and biotite trondhjemite and granodiorite in the eastern part (color index 6-15). The La Posta pluton is intruded by small plutons and voluminous dikes consisting of garnetiferous two-mica leucogranodiorite, leucomonzogranite, and pegmatite. Characteristic of the unit are abundant white-weathering plagioclase grains, light-gray bipyramidal quartz grains up to 1.5 cm long, and euhedral, barrel-shaped biotite crystals from 1 to 1.5 cm long.

Scattered 2- to 5-cm-long, irregular poikilitic K-feldspar grains appear as glassy reflective cleavages on outcrop surfaces, and euhedral grains of pale-yellow sphene are visible in hand specimen. Plutons of the La Posta unit either bear a weak magmatic foliation or are massive, but locally, pluton margins are moderately to strongly foliated and La Posta apophyses are folded with metamorphic wallrocks. Moderately foliated tonalite that is finer-grained and darker than the average rock occurs over a distance of at least 5 km from pluton walls. The marginal foliation is oriented parallel to pluton walls. Thin-sections of marginal rocks indicate minor subsolidus strain and recrystallization: large biotite grains are broken down to fine-grained scaly aggregates and large quartz phenocrysts have ovoid shapes reflecting partial recrystallization. Away from the walls, the tonalite of La Posta is weakly foliated to massive. Sparse, two- to three-cm-long wisps of coarse biotitic rock (remnants of pelitic wallrocks?) are aligned with the marginal foliation. Rare xenoliths in the marginal zone consist of rhythmically interlayered biotitic and quartzo-feldspathic cumulate rocks that grade to mafic and leucocratic schlieren. Exposures of contacts between the tonalite of La Posta and Early Cretaceous plutons are scarce in the western part of the quadrangle, but in two places the La Posta unit intrudes the Japatul Valley Tonalite. Uranium-lead zircon ages of  $95 \pm 3$  Ma were reported for three samples from the La Posta pluton in the central-eastern part of the quadrangle (Walawender and others, 1990). The westernmost La Posta pluton (Loveland Reservoir) yielded an U-Pb zircon age of  $104 \pm 2$  Ma whereas the Long Potrero pluton gave an age of about 102 Ma (D.L. Kimbrough, oral commun., 1993; R.R. Rector, oral commun., 1993). These ages suggest that the La Posta magma younged to the east

**Kgm Tonalite of Granite Mountain (Early Cretaceous)**—In the western part of the El Cajon quadrangle, the tonalite of Granite Mountain (Todd, 1979) forms a discontinuous envelope of variable but narrow width around plutons of the tonalite of La Posta, separating the latter from older plutons. In contrast, the Granite Mountain unit forms large composite plutons in the central and eastern parts of the quadrangle (Grove, 1987; Todd and others, 1987a; Lampe, 1988). In the western and central parts of the quadrangle, Granite Mountain plutons are weakly to strongly foliated and in the latter case, share the fabric of the adjacent Early Cretaceous plutons. In the eastern part and north of the quadrangle, the plutons have undergone intense synintrusive deformation and are locally mylonitic (Grove, 1987). Grove reported that the pluton at Granite Mountain itself, north of the quadrangle, bears three deformational fabrics, the earliest of which may correlate with the major deformation in the Cuyamaca-Laguna Mountains Shear Zone to the west. The fact that the unit is strongly deformed in the eastern part of the batholith probably reflects the eastward migration of pluton emplacement and intra-arc ductile deformation during the Cretaceous (Todd and others, 1988b). The Granite Mountain unit is composed of medium- to coarse-grained, white- and grayish-white-weathering biotite-hornblende tonalite; hornblende-biotite tonalite and lesser granodiorite; and minor quartz diorite (color index 17 to 27). Abundant euhedral and subhedral, stubby and prismatic hornblende grains ranging up to 2 cm long are characteristic of the unit. Flattened mafic inclusions are present locally and are oriented parallel to foliation. Rarely, outcrops show scattered 5-cm-wide, glassy K-feldspar oikocrysts. Magmatic foliation is marked by aligned subhedral hornblende and plagioclase grains and lenticular mafic aggregates. The Granite Mountain unit intrudes the tonalite of Las Bancas and the granodiorite of Cuyamaca Reservoir. Although deformed tonalite of Granite Mountain is similar in appearance and composition to the Japatul Valley Tonalite, the latter unit is typically more mafic and has undergone a greater degree of subsolidus recrystallization; the contact between the two is sharp. In the eastern part of the quadrangle, the tonalite of Granite Mountain grades to, and is intruded by, the tonalite of La Posta; locally,

screens of metasedimentary rocks separate the two units. In the south-central part of the area, the units are separated by a 1- to 1.5-km-wide zone of rocks that are texturally and compositionally transitional between the two; elsewhere, the contact zone is narrow and Granite Mountain and La Posta rocks are interlayered over a distance of a few meters. In the latter case, contacts between individual layers are sharp to indistinct and fine-grained La Posta dikes cut the Granite Mountain unit. A sample of the tonalite of Granite Mountain collected just north of the quadrangle yielded an U-Pb zircon age of  $98 \pm 3$  Ma (L.T. Silver, oral commun., 1979). More recently, the Granite Mountain-type pluton at Morena Reservoir in the south-central part of the quadrangle was dated by U-Pb method as  $101 \pm 2$  Ma (D.L. Kimbrough, oral commun., 1993). In the Morena Reservoir 7.5' quadrangle the unit is divided into four subunits. All subunits contain mafic inclusions. Subunits Kgm<sub>1</sub>, Kgm<sub>2</sub>, and Kgm<sub>3</sub> are intruded by locally abundant pegmatite-aplite dikes:

- Kgm<sub>4</sub>     **Tonalite of Granite Mountain, Unit 4**—Biotite-hornblende tonalite having subidiomorphic texture, scattered poikilitic biotite grains, moderate to well developed foliation, and relatively high color index
- Kgm<sub>3</sub>     **Tonalite of Granite Mountain, Unit 3**—Hornblende-biotite tonalite and granodiorite having moderate to faint magmatic foliation and containing large, oval biotite grains  $\pm$  small acicular hornblende grains. Relatively leucocratic
- Kgm<sub>2</sub>     **Tonalite of Granite Mountain, Unit 2**—Biotite-hornblende tonalite having idiomorphic texture, moderate to faint magmatic foliation, and lower color index than marginal phase
- Kgm<sub>1</sub>     **Tonalite of Granite Mountain, Unit 1**—Biotite-hornblende tonalite. Compared to rocks typical of interior parts of tonalite of Granite Mountain, rocks of this unit are finer-grained, have well developed solid-state foliation that overprints magmatic foliation, and have higher color index
- Kpv     **Monzogranite of Pine Valley (Early Cretaceous)**—The monzogranite of Pine Valley (V. Todd, 1977a) occurs exclusively east of the I-S line in a series of large, NNW-elongate, steep-walled plutons. The unit consists of medium- to coarse-grained, white-weathering hornblende-biotite leucomonzogranite and leucogranodiorite with minor biotite-hornblende tonalite (color index 4 to 10). The westernmost Pine Valley pluton in the quadrangle is locally subporphyritic due to abundant white, 1- to 2.5-cm-long prismatic K-feldspar phenocrysts. Scarce hornblende is present in leucomonzogranite and leucogranodiorite mainly as small skeletal to anhedral relics, but tonalite contains subhedral grains that are visible in hand specimen. Alignment of 4-cm-long lenticular aggregates of light-gray quartz and 2-cm scaly mafic aggregates imparts a moderate to strong foliation to Pine Valley rocks, some rocks are protomylonite. Locally, indistinct quartzo-feldspathic and mafic layers produce gneissic texture. Pine Valley plutons rarely contain mafic inclusions; exceptions are marginal zones adjacent to gabbro plutons, in which synplutonic basaltic dikes, fine-grained gabbroic inclusions, and mingling textures are observed. Pine Valley plutons have typically given rise to voluminous leucocratic dikes consisting of leucogranite, alaskite, granophyre, and pegmatite-aplite. The easternmost plutons and dikes contain primary muscovite, garnet, and schorl as magmatic accessory minerals. The monzogranite of Pine Valley intrudes the gneiss of Harper Creek, the granodiorite of Cuyamaca Reservoir, the Chiquito Peak Monzogranite, and the tonalite of Las Bancas. It has synplutonic contacts with the quartz diorite of East Mesa and the Cuyamaca Gabbro. Reported U-Pb zircon ages of two Pine Valley plutons are about 118 Ma (D.L. Kimbrough, oral commun., 1994) and about 122 Ma (Bracchi and others, 1993)
- KJem     **Quartz Diorite of East Mesa (Cretaceous and Jurassic)**—The quartz diorite of East Mesa (Todd, 1977a) is restricted to a 10- to 12-km-wide zone in the central part of the El Cajon quadrangle. This zone (Cuyamaca-Laguna Mountains Shear Zone, Todd and others, 1988; Thomson and Girty, 1994) strikes north-northwest

and contains the most highly deformed plutons in the quadrangle. Plutons of the East Mesa unit are narrow, greatly elongated bodies with strongly foliated to mylonitic textures. Microtextures range from well preserved igneous textures to magmatic textures strongly overprinted by subsolidus recrystallization. Smaller East Mesa plutons are dike-like and grade along strike to swarms of fine-grained mafic dikes. East Mesa plutons are texturally and compositionally heterogeneous, typically consisting of 1) fine- to medium-grained, gneissic biotite-hornblende tonalite and quartz diorite and 2) fine-grained, locally porphyritic (plagioclase and biotite phenocrysts) biotite-hornblende quartz diorite and tonalite (color index 23 to 52). Both phases may contain hypersthene  $\pm$  clinopyroxene. These two rock types may be gradational, mixed, or the fine-grained phase may dike the coarser grained phase. The East Mesa unit also includes lesser diorite, granodiorite, quartz monzodiorite, and gabbro. The rocks weather dark-gray to reddish- or buff-gray and are commonly poorly exposed in low brushy hills and valleys. Fine-grained mafic inclusions and(or) metasedimentary inclusions are present locally. In protomylonitic rocks of this unit, the mafic inclusions are greatly flattened and elongated parallel to foliation, although in less strained rocks, their shapes are variable. Closely packed, blocky dark inclusions contain variably mafic subareas; scattered bodies of fine-grained gabbro are common but rarely large enough to be mapped separately. In a few places, dike-like bodies of the East Mesa unit grade to small gabbro plutons. The quartz diorite of East Mesa has many features in common with the tonalite of Las Bancas (Hoggatt and Todd, 1977), notably the presence in the interiors of larger East Mesa plutons of tonalite containing as much as 14% pyroxene and 7% K-feldspar. Some of the fine-grained East Mesa bodies could be interpreted as Las Bancas magma emplaced into and quenched within the Cuyamaca-Laguna Mountains Shear Zone. Complex internal contacts and the occurrence of texturally different rock types in East Mesa plutons suggest repeated intrusion of magma into the shear zone. The chief mineralogical difference between the two units is the predominance of hornblende over pyroxene in East Mesa plutons and the lower hornblende:pyroxene ratio in the Las Bancas unit. The quartz diorite of East Mesa has complex synplutonic dike relations with adjacent Early Cretaceous I-type granitoid plutons, indicating that it is partly Cretaceous in age. However, the East Mesa unit is also spatially associated with, interfingers with, and locally grades into (or is mixed with) the granodiorite of Cuyamaca Reservoir. These relations suggest that some East Mesa plutons may be Jurassic in age. Isotopic age determinations made on the quartz diorite of East Mesa confirm the above age range: two East Mesa plutons yield Early Cretaceous U-Pb zircon ages ( $118 \pm 1$  and  $117 \pm 1$  Ma) and a third is Middle Jurassic ( $170 \pm 2$  Ma) (Todd and others, 2003). The unit's age is regarded as Cretaceous and Jurassic

Jcr      **Granodiorite of Cuyamaca Reservoir (Late and Middle Jurassic)**—The granodiorite of Cuyamaca Reservoir (Todd, 1977a) forms steep-walled, elongate plutons as much as 20 km long and 5 km wide; the unit also occurs as lensoid bodies less than 1 km long within Harper Creek and Stephenson Peak bodies. Plutons of the Cuyamaca Reservoir unit underlie low hills and meadows and weather to a distinctive orange-tan color. The unit consists of fine- to medium-grained, light- to dark-gray biotite and hypersthene-biotite granodiorite and subequal tonalite (average color index 25). Both compositions contain actinolitic amphibole. The granodiorite of Cuyamaca Reservoir is strongly foliated and, next to the larger (up to 2 km wide) metasedimentary screens, consists of mylonite gneiss. Locally, the combination of assimilation of metasedimentary inclusions and contamination of granodiorite in these marginal zones produced rocks that resemble the gneiss of Harper Creek. The Cuyamaca Reservoir unit carries both fine-grained mafic enclaves as well as metasedimentary inclusions. Adjacent to gabbro plutons, the rocks have a higher color index, are cut by

abundant synplutonic basaltic dikes, and contain bodies of hornblende tonalite with the modal and geochemical characteristics of Early Cretaceous I-type tonalite. Contact relations between the granodiorite of Cuyamaca Reservoir and adjacent Early Cretaceous I-type plutons are complex, in places suggesting mingling of coeval magmas. Middle and Late Jurassic U-Pb zircon ages for the four Cuyamaca Reservoir plutons indicate they are Middle and Late Jurassic (G.H. Girty, oral commun., 1993; Shaw and others, 2003), and suggest that these pseudosynplutonic contacts are the result of partial melting or remobilization of the Cuyamaca Reservoir rocks by the intrusion of younger plutons

Jhc      **Gneiss of Harper Creek (Late and Middle Jurassic)**—The gneiss of Harper Creek (Todd, 1977a) crops out in the central part of the quadrangle in narrow plutons as much as 20 km long and 6 km wide. The unit consists of fine- to medium-grained, gneissic to mylonitic biotite granodiorite and subequal tonalite and lesser monzogranite (average color index 22) containing variable amounts of muscovite, cordierite, sillimanite, and garnet. The rocks are medium- to dark-gray on fresh surfaces, weather to distinctive reddish- and yellowish-brown hues, and are notably rich in quartz and mica. The gneiss of Harper Creek is also characterized by abundant, evenly distributed inclusions in a range of sizes. Raft-like inclusions from 10 cm to several meters long consist of refractory metasedimentary rocks and amphibolite, the latter grading along strike to fine-grained metagabbro. The unit also contains lenticular biotite aggregates from 0.5 to 3 mm thick and several cm long. Reactions between pelitic schist inclusions and host granodiorite suggest that the biotitic lenses are relics of partly melted and(or) assimilated pelitic schist. Mylonitic gneiss and schist contain thin (less than 1 cm) white quartz strings and flattened quartz segregations oriented parallel to foliation. The alignment of raft-like inclusions, biotitic lenses, and quartz bodies parallel to the strong mineral foliation formed by recrystallized igneous grains and aggregates imparts gneissic layering to the Harper Creek rocks. Locally, both mineral foliation and gneissic layering are parallel to the axial planes of tight isoclinal folds. Contacts between the gneiss of Harper Creek and the Julian Schist are sharp or are marked by zones of interlayering up to a few tens of meters wide. Contacts between the Harper Creek and the Cuyamaca Reservoir units (see below) are gradational or the two are interlayered over distances of a few meters to several tens of meters. In a few places, the contact is sharp, and the Cuyamaca Reservoir is either leucocratic and coarse-grained, near-pegmatitic, or is fine-grained against the Harper Creek, suggesting that Cuyamaca Reservoir magma intruded the Harper Creek unit. Uranium-lead dating of clear overgrowths on zircons from Harper Creek plutons yielded ages that cluster in the Middle and Late Jurassic (Todd and others, 1991; G.H. Girty and others, 1993; Thomson and Girty, 1994; S.E. Shaw, unpublished data, 2000). U-Pb zircon age determination yields a Middle Jurassic age ( $164 \pm 4$  Ma) for a Harper Creek pluton (Shaw and others, 2003)

Jsp      **Migmatitic schist and gneiss of Stephenson Peak (Late and Middle Jurassic)**—The migmatitic schist and gneiss of Stephenson Peak (Todd, 1978a) is the dominant Jurassic granitoid unit in the eastern part of the El Cajon quadrangle. The unit forms relatively narrow, partial mantles around plutons of the gneiss of Harper Creek in the Laguna Mountains and underlies more extensive areas in the Jacumba and western Coyote Mountains. Bodies of similar rocks too small to show at the map scale are present in plutons of the Harper Creek and Cuyamaca Reservoir units west of the main outcrop area of the Stephenson Peak unit. The Stephenson Peak unit consists of subequal granodiorite orthogneiss; paragneiss; migmatitic pelitic schist; and lesser calcsilicate-bearing quartzite, marble, and amphibolite. Orthogneiss and schist alternate in layers from several centimeters to tens of meters thick, other metamorphic inclusions range from centimeter-scale to a few meters thick. The orthogneiss component is compositionally and

geochemically similar to mylonitic gneiss of Harper Creek. It is medium- to coarse-grained and contains lenticular quartz segregations as much as 8 cm thick and 30 cm long, biotitic lenses and streaks as long as 30 cm, and boudins and rafts of refractory metasedimentary rocks and amphibolite. Migmatitic pelitic schist with granitic leucosomes ranging in thickness from a few millimeters to 25 cm appears to grade to quartz-feldspar-biotite-muscovite paragneiss by increase in grain size and thickness of quartzo-feldspathic laminae. Quartzo-feldspathic and micaceous streaks form poorly defined chaotic patterns that apparently resulted from disruption of folds. The granitoid component of the Stephenson Peak unit grades into less heterogeneous gneiss of Harper Creek. Based solely upon field relations, the Stephenson Peak unit apparently originated as a partial melt of predominantly metasedimentary rocks that are lithologically similar to the Julian Schist and the rocks of Jacumba Mountains. Layers of quartzite, marble, and amphibolite did not have appropriate compositions to form granitic melt. The Stephenson Peak unit is interpreted as material that formed closer to the S-type source region from which more discrete Harper Creek magmas pooled and rose through the crust. For this reason, the age of the unit is considered to be the same as that of the gneiss of Harper Creek, Middle and Late Jurassic

### *Prebatholithic and Suprabatholithic rocks*

- Ksp      **Santiago Peak Volcanics (Early Cretaceous)**—The Santiago Peak Volcanics of Larsen (1948), forms the western edge of the batholith in southern California. It is composed of unmetamorphosed to slightly metamorphosed volcanic, volcanoclastic, and minor hypabyssal rocks (Kennedy and Peterson, 1975; Herzig, 1991). Volcanic components are chiefly dacitic and andesitic breccia, tuff, and flows with lesser basaltic and rhyolitic compositions. Uranium-lead zircon dating of silicic subunits of the Santiago Peak Volcanics in the type area in the Santa Ana Mountains and in the eastern part of the city of San Diego indicate an Early Cretaceous age (130 to 120 Ma) (Kimbrough and others, 1990; Herzig and Kimbrough, 1991; Anderson, 1991; Herzig, 1991). A sequence of volcanoclastic rocks located about 2.5 km north of the El Cajon quadrangle contains Late Jurassic fossils (Fife and others, 1967; Jones and Miller, 1982). In addition, a volcanic flow from this sequence has been dated by U-Pb zircon method as Late Jurassic (Anderson, 1991). This Late Jurassic volcanic-volcanoclastic sequence appears to underlie the Santiago Peak Volcanics unconformably (C.T. Herzig, oral commun., 1994; Todd and others, 1994a). The age of the Santiago Peak Volcanics is considered to be Early Cretaceous
- Kmv      **Metavolcanic rocks (Early Cretaceous)**—Screens between and within plutons in the western part of the El Cajon quadrangle consist of amphibolite-facies metavolcanic tuff, tuff-breccia, and flows of andesitic, dacitic, and basaltic composition, and scarce feldspathic metaquartzite, pelitic schist, and granitoid-cobble metaconglomerate (Todd, 1980; 1983). These metamorphic rocks were isoclinally folded and transposed to produce tectonic layering. Layering and primary textures suggest that mafic and silicic volcanic rocks were interbedded on a scale of centimeters to meters. Interbedding and the occurrence of tuff-breccia containing mafic and silicic clasts indicate that adjacent volcanic centers produced silicic and mafic magmas simultaneously. The metavolcanic screens are lithologically similar to the Santiago Peak Volcanics. Uranium-lead zircon dating of several of these screens in the El Cajon quadrangle yielded Early Cretaceous ages that are only slightly older than those of the adjacent plutons (Anderson, 1991; D.L. Kimbrough, oral commun., 1994). However, it is possible that some of the metavolcanic and volcanoclastic rocks are deposits of a

Late Jurassic precursor of the Santiago Peak Volcanics island arc (Anderson, 1991; C.T. Herzig, oral commun., 1994), and are tentatively considered to be Early Cretaceous in age

- KJvs**     **Metavolcanic and metasedimentary rocks (Cretaceous and Jurassic?)**—Screens within a narrow (less than 2 km wide), discontinuous band in the central part of the quadrangle are composed of interlayered, subequal volumes of metavolcanic and metasedimentary rocks including amphibolite (grading to fine-grained gabbro), calcsilicate rocks, felsic tuff-breccia, biotite-rich schist, and quartzite. Although these lithologies are present in both the Julian Schist to the east and in metavolcanic screens in the western part of the quadrangle, this mix of rock types appears distinctive enough to represent a separate unit. Its position between Julian Schist and rocks probably equivalent to Santiago Peak Volcanics, and its coincidence with the western boundary of Jurassic S-type plutons suggest that the rocks were caught up tectonically between Jurassic continental crust and a Late Jurassic island arc during latest Jurassic to earliest Cretaceous convergence and faulting (possibly closing of a back-arc basin). The age of these rocks may be Cretaceous and (or) Jurassic
- JFrm**     **Metasedimentary and metavolcanic rocks (Jurassic and Triassic)**—Screens in the Cuyamaca and Laguna Mountains are composed of upper amphibolite-facies metasedimentary rocks interlayered with minor amounts of amphibolite (the Julian Schist of Hudson, 1922). The metasedimentary rocks consist of interlayered semi-pelitic, pelitic, and quartzitic schists; calcsilicate-bearing feldspathic metaquartzite; and minor small-pebble metaconglomerate. Variable but minor amounts of calcsilicate minerals in all rock types indicate that the original clastic sediments were limy. Although bedding was isoclinally folded and transposed during metamorphism, the thin layers (1 cm to 0.5 m), overall fine grain size, and local turbidite structures indicate that the protolith was a thin-bedded sequence of fine-grained sandstone, siltstone, silty mudstone, and conglomerate (flysch). Pelitic schist contains andalusite, sillimanite, and less common garnet and staurolite (Grove, 1989). Relict sedimentary structures in thick layers (up to 5 m) of pale tan-weathering gray metaquartzite suggest that some sandstone beds represent massive submarine channel fillings. Scarce beds of white-weathering, subarkosic sandstone and quartz-pebble conglomerate with rounded clasts are interlayered with sandstone-mudstone. Lensoid blocks of relatively pure, white to light-gray laminated marble as much as 6 m long are rare. The marble appears to have been interbedded with the flysch (olistostromal blocks?) and blocks were boudinaged and aligned parallel to metamorphic foliation. The above metasedimentary rocks are interlayered with fine-grained black amphibolite that grades locally to lenticular bodies of fine-grained metagabbro. The mafic rocks are associated locally with light-gray- to white-weathering metamorphosed felsic tuff, tuff-breccia, and conglomerate containing siliceous tuff clasts. These rocks are interpreted as remnants of mafic and felsic flows, sills, tuffs, and volcanic breccia and conglomerate that were deposited sporadically within a submarine fan complex. Limited evidence suggests a Jurassic and Triassic age for the Julian Schist. An ammonite imprint of probable Triassic age was reported for the unit (Hudson, 1922), but the specimen was lost and its age cannot be confirmed. Metasedimentary rocks in the northern part of the batholith that may be correlative with the Julian Schist (French Valley Formation of Schwarcz, 1969) contain a possible Late Triassic fossil (Todd and others, 1988). Gastil and others (1988) summarized Rb/Sr whole rock data that support a Jurassic and Triassic depositional age for the Julian Schist
- MzFzm**     **Rocks of Jacumba Mountains (Mesozoic and Paleozoic?)**—Metasedimentary and metavolcanic rocks are present as screens within Jurassic S-type granitoids and plutons of the mid- to Late Cretaceous tonalites of Granite Mountain and La Posta in the Jacumba Mountains. These metamorphic rocks consist of upper



amphibolite-facies interlayered marble, schist, and metaquartzite informally named the rocks of Jacumba Mountains (Todd and others, 1987b,c). Weber (1963) described graphitic to magnesian "limestone" with interbeds containing finely disseminated garnet as part of this sequence. Hoggatt (1979) reported marble layers ranging from irregular, 0.5-m-long pods and boudin-like bodies to relatively thin (up to 30 m) tabular bodies hundreds of meters in length along strike. Weathered surfaces of marble are pale tan and pitted; fresh rock is light-gray to white, coarsely crystalline, and equigranular. Indistinct laminae are defined by subtle color changes from gray to white to shades of pink, yellow, and green, as well as by variation in grain size. Todd and others (1987b,c) described a sequence of interlayered marble, schist, metaquartzite, calc-silicate rocks, metachert, and mafic metavolcanic rocks in the Jacumba Mountains. Calcitic and dolomitic marble contain siliceous laminae and disseminated graphite. Skarns that developed along contacts between marble beds and surrounding tonalitic plutons have been prospected and mined for tungsten (Weber, 1963; Todd and others, 1987c). Schist layers include semi-pelitic biotite-quartz-feldspar schist, biotite-rich schist, and biotite-muscovite schist. Metaquartzite layers consist of 1) gray- and grayish-white-weathering feldspathic quartzite, locally with biotite-rich laminae, and 2) dark brown phyllitic quartzite with 2.5-cm-long graphitic lenses. Interlayered with these rocks are minor thin-bedded, vitreous white metachert and relatively abundant hornblende schist that grades to fine-grained amphibolite and metagabbro. The association of thin-bedded limestone, impure sandstone and shale, bedded chert, and mafic volcanic rocks suggests a deep-water marine depositional environment. The age of the metasedimentary rocks in the Jacumba Mountains is unknown, but they bear lithologic similarities to fossiliferous rocks of slope-basin facies in Baja California, Mexico assigned a Mesozoic and(or) Late Paleozoic(?) age (e.g., Leier-Engelhardt, 1993). Pending further study, the rocks in the Jacumba Mountains are tentatively assigned a Mesozoic and Paleozoic(?) age

**Pzm Metasedimentary rocks (Paleozoic)**—Screens composed of metamorphosed miogeoclinal strata in the Coyote and Fish Creek Mountains consist of greenschist- and amphibolite-facies interlayered marble, schist, and metaquartzite. A 570-m-thick screen at Carrizo Mountain in the northern Coyote Mountains is composed of interlayered 1) fine- to coarse-grained white, gray, and light- to dark-blue calcitic marble, locally containing thin (5 to 8 cm) chert ribbons (85 percent of unit) and 2) quartz-muscovite schist and minor biotite, chlorite, garnet, and opaque minerals plus virtually pure quartzite containing minor muscovite (Dockum, 1982). One of three marble subunits in this section contains Lower Ordovician conodonts (Dockum, 1982; Miller and Dockum, 1983). Dolomitic marble interlayered with biotite schist has been quarried from the large screen near the western end of the range (Weber, 1963, p. 174). Screens consisting of marble, biotite schist, and metaquartzite in the western Coyote Mountains are enclosed by migmatitic and gneissic rocks (Hoggatt, 1979) assigned to the Jurassic migmatitic schist and gneiss of Stephenson Peak (Todd, 1978a). Metasedimentary rocks in the Fish Creek Mountains consist of interlayered marble, schist, metaquartzite, and metaconglomerate. These rocks were intruded by a large composite pluton assigned to the tonalite of Granite Mountain (Todd and others, 1987a). The largest screen (about 800 m thick), which consists almost wholly of subequal calcitic and dolomitic marble, crosses the northeast corner of the quadrangle. Marble beds consist of 1) thinly laminated (2.5 cm) pink-, yellow-, and light-gray-weathering marble, 2) dark-gray and dark-bluish-gray finely laminated (0.5-1 mm) marble with fossil hash, 3) gray-, tan-, and dark-brown-weathering marble with siliceous laminae and concretions, and 4) coarsely clastic marble (limestone-clast conglomerate) (Todd and others, 1987a). Metaquartzite consists of 1) light-gray- to white-

weathering, relatively pure, fine- to coarse-grained quartzite, grit, and small-pebble conglomerate, locally containing biotite flakes and 1-mm biotitic laminae, irregular aggregates of pink garnet, and relict crossbeds; 2) dark-gray-weathering platy metasandstone and metasilstone; and 3) impure quartzite with silicified burrows. Schist layers in the screen include 1) coarse-grained, black biotitic schist containing andalusite porphyroblasts and 2) semi-pelitic biotite-quartz-feldspar schist. Interlayered with these rocks are minor pebble-conglomerate layers up to 3 m thick. The protolith of metasedimentary rocks in the eastern part of the Peninsular Ranges Batholith is interpreted as quartz-rich sandstone, shale, and limestone deposited in a shallow continental shelf sea (Hill, 1984; Gastil and Miller, 1984). The presence of Ordovician fossils and pipe rock of probable Cambro-Ordovician age (M. Droser, oral commun., 1993) suggests that most or all of the metasedimentary rocks in the quadrangle east of the Elsinore Fault Zone are Paleozoic in age.

#### REFERENCES CITED

- Abbott, P.L., and Smith, T.E., 1978, Trace-element comparison of clasts in Eocene conglomerates, southwestern California and northwestern Mexico: *Journal of Geology*, v. 86, p. 753-762.
- Abbott, P.L., and Smith, T.E., 1989, Sonora, Mexico source for the Eocene Poway Conglomerate of southern California: *Geology*, v. 17, p. 329-332.
- Anderson, C.L., 1991, Zircon uranium-lead isotopic ages of the Santiago Peak Volcanics and spatially related plutons of the Peninsular Ranges batholith, southern California: M.S. thesis, San Diego State University, 111 p.
- Artim, E.R., and Pinckney, C.T., 1973, La Nacion fault system, San Diego, California: *Geological Society of America Bulletin*, v. 84, p. 1075-1080.
- Atwater, T.M., 1992, Constraints from plate reconstructions for Cenozoic tectonic regimes of southern and eastern California: *in* Richard, S.M., ed., Deformation associated with the Neogene Eastern California Shear Zone, southwestern Arizona and southeastern California: Redlands, California, San Bernardino County Museum Special Publication, p. 1-2.
- Bracchi, K.A., Girty, G.H., and Girty, M.S., 1993, Cuyamaca-Laguna Mountains shear zone (CLMSZ), Garnet Mountain area, southern California: A collisionally generated contractional shear zone (abs.): *Geological Society of America Abstracts with Programs*, v. 25, no. 5, p. 13.
- Chappell, B.W., and White, A.J.R., 1974, Two contrasting granite types: *Pacific Geology*, v. 8, p. 173-174.
- Christensen, A.D., 1957, Part of the geology of the Coyote Mountain area, Imperial County, California: M.S. thesis, University of California, Los Angeles, 188 p.
- Dean, M.A., 1988, Genesis, mineralogy and stratigraphy of the Neogene Fish Creek Gypsum, southwestern Salton Trough, California: M.S. thesis, San Diego State University, 150 p.
- Dibblee, T.W., Jr., 1954, Geology of the Imperial Valley region, California: *in* Jahns, R.H., ed., *Geology of California*, Chapter 2: California Division of Mines Bulletin 170, p. 21-28.
- Dockum, M.S., 1982, Greenschist-facies carbonates, eastern Coyote Mountains, western Imperial County, California: M.S. thesis, San Diego State University, 89 p.
- Engelbreton, D.C., Cox, Allan, and Gordon, R.G., 1985, Relative motions between continental plates in the Pacific basin: *Geological Society of America Special Paper* 206, 59 p.
- Erskine, B.G., 1986, Mylonitic deformation and associated low-angle faulting in the Santa Rosa mylonite zone, southern California: Unpublished Ph.D. dissertation, University of California, Berkeley, 247 p.
- Everhart, D.L., 1951, Geology of the Cuyamaca Peak quadrangle, San Diego County, California: California Division of Mines Bulletin 159, p. 51-115.
- Fife, D.L., Minch, J.A., and Crampton, P.J., 1967, Late Jurassic age of the Santiago Peak Volcanics, California: *Geological Society of America Bulletin*, v. 78, p. 299-304.
- Gastil, R.G., Phillips, R.P., and Allison, E.C., 1975, Reconnaissance geology of the state of Baja California: *Geological Society of America Memoir* 140, 170 p.

- Gastil, R.G., and Miller, R.H., 1984, Prebatholithic paleogeography of peninsular California and adjacent Mexico: *in* Frizzell, V.A., Jr., ed., *Geology of Baja California Peninsula: Pacific Section*, Society of Economic Paleontologists and Mineralogists, v. 39, p. 9-16.
- Gastil, G., Girty, G., Wardlaw, M., and Davis, T., 1988, Correlation of Triassic-Jurassic sandstone in peninsular California (abs.): *Geological Society of America Abstracts with Programs*, v. 20, no. 3, p. 162.
- George, P.G., and Dokka, R.K., 1994, Major Late Cretaceous cooling events in the eastern Peninsular Ranges, California, and their implications for Cordilleran tectonics: *Geological Society of America Bulletin*, v. 106, p. 903-914.
- Girty, G.H., Thomson, C.N., Girty, M.S., Miller, J., and Bracchi, K., 1993, The Cuyamaca-Laguna Mountains shear zone, Late Jurassic plutonic rocks and Early Cretaceous extension, Peninsular Ranges, southern California: *in* *Geological investigations in Baja California, Mexico*, Abbott, P.L., Sangines, E.M., and Rendina, M.A., eds., *South Coast Geological Society Volume*, Santa Ana, California, p. 173-181.
- Gjerde, M.W., 1982, Petrography and geochemistry of the Alverson Formation, Imperial County, California: M.S. thesis, San Diego State University, 85 p.
- Grove, Marty, 1987, Metamorphism and deformation of prebatholithic rocks in the Box Canyon area, eastern Peninsular Ranges, San Diego County, California: Unpublished Master's thesis, University of California, Los Angeles, Los Angeles, California, 174 p.
- Grove, Marty, 1989, Nature of the metamorphic discontinuity across the Chariot Canyon fault, east-central Peninsular Ranges batholith, California (abs.): *Geological Society of America Abstracts with Programs*, v. 21, no. 5, p. 87.
- Hanna, M.A., 1926, *Geology of the La Jolla quadrangle, California*: University of California, Department of Geological Sciences Bulletin, v. 16, p. 187-246.
- Hart, M.W., 1991, Landslides in the Peninsular Ranges, southern California, in *Geological excursions in southern California and Mexico*, Walawender, M.J., and Hanan, B.B., eds.: *Guidebook for the 1991 annual meeting of the Geological Society of America*, San Diego, California, p.349-365.
- Hawkins, J.W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, southern California and Baja California: *Geological Society of America Bulletin*, v. 81, p. 3323-3338.
- Herzig, C.T., 1991, Petrogenetic and tectonic development of the Santiago Peak Volcanics, northern Santa Ana Mountains, California: Unpublished Ph.D. dissertation, University of California, Riverside, Riverside, California
- Herzig, C.T., and Kimbrough, D.L., 1991, Early Cretaceous zircon ages prove a non-accretionary origin for the Santiago Peak Volcanics, northern Santa Ana Mountains, California: *Geological Society of America Abstracts with Programs*, v. 23, no. 2, p. 35.
- Hill, R.I., 1984, Petrology and petrogenesis of batholithic rocks, San Jacinto Mountains, southern California: Unpublished Ph.D. dissertation, California Institute of Technology, Pasadena, California, 660 p.
- Hoggatt, W.C., 1979, Geologic map of the Sweeney Pass quadrangle, San Diego County, California: U.S. Geological Survey Open-File report 79-754, 28 p., scale 1:24,000.
- Hoggatt, W.C., and Todd, V.R., 1977, Geologic map of the Descanso quadrangle, San Diego County, California: U.S. Geological Survey Open-File report 77-406, 12 p., scale 1:24,000.
- Hudson, F.S., 1922, *Geology of the Cuyamaca region of California, with special reference to the origin of nickeliferous pyrrhotite*: University of California, Department of Geological Sciences Bulletin, v. 13, p. 175-252.
- Isaac, S., Rockwell, T.K., and Gastil, G., 1986, Plio-Pleistocene detachment faulting, Yuha Desert region, western Salton Trough, northern Baja California: *Geological Society of America Abstracts with Programs*, p. 120.
- Jachens, R.C., Todd, V.R., Morton, D.M., and Griscom, Andrew, 1991, Constraints on the structural evolution of the Peninsular Ranges batholith, California, from a new aeromagnetic map: *Geological Society of America Abstracts with Programs*, v. 23, no. 2, p. 38.
- Jachens, R.C., 1992, Aeromagnetic map of the El Cajon 1:100,000 scale quadrangle, California: U.S. Geological Survey Open-File report 92-548.

- Johnson, N.M., Officer, C.B., Opdyke, N.D., Woodard, G.D., Zeitler, P.K., and Lindsay, E.H., 1983, Rates of late Cenozoic tectonism in the Vallecito-Fish Creek basin, western Imperial Valley, California: *Geology*, v. 11, p. 664-667.
- Jones, D.A., and Miller, R.H., 1982, Jurassic fossils from the Santiago Peak Volcanics, San Diego County, California, *in* Abbott, P.L., ed., *Geologic studies in San Diego*: San Diego Association of Geologists Publication, p. 93-103.
- Kennedy, M.P., 1975, Geology of western San Diego metropolitan area, California: California Division of Mines and Geology Bulletin 200, p. 9-39.
- Kennedy, M.P., in press, Geologic map of the San Diego 30- X 60-minute quadrangle, California: scale 1:100,000.
- Kennedy, M.P., and Moore, G.W., 1971, Stratigraphic relations of Upper Cretaceous and Eocene formations, San Diego coastal area, California: American Association of Petroleum Geologists, Bulletin 55, p. 709-722.
- Kennedy, M.P., and Peterson, G.L., 1975, Geology of the eastern San Diego metropolitan area, California: California Division of Mines and Geology Bulletin 200, p. 43-56.
- Kennedy, M.P., and Tan, S.S., 1977, Geology of National City, Imperial Beach, and Otay Mesa quadrangles, southern San Diego metropolitan area, California: California Division of Mines and Geology, Map Sheet 29, scale 1:24,000.
- Kerr, D.R., 1984, Early Neogene continental sedimentation in the Vallecito and Fish Creek Mountains, western Salton Trough, California: *Sedimentary Geology*, v. 38, p. 217-246.
- Kerr, D.R., and Kidwell, S.M., 1991, Late Cenozoic sedimentation and tectonics, western Salton Trough, California, *in* Geological excursions in southern California and Mexico, Walawender, M.J., and Hanan, B.B., eds.: Guidebook for the 1991 Annual Meeting of the Geological Society of America, San Diego, California, p. 397-416.
- Kimbrough, D.L., Anderson, C.L., Glass, S.N., Kenney, M.D., Thomas, A.D., and Vitello, Theresa, 1990, Early Cretaceous zircon U-Pb ages from the Santiago Peak Volcanics, western Peninsular Ranges batholith, San Diego County, California: *Geological Society of America Abstracts with Programs*, v. 22, no. 3, p. 35.
- Kimzey, J.A., 1982, Petrography and geochemistry of the La Posta granodiorite: M.S. thesis, San Diego State University, San Diego, California, 64 p.
- Lampe, C.M., 1988, Geology of the Granite Mountain area: Implications of the extent and style of deformation along the southeast portion of the Elsinore fault: M.S. thesis, San Diego, California, San Diego State University, 150 p.
- Larsen, E.S., Jr., 1948, Batholith and associated rocks of Corona, Elsinore, and San Luis Rey quadrangles, southern California: *Geological Society of America Memoir* 29, 182 p.
- Leier-Engelhardt, Paula, 1993, Middle Paleozoic strata of the Sierra Las Pintas, northeastern Baja California Norte, Mexico, *in* Gastil, R. Gordon, and Miller, R.H., eds., *The prebatholithic stratigraphy of peninsular California*: Geological Society of America Special Paper 279, p. 23-41.
- Miller, C.F., and Bradfish, L.J., 1980, An inner Cordilleran belt of muscovite-bearing plutons: *Geology*, v. 8, p. 412-416.
- Miller, R.H., and Dockum, M.S., 1983, Ordovician conodonts from metamorphosed carbonates of the Salton Trough, California: *Geology*, v. 11, p. 410-412.
- Miller, W.J., 1935, A geologic section across the southern Peninsular Ranges of California: *California Journal of Mines and Geology*, v. 381, p. 115-142.
- Milow, E.D., and Ennis, D.B., 1961, Guide to geologic field trip of southwestern San Diego County: Geological Society of America, Cordilleran Section, 57th Annual Meeting, Guidebook, p. 23-43.
- Minch, J.A., 1972, The late Mesozoic-early Tertiary framework of continental sedimentation, northern Peninsular Ranges, Baja California, Mexico: PH.D. dissertation, Riverside, California, University of California, Riverside, 192 p.
- Minch, J.A., and Abbott, P.L., 1973, Post-batholithic geology of the Jacumba area, southeastern San Diego County, California: *San Diego Society of Natural History, Transactions*, 17(11), p. 129-136.
- Murchey, B.L., and Blake, M.C., Jr., 1993, Evidence for subduction of a major ocean plate along the California margin during the Middle to early Late Jurassic: *in* Dunn, G., and McDougall, K., eds., *Mesozoic paleogeography of the western United States- II: Pacific Section SEPM, Book 71*, p. 1-18.

- Naeser, C.W., Naeser, N.D., Snee, L.W., Todd, V.R., and Bohannon, R.G., 1996, Thermochronology of the Peninsular Ranges batholith, southern California, from fission-track and  $^{40}\text{Ar}$ - $^{39}\text{Ar}$  analysis (abs.): Geological Society of America Abstracts with Programs
- Nishimori, R.K., 1976, Petrology and geochemistry of gabbros from the Peninsular Ranges and a model for their origin: Ph.D. dissertation, San Diego, California, University of California, San Diego, 272 p.
- Nordstrom, C.E., 1970, Lusardi Formation- a post-batholithic Cretaceous conglomerate north of San Diego, California: Geological Society of America Bulletin, v. 81, p. 601-605.
- Parrish, K.E., Walawender, M.J., Clinkenbeard, J.F., and Wardlaw, M.S., 1986, The Indian Hill Granodiorite, a peraluminous, garnet-bearing granitoid, eastern Peninsular Ranges [abs.]: Geological Society of America Abstracts with Programs, v. 18, no. 2, p. 168.
- Peterson, G.L., and Kennedy, M.P., 1974, Lithostratigraphic variations in the Poway Group near San Diego, California: San Diego Society of Natural History Transactions, v. 17, p. 251-258.
- Ruisaard, C.I., 1979, Stratigraphy of the Miocene Alverson Formation, Imperial County, California: M.S. thesis, San Diego, California, San Diego State University, 125 p.
- Schwarcz, H.P., 1969, Pre-Cretaceous sedimentation and metamorphism in the Winchester area, northern Peninsular Ranges, California: Geological Society of America Special Paper 100, 61 p.
- Sharp, R.V., 1979, Some characteristics of the eastern Peninsular Ranges mylonite zone, *in* Proceedings, Conference VIII, Analysis of actual fault zones in bedrock: U.S. Geological Survey Open-File Report 79-1239, p. 258-267.
- Shaw, S.E., Todd, V.R., and Grove, M., 2003, Jurassic peraluminous and gneissic granites in the axial zone of the Peninsular Ranges, southern California, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., and Martin-Barajas, A., eds., Tectonic evolution of northwestern Mexico and the southwestern USA: Boulder, Colorado, Geological Society of America Special Paper 374, p. 157-183.
- Silver, L.T., Taylor, H.P., Jr., and Chappell, B., 1979, Some petrological, geochemical and geochronological observations of the Peninsular Ranges batholith near the international border of the U.S.A. and Mexico, *in* Abbott, P.L., and Todd, V.R., eds., Mesozoic crystalline rocks: San Diego State University, Department of Geological Sciences, Guidebook for Geological Society of America Annual Meeting, San Diego, California, Nov. 1979, p. 83-110.
- Snee, L.W., Naeser, C.W., Naeser, N.D., Todd, V.R., and Morton, D.M., 1994, Preliminary  $^{40}\text{Ar}/^{39}\text{Ar}$  and fission-track cooling ages of plutonic rocks across the Peninsular Ranges batholith, southern California (abs.): Geological Society of America Abstracts with Programs, v. 26, no. 2, p. 94.
- Strand, R.G., 1962, Geologic map of California, San Diego-El Centro sheet, scale 1:250,000: California Division of Mines and Geology.
- Streckeisen, A.L., 1973, Plutonic rocks, classification and nomenclature recommended by the I.U.G.S. Subcommittee on the systematics of igneous rocks: *Geotimes*, v. 18, no. 10, p. 26-30.
- Tan, S.S., 1992a, Landslide hazards in the El Cajon quadrangle, San Diego County, California: California Division of Mines and Geology Open-File Report 92-11, scale 1:24,000.
- Tan, S.S., 1992b, Landslide hazards in the San Vicente Reservoir quadrangle, San Diego County, California: California Division of Mines and Geology Open-File Report 92-04, scale 1:24,000.
- Tan, S.S., 1992c, Landslide hazards in the Jamul Mountains quadrangle, San Diego County, California: California Division of Mines and Geology Open-File Report 92-12, scale 1:24,000.
- Tarbet, L.A., 1951, Imperial Valley, in possible future petroleum provinces of North America: American Association of Petroleum Geologists Bulletin, v. 35, p. 260-263.
- Tarbet, L.A., and Holman, W.H., 1944, Stratigraphy and micropaleontology of the west side of the Imperial Valley, California [abs.]: American Association of Petroleum Geologists Bulletin, v. 28, p. 1781-1782.
- Thomson, Celeste N., and Girty, Gary H., 1994, Early Cretaceous intra-arc ductile strain in Triassic-Jurassic and Cretaceous continental margin arc rocks, Peninsular Ranges, California: *Tectonics*, v. 13, no. 5, p. 1108-1119.
- Todd, V.R., 1977a, Geologic map of the Cuyamaca Peak quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 77-405, 13 p., scale 1:24,000.
- Todd, V.R., 1977b, Geologic map of the Agua Caliente Springs quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 77-742, 20 p., scale 1:24,000.
- Todd, V.R., 1978a, Geologic map of the Monument Peak quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 78-697, 47 p., 1:24,000.

- Todd, V.R., 1978b, Geologic map of the Viejas Mountain quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 78-113, 30 p., scale 1:24,000.
- Todd, V.R., 1979, Geologic map of the Mount Laguna quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 79-862, 40 p., scale 1:24,000.
- Todd, V.R., 1980, Geologic map of the Alpine quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 80-82, 42 p., scale 1:24,000.
- Todd, V.R., 1982, Geologic map of the Tule Springs quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 82-221, 23 p., scale 1:24,000.
- Todd, V.R., 1983, Geologic map of the El Cajon Mountain quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 83-781, 47 p., scale 1:24,000.
- Todd, V.R., 1995, Geologic map of the Mount Laguna 15-minute quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 95-522, 29 p., scale 1:62,500.
- Todd, V.R., unpublished mapping, Geologic map of the Morena Reservoir quadrangle, San Diego County, California: U.S. Geological Survey Open-File Report 95-50, Director's Approval 1-13-95, scale 1:24,000.
- Todd, V.R., Detra, D.E., Kilburn, J.E., Griscom, Andrew, Kruse, F.A., and Campbell, H.W., 1987a, Mineral resources of the Fish Creek Mountains Wilderness Study Area, Imperial County, California: U.S. Geological Survey Bulletin 1711-C, 14 p.
- Todd, V.R., Kilburn, J.E., Detra, D.E., Griscom, Andrew, Knepper, Jr., D.H., Kruse, F.A., Cather, Eric, and Lipton, D.A., 1987b, Mineral resources of the Sawtooth Mountains and Carrizo Gorge/eastern McCain Valley Wilderness Study Areas, San Diego County, California: U.S. Geological Survey Bulletin 1711-B, 15 p.
- Todd, V.R., Kilburn, J.E., Detra, D.E., Griscom, Andrew, Kruse, F.A., and McHugh, E.L., 1987c, Mineral resources of the Jacumba (In-ko-pah) Wilderness Study Area, Imperial County, California: U.S. Geological Survey Bulletin 1711-D, 18 p.
- Todd, V.R., Lee, G.K., Oliver, H.W., Causey, J.D., and Schmauch, S.W., 1988a, Mineral resources of the Southern Otay Mountain and Western Otay Mountain Wilderness Study Areas, San Diego County, California: U.S. Geological Survey Bulletin 1711-E, 18 p.
- Todd, V.R., Erskine, B.G., and Morton, D.M., 1988b, Metamorphic and tectonic evolution of the northern Peninsular Ranges batholith, *in* Ernst, W.G., ed., *Metamorphism and crustal evolution of the western United States*, Rubey Volume VII, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, p. 894-937.
- Todd, V.R., Shaw, S.E., Girty, G.H., and Jachens, R.C., 1991, A probable Jurassic plutonic arc of continental affinity in the Peninsular Ranges batholith, southern California: Tectonic implications [abs.]: Geological Society of America Abstracts with Programs, v. 23, no. 2, p. 104.
- Todd, V.R., Kimbrough, D.L., and Herzig, C.T., 1994a, The Peninsular Ranges batholith from western volcanic arc to eastern mid-crustal intrusive and metamorphic rocks, San Diego County, California, *in* McGill, S.F., and Ross, T.M., eds., *Geological investigations of an active margin: Geological Society of America Cordilleran Section Guidebook, 27th Annual Meeting*, San Bernardino, California, Mar., 1994, p. 227-235.
- Todd, V.R., Kimbrough, D.L., and Grove, Marty, 1994b, Volcanic to plutonic transect across the Peninsular Ranges batholith, San Diego County, California, Roadlog for field trip, *in* McGill, S.F., and Ross, T.M., eds., *Geological Investigations of an active margin: Geological Society of America Cordilleran Section Guidebook, 27th Annual Meeting*, San Bernardino, California, Mar., 1994, p. 214-226.
- Todd, V.R., Shaw, S.E., and Hammarstrom, J.M., 2003, Cretaceous plutons of the Peninsular Ranges batholith, San Diego and westernmost Imperial Counties, California: Intrusion across a Late Jurassic continental margin, *in* Johnson, S.E., Paterson, S.R., Fletcher, J.M., Girty, G.H., Kimbrough, D.L., and Martin-Barajas, A., eds., *Tectonic evolution of northwestern Mexico and the southwestern USA: Boulder, Colorado, Geological Society of America Special Paper 374*, p. 185-235.
- Walawender, M.J., 1979, Basic plutons of the Peninsular Ranges batholith, southern California, *in* Abbott, P.L., and Todd, V.R., eds., *Mesozoic crystalline rocks: San Diego State University, Department of Geological Sciences, Guidebook for the Geological Society of America Annual Meeting*, San Diego, California, Nov. 1979, p. 151-162.

- Walawender, M.J., Gastil, R.G., Clinkenbeard, J.P., McCormick, W.V., Eastman, B.G., Wernicke, R.S., Wardlaw, M.S., and Gunn, S.H., 1990, Origin and evolution of the zoned La Posta-type plutons, eastern Peninsular Ranges batholith, southern and Baja California, *in* Anderson, J.L., ed., The nature and origin of Cordilleran magmatism: Geological Society of America Memoir 174, p. 1-18.
- Weber, F.H., Jr., 1963, Geology and mineral resources of San Diego County, California: California Division of Mines and Geology County Report 3, 309 p.
- White, Allan J.R., and Chappell, Bruce W., 1977, Ultrametamorphism and granitoid genesis: *Tectonophysics*, v. 43, p. 7-22.
- Winker, C.D., 1987, Neogene stratigraphy of the Fish Creek-Vallecito section, southern California: Implications for early history of the northern Gulf of California and Colorado Delta: Ph.D. dissertation, Tucson, Arizona, University of Arizona, 494 p.
- Woodard, G.D., 1963, The Cenozoic succession of the west Colorado Desert, San Diego and Imperial Counties, southern California: Ph.D. dissertation, Berkeley, California, University of California, Berkeley, 173 p.
- Woodard, G.D., 1967, The Cenozoic succession of the west Colorado Desert, San Diego and Imperial Counties, southern California: *Dissertation Abstracts*, Section B, v. 27, no. 8, p. 2752.
- Woodard, G.D., 1974, Redefinition of Cenozoic stratigraphic column in Split Mountain Gorge, Imperial Valley, California: *American Association of Petroleum Geologists Bulletin*, v. 58, p. 521-526.
- Woodring, W.P., 1932, Distribution and age of the Tertiary deposits of the Colorado Desert: Carnegie Institution of Washington Publication 148, p. 1-25.