

# Geologic Map of the San Diego 30' x 60' Quadrangle, California

By

Michael P. Kennedy<sup>1</sup> and Siang S. Tan<sup>1</sup>

Digital Preparation by

Kelly R. Bovard<sup>2</sup>, Anne G. Garcia<sup>2</sup>, Diane Burns<sup>2</sup>, and Carlos I. Gutierrez<sup>1</sup>

2008



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JOHN G. PARRISH, Ph.D., State Geologist  
CALIFORNIA GEOLOGICAL SURVEY

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<sup>1</sup>Department of Conservation, California Geological Survey

<sup>2</sup>U.S. Geological Survey, Department of Earth Sciences, University of California, Riverside



**CALIFORNIA GEOLOGICAL SURVEY  
JOHN G. PARRISH, Ph.D.  
STATE GEOLOGIST**

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## Introduction

In 1990 the U.S. Geological Survey, as part of the National Geologic Mapping Program, initiated the Southern California Areal Mapping Project (SCAMP) (<http://scamp.wr.usgs.gov>) in cooperation with the California Geological Survey (then Division of Mines and Geology) Regional Geologic Mapping Project (<http://www.conservation.ca.gov/cgs/rghm/rgm/index.htm>). SCAMP's objectives were two-fold: to provide a basic understanding of the geologic framework and geologic history of southern California; and to develop a uniform digital geologic map database that could be used in a Geographic Information System (GIS) and be the foundation for geologic hazard investigations, natural resource evaluations, and other related earth science studies. These types of digital data can provide an important component for performing GIS analyses throughout southern California.

This map was prepared by the Department of Conservation, California Geological Survey and is a product of SCAMP. This project was supported in part by the U.S. Geological Survey STATEMAP award no. 98HQAG2049.

## Geologic Summary

The San Diego 1:100,000-scale quadrangle lies within the Peninsular Ranges Geomorphic Province of southern California, between 32°30' and 33° N. latitude and 117° and 118° W. longitude, and encompasses the greater San Diego area, the second largest metropolitan area of California (Fig. 1). The Peninsular Ranges of southern California form a northwest-trending geomorphic province that occupies the southwestern corner of California and extends southeastward to form the Baja California peninsula. Its physiography is characterized principally by steep mountain highlands with elevations exceeding 3,500 meters and dramatic intermontane basins, valleys, and rivers. The highlands are flanked on the west by a

relatively narrow, westward sloping coastal margin that includes the San Diego embayment. On the east the highlands are bounded from the adjoining Colorado Desert and the Gulf of California by precipitous fault scarps, 2,000 to more than 3,000 meters high.

The area within the San Diego 30' x 60' quadrangle is tectonically and seismically active and includes parts of four major, northwest-trending, oblique, right-lateral, strike-slip, Pacific/North American Plate boundary fault zones. They include the Rose Canyon-Newport-Inglewood Fault Zone along the eastern coastal margin of the quadrangle, the Palos Verdes-Coronado Bank Fault Zone offshore on the inner shelf, the San Diego Trough Fault Zone (source of the 1986,  $M_L=5.3$ , Oceanside earthquake) in the central offshore region, and the San Clemente Fault Zone on the outer offshore margin (Fig. 1).

Within the greater San Diego metropolitan area, the Rose Canyon Fault Zone, as depicted by Kennedy and others (1975), Moore and Kennedy (1975), Kennedy and Welday (1980), Clarke and others (1987), Treiman (1993) and Kennedy and Clarke (2001), includes the Mount Soledad, Old Town, Point Loma, Silver Strand, Coronado and Spanish Bight faults. The Rose Canyon Fault Zone displaces Holocene sediment in Rose Canyon 7 km north of San Diego Bay where a late Pleistocene slip rate of 1-2 mm/yr has been estimated (Lindvall and Rockwell, 1995). A study of the recency and character of faulting in the greater San Diego metropolitan area suggests a long-term Tertiary slip rate for the Rose Canyon Fault Zone of about 1-2 mm/yr (Kennedy and others, 1975). Although there is significant late Quaternary deformation in the San Diego region the seismicity is relatively low (Simons, 1977).

The eastern part of the San Diego 1:100,000-scale quadrangle is underlain by plutonic rocks of the western Peninsular Ranges batholith and a thick sequence (>5 km) of Mesozoic fore-arc and fore-arc basin volcanic and volcanoclastic deposits. The

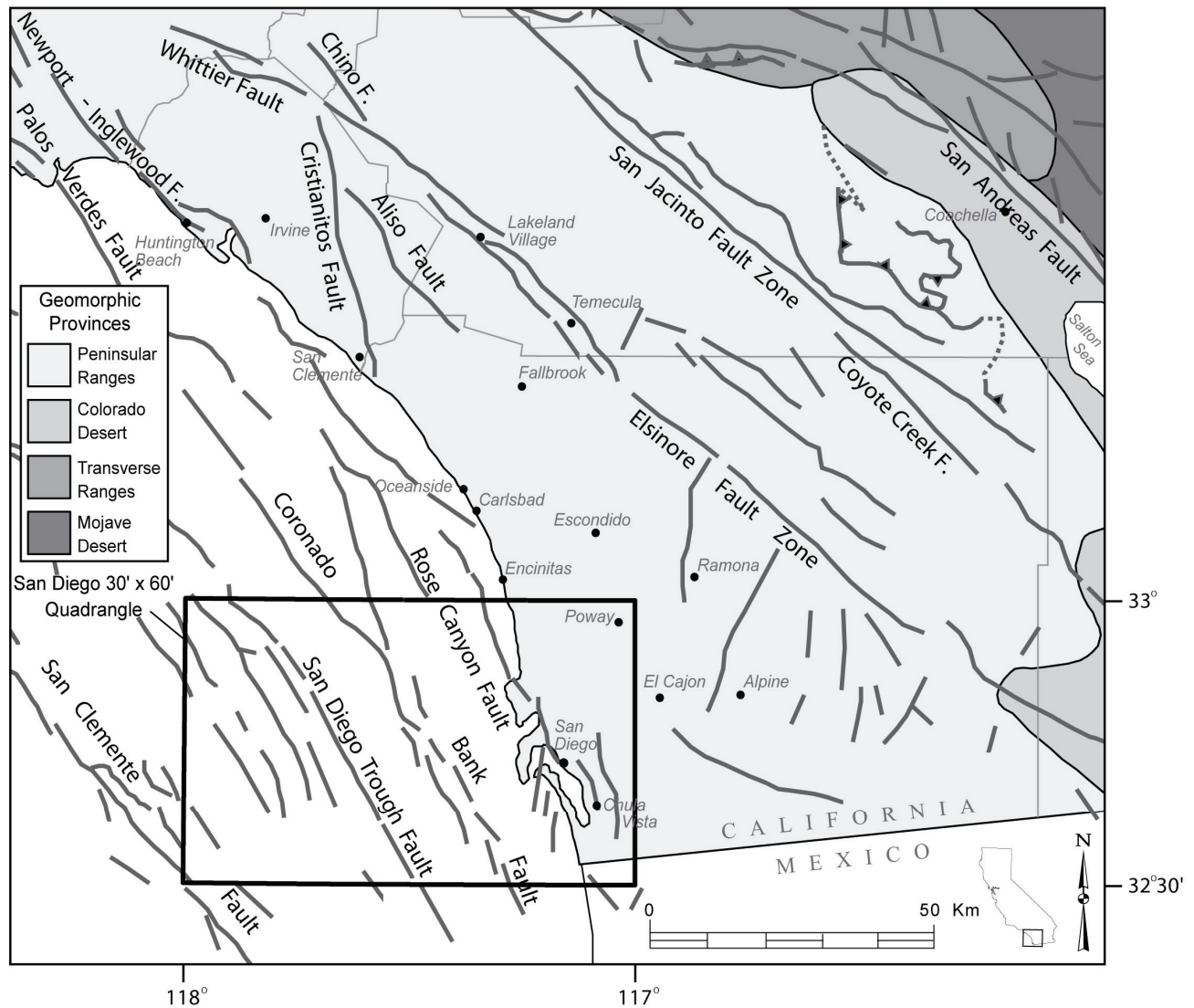


Figure 1. Index map showing the location of the San Diego 30' x 60' quadrangle, major cities and faults, as well as the geomorphic provinces of southwestern California. Modified from Jennings and Saucedo, 2002.

batholithic rocks are mostly granodiorite and tonalite (Fig. 2) and based on U/Pb isotopic ages range from 140 Ma to 105 Ma (Silver and Chappell, 1988). The andesitic flows and coarse-grained volcanoclastic breccias of the Mesozoic fore-arc deposits have, in large part, been metamorphosed to low-grade greenschist facies and exhibit penetrative deformation. However, in the upper part of the section these rocks are not metamorphosed and are only moderately de-

formed. Marine sedimentary interbeds in Penasquitos Canyon, near Del Mar, contain the fossil *Buchia piochii*, which indicates a Late Jurassic (Tithonian) age for these strata (Fife and others, 1967; Jones and Miller, 1982). Zircon U/Pb ages from the metavolcanic rocks are reported to range from 137 Ma to 119 Ma (Anderson, 1991) indicating that they are coeval with the surrounding plutonic rocks of the western Peninsular Ranges batholith. Much of the

basement rock has been deeply weathered and altered. The weathered bedrock and Quaternary alluvial deposits derived from them contain expansible clays, mostly smectite.

The western part of the quadrangle is underlain by a relatively thick (>1,000 m) succession of Upper Cretaceous, Tertiary and Quaternary sedimentary rocks that unconformably overlie basement rocks. They consist of marine, paralic, and continental claystone, siltstone, sandstone and conglomerate. The Upper Cretaceous rocks are composed of marine turbidites and continental fan deposits assigned to the Rosario Group (Kennedy and Moore, 1971). The Lusardi Formation, the basal formation of the Rosario Group, is a nonmarine boulder conglomerate deposited along the western margin of a tectonic highland upon a deeply weathered surface of the older Cretaceous and Jurassic plutonic and metamorphic basement rocks. Clasts within the Lusardi Formation are composed exclusively of these weathered basement rocks. The Lusardi Formation is overlain by the Point Loma Formation, the middle part of the Rosario Group. It is composed mostly of marine sandstone, siltstone and conglomerate sequences that together form massive turbidite deposits. The Point Loma Formation is Campanian and Maestrichtian in age (Sliter, 1968; Bukry and Kennedy, 1969) and underlies most of the Point Loma Peninsula and the hills southeast of La Jolla. It is conformably overlain by the uppermost part of the Rosario Group, marine sandstone and conglomerate of the Maestrichtian (Sliter, 1968; Bukry and Kennedy, 1969) Cabrillo Formation. Following the deposition of the Rosario Group, the San Diego coastal margin underwent uplift and erosion until the middle Eocene when nine partially intertonguing middle and upper Eocene sequences composed of siltstone, sandstone, and conglomerate were deposited during several major transgressive-regressive cycles. The succession is over

700 meters thick and grades from non-marine fan and dune deposits on the east through lagoonal and nearshore beach and beach-bar deposits to marine continental shelf deposits on the west near the present-day coastline. The age and environmental interpretation of the Eocene sequence is based on the mapped distribution of lithofacies coupled with the presence of a pelagic fossil calcareous nannoplankton flora in the continental shelf facies (e.g., Bukry and Kennedy, 1969), a shallow water molluscan fauna in the nearshore facies (e.g., Givens and Kennedy, 1979), and a fossil terrestrial vertebrate mammal fauna in the paralic facies (e.g., Golz, 1973). Cross bedding, cobble imbrications, paleostream gradients and clast petrology indicate a local eastern source for these rocks. The nonmarine facies of the Eocene formations are typically well indurated and cemented whereas the lagoonal facies are soft and friable. The nearshore facies are well indurated, well sorted, and locally concretionary. The marine deposits are typically fine-grained, indurated, and cemented. Following the deposition of Eocene rocks, the San Diego margin was again elevated and eroded. During the Oligocene, continental and shallow water lagoonal deposits of the Otay Formation were deposited. The Otay Formation is light-gray and light-brown, medium- and coarse-grained, arkosic sandstone intertongued with light-brown siltstone and light-gray claystone. Much of the claystone is composed of light-gray bentonite in beds up to 1 m in thickness. Following Oligocene time, the San Diego coastal margin underwent uplift and extensive erosion. The next major marine transgression did not occur until Pliocene time when the strata of the San Diego Formation were deposited. The San Diego Formation rests unconformably upon Oligocene, Eocene, and Upper Cretaceous beds across its outcrop from Pacific Beach to the International border with Mexico. The San Diego Formation is late Pliocene in age

and contains a rich molluscan fauna (e.g., Arnold, 1903; Demere, 1983). It consists mostly of yellowish-brown and gray, fine- to medium-grained, marine sandstone and reddish-brown, transitional marine and nonmarine pebble and cobble conglomerate. Following the deposition of the San Diego Formation and continuing today, the San Diego coastal margin has undergone relatively steady uplift. A series of continually evolving marine abrasion platforms have been carved and uplifted during this time and are manifest in the marine terraces and their deposits that are ubiquitous to the San Diego coastal region (Plate 2). The deposits consist of nearshore marine, beach, estuarine, lagoonal and continental dune facies that were deposited across a marine/nonmarine transition zone and along a coastal strandline. Changes in sea level coupled with regional uplift give rise to the preservation and/or obliteration of both the abrasion platforms and their overlying deposits (e.g. Lajoie, and others, 1991; Kern and Rockwell, 1992; Kern, 1996a, 1996b).

### **Compilation**

The onshore part of the ***Geologic Map of the San Diego 30' x 60' Quadrangle, California*** was digitized at a scale of 1:24,000 while the offshore part has been enlarged from the 1:250,000-scale Continental Margin Map (Clarke and others, 1987) with fault additions and modifications based on larger scale mapping (e.g. Kennedy and others, 1980a,b; Kennedy and Weldon, 1980; Kennedy and Clarke, 1999a,b). Geology for the seven 7.5-minute quadrangles onshore was compiled from published geologic mapping (Fig. 3). Geologic maps of the Del Mar, La Jolla, Point Loma, La Mesa, and Poway quadrangles were published by the California Geological Survey (Division of Mines and Geology) as Bulletin 200 (Kennedy, 1975; Kennedy and Peterson, 1975). The National City and Imperial Beach quadrangles were

published by the California Geological Survey (Division of Mines and Geology) as Map Sheet 29 (Kennedy and Tan, 1977). These published geologic maps were digitized with minor modifications to produce a seamless digital map.

The original digital work for the individual quadrangles, as well as the merged database file, was completed using ArcInfo® 8.3, a commercial GIS software package by Environmental Systems Research Institute (ESRI). For publication purposes the merged coverage was converted into the ESRI geodatabase format. The merged geology, structure, and annotation files along with base layers and shaded-relief images were combined using the ArcMap application within ArcInfo® 9.1 (ESRI).

An effort was made to apply the currently accepted standards for unit designations and colors to the geologic map (<http://ngmdb.usgs.gov/fqdc/gds/>). On the geologic map Quaternary sedimentary rocks are shown in shades of yellow and gold, Tertiary sedimentary rocks are depicted in shades of brown and reddish-brown, while Cretaceous sedimentary rocks and Jurassic metasedimentary rocks are shown in shades of green. Volcanic rocks are depicted in shades of orange while plutonic rocks are shown in shades of pink or purple, with purple designating more mafic units.

### **Base Material**

The base for the San Diego 30' x 60' quadrangle consists of shaded-relief and topographic digital data. The onshore portion of the base consists of hypsography, transportation, hydrography, and place name layers. The hypsography and transportation layers were converted from 1:100,000 Digital Line Graph (DLG) data into ArcInfo® coverages and then into ESRI geodatabase feature classes. The DLG data is available from the USGS Geographic Data Download website at <http://edc2.usgs.gov/geodata/index.php>. The hydrography layers are

derived from data obtained from the National Hydrography Dataset at <http://nhd.usgs.gov/data.html>. Place names were generated from data obtained from the U.S. Board on Geographic Names GNIS website at [http://geonames.usgs.gov/domestic/download\\_data.htm](http://geonames.usgs.gov/domestic/download_data.htm). Carlos Gutierrez (CGS) generated the onshore shaded-relief image from 30-meter resolution elevation data obtained from the National Elevation Dataset (NED) at <http://ned.usgs.gov/>. The offshore shaded-relief image was prepared by Peter Dartnell (USGS) from multibeam- and singlebeam-bathymetry data acquired by Federal and local agencies as well as academic institutions including: U.S. Geological Survey - <http://pubs.usgs.gov/of/2004/1221/>; Woods Hole Oceanographic Institution and SCRIPPS Institution of Oceanography - <http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html>; California

State University, Monterey Bay - <http://seafloor.csumb.edu/SFMLwebDATA.htm>; the National Oceanic and Atmospheric Administration - <http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html>; and the California Coastal Conservancy, San Diego Association of Governments (SANDAG), California Department of Fish and Game, and Fugro Pelagos.

### **Acknowledgements**

This compilation was the result of a collaborative effort between the California Geological Survey and the U.S. Geological Survey. The authors wish to thank J.P. Kern, D.M. Morton, G.J. Saucedo, and V.R. Todd for their valuable reviews. We would also like to thank Carlos Gutierrez, Karen Toman-Sager, and Heather Lackey for their assistance in the preparation of this map for publication.

## DESCRIPTION OF MAP UNITS

Approximate stratigraphic relationships; see Plate 2 for detailed correlation.

### MODERN SURFICIAL DEPOSITS

Sediment that recently has been transported and deposited in channels and washes, on surfaces of alluvial fans and alluvial plains, and on hill slopes and in artificial fills. Soil-profile development is nonexistent. Includes:

- af **Artificial fill (late Holocene)** – Deposits of fill resulting from human construction, mining, or quarrying activities; includes compacted engineered and non-compacted, non-engineered fill. Some large deposits are mapped, but in some areas no deposits are shown.
- Qw **Wash deposits (late Holocene)** – Unconsolidated bouldery to sandy alluvium of active and recently active washes.
- Qls **Landslide deposits, undivided (Holocene and Pleistocene)** – Highly fragmented to largely coherent landslide deposits. Unconsolidated to moderately well consolidated. Most mapped landslides contain scarp area as well as slide deposit. Many Pleistocene age landslides were reactivated in part or entirely during late Holocene.
- Qmb **Marine beach deposits (late Holocene)** – Unconsolidated beach deposits consisting mostly of fine- and medium-grained sand.
- Qpe **Paralic estuarine deposits (late Holocene)** – Unconsolidated estuarine deposits. Composed mostly of fine-grained sand and clay.

Qmo **Undivided marine deposits in offshore region (late Holocene)** – Unconsolidated, often ponded marine sediments. Composed mostly of very fine- to medium-grained sand and silt.

Qcf **Canyon fill deposits in offshore region (late Holocene)** – Unconsolidated deposits of mixed gravel, sand, and mud on the canyon floor.

### YOUNG SURFICIAL DEPOSITS

Sedimentary units that are slightly consolidated to cemented and slightly to moderately dissected. Alluvial fan deposits typically have high coarse-fine clast ratios. Young surficial units have upper surfaces that are capped by slight to moderately developed pedogenic soil profiles. Includes:

- Qya **Young alluvial flood-plain deposits (Holocene and late Pleistocene)** – Poorly consolidated, poorly sorted, permeable flood-plain deposits of sandy, silty or clay-bearing alluvium.
- Qyc **Young colluvial deposits (Holocene and late Pleistocene)** – Poorly consolidated and poorly sorted sand and silt slope wash deposits.
- Qct **Undivided canyon terrace deposits in offshore region (Holocene and Pleistocene)** – Unconsolidated deposits of mixed gravel, sand, and mud on canyon formed terrace.

### OLD SURFICIAL DEPOSITS

Sediments that are moderately consolidated and slightly to moderately dissected. Older surficial deposits have upper surfaces that are capped by moderate to well-developed pedogenic soils. Includes:



Qoa **Old alluvial flood-plain deposits, undivided (late to middle Pleistocene)** – Fluvial sediments deposited on canyon floors. Consists of moderately well consolidated, poorly sorted, permeable, commonly slightly dissected gravel, sand, silt, and clay-bearing alluvium.

Qop **Old paralic deposits, undivided (late to middle Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the now emergent wave cut abrasion platforms preserved by regional uplift (Plate 2). Where more than one number is shown (e.g., Qop<sub>2-4</sub>), those deposits are undivided. Includes:

Qop<sub>7</sub> **Old paralic deposits, Unit 7 (late to middle Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 9-11 m Bird Rock terrace (Plate 2).

Qop<sub>6</sub> **Old paralic deposits, Unit 6 (late to middle Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 22-23 m Nestor terrace (Plate 2).

Qop<sub>2-4</sub> **Old paralic deposits, Units 2 - 4 undivided (late to middle Pleistocene)** – Poorly sorted, moderately

permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. In much of the area, marine terraces and their paralic deposits cannot be divided as they merge with and are alternately covered by one another. Their physical and temporal relationships are diagrammatically illustrated in Plate 2.

**VERY OLD SURFICIAL UNITS** - Sediments that are slightly to well-consolidated to indurated, and moderately to well-dissected. Upper surfaces are capped by moderate to well-developed pedogenic soils. Includes:

Qvoa **Very old alluvial flood-plain deposits, undivided (middle to early Pleistocene)** – Fluvial sediments deposited on canyon floors. Consists of moderately to well-indurated, reddish-brown, mostly very dissected gravel, sand, silt, and clay-bearing alluvium.

Qvop **Very old paralic deposits, undivided (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the now emergent wave cut abrasion platforms preserved by regional uplift (Plate 2). Includes:

Qvop<sub>13</sub> **Very old paralic deposits, Unit 13 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, interfingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and

conglomerate. These deposits rest on the 67-69 m San Elijo terrace (Plate 2).

Qvop<sub>12</sub> **Very old paralic deposits, Unit 12 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 83-85 m Fire Mountain terrace (Plate 2).

Qvop<sub>11</sub> **Very old paralic deposits, Unit 11 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 92-94 m Clairemont terrace (Plate 2).

Qvop<sub>11a</sub> **Very old paralic deposits, Unit 11a (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strandline, on and as a part of Qvop<sub>11</sub>.

Qvop<sub>10</sub> **Very old paralic deposits, Unit 10 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 104-106 m Tecolote terrace (Plate 2).

Qvop<sub>10a</sub> **Very old paralic deposits, Unit 10a (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strandline, on and as a part of Qvop<sub>10</sub>.

Qvop<sub>9</sub> **Very old paralic deposits, Unit 9 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 113-115 m Linda Vista terrace (Plate 2).

Qvop<sub>9a</sub> **Very old paralic deposits, Unit 9a (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, dune and back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strandline, on and as a part of Qvop<sub>9</sub>.

Qvop<sub>8</sub> **Very old paralic deposits, Unit 8 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 123-125 m Tierra Santa terrace (Plate 2).

Qvop<sub>8a</sub> **Very old paralic deposits, Unit 8a (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, dune and

back beach "beach ridge" deposits composed of cross-bedded sandstone. The ridge is a conspicuous linear topographic high that has formed along a strand line, on and as a part of Qvop<sub>8</sub>.

Qvop<sub>7</sub> **Very old paralic deposits, Unit 7 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 129-131 m Mira Mesa terrace (Plate 2).

Qvop<sub>6</sub> **Very old paralic deposits, Unit 6 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 139 m Black Mountain terrace (Plate 2).

Qvop<sub>5</sub> **Very old paralic deposits, Unit 5 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 153-157 m Rifle Range terrace (Plate 2).

Qvop<sub>4</sub> **Very old paralic deposits, Unit 4 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest

on the 170-174 m Aqueduct terrace (Plate 2).

Qvop<sub>3</sub> **Very old paralic deposits, Unit 3 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 181-185 m Aliso Canyon terrace (Plate 2).

Qvop<sub>2</sub> **Very old paralic deposits, Unit 2 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 190-194 m Flores Hill terrace (Plate 2).

Qvop<sub>1</sub> **Very old paralic deposits, Unit 1 (middle to early Pleistocene)** – Poorly sorted, moderately permeable, reddish-brown, inter-fingered strandline, beach, estuarine and colluvial deposits composed of siltstone, sandstone and conglomerate. These deposits rest on the 201-205 m Eagle terrace (Plate 2).

## **SEDIMENTARY AND VOLCANIC BEDROCK UNITS**

QTso **Undivided sediments and sedimentary rocks in offshore region (Holocene, Pleistocene, Pliocene and Miocene)** – Unconsolidated and poorly consolidated Pleistocene sand, silt and clay deposits that mantle the modern seafloor. Includes unmapped sandstone, siltstone, conglomerate and breccia.

- Tsd **San Diego Formation (early Pleistocene and late Pliocene)** –  
 Tsdss  
 Tsdcg Predominantly yellowish–brown and gray, fine- to medium-grained, poorly indurated fossiliferous marine sandstone (**Tsdss**) and reddish-brown, transitional marine and nonmarine pebble and cobble conglomerate (**Tsdcg**). In part of the area the sandstone and conglomerate are undivided (**Tsd**). The San Diego Formation consists of approximately 75 m of marine and 9 m of nonmarine sedimentary rocks (Demere, 1983). These rocks and their associated marine fossils were first described by Dall (1898) and given the name "San Diego Beds." The name San Diego Formation was given to these rocks in an extensive biostratigraphic study by Arnold (1903). Several comprehensive studies of the marine invertebrate fossil faunas of the San Diego Formation have been published subsequently by Grant and Gale (1931) and Hertlein and Grant (1944, 1960, 1972). Most recently Demere (1982, 1983) presents a concise discussion on the history of work, geologic setting, biostratigraphy and age of the San Diego Formation.
- Tba **Basaltic-andesite dike (Miocene)** – Black, fine-grained, massive, very fresh, basaltic-andesite dike located approximately 600 m north of the Scripps Institution of Oceanography pier. A whole-rock potassium-argon analysis of this rock, which shows some evidence of wall rock assimilation, gave an approximate age of 11 Ma (J.W. Hawkins, written communication, 1972).
- Tmo **Undivided sedimentary rocks in offshore region (Miocene)** – Consists primarily of well-consolidated, bedded sandstone and siltstone.
- Tmvo **Undivided volcanic rocks in offshore region (Miocene)** – Consists primarily of dark-gray and black basaltic rock.
- Tmuo **Undivided volcanic and sedimentary rocks in offshore region (Miocene)** – includes **Tmo** – well-consolidated, bedded sandstone and siltstone; or **Tmvo** – dark-gray and black basaltic rock.
- To **Otay Formation (late Oligocene)** – Light-gray and light-brown, medium- and coarse-grained, nonmarine arkosic sandstone intertongued with light-brown siltstone and light-gray claystone. Much of the claystone is composed of light-gray bentonite that occurs in beds up to 1 m in thickness. A rich vertebrate fossil assemblage from the Otay Formation yields an Arikareean North American mammal "age" (Walsh and Demere, 1991). An  $^{40}\text{Ar}/^{39}\text{Ar}$  date of 28.86 Ma from a bentonite bed within the upper part of the Otay Formation has been provided by J.D. Obradovich of the U.S. Geological Survey and reported in Berry (1991). Berry (1991) provides an excellent summary of the bentonite clay deposits of the Otay Formation.
- Tp **Pomerado Conglomerate (middle Eocene)** – Massive cobble conglomerate with a dark-yellowish-brown, coarse-grained sandstone matrix (**Tp**) and an intervening, 10 m thick, light-olive-gray, soft and friable, fine- to medium-grained

sandstone tongue designated the Miramar Sandstone Member of the Pomerado Conglomerate (**Tpm**). The Pomerado Conglomerate is the upper-most formation of the Poway Group, and has a thickness of 56 m at its type section. Sandstone beds within the Pomerado Conglomerate and Miramar Sandstone Member contain a middle Eocene (late Uintan) vertebrate fossil assemblage (Walsh and others, 1996). The Pomerado Conglomerate was named for exposures located in a divide between Carroll Canyon and Poway Valley along Pomerado Road (Peterson and Kennedy, 1974). The Miramar Sandstone Member is 10 m thick at its type section in the vicinity of Miramar Reservoir where it is lithologically nearly identical to the Mission Valley Formation but is stratigraphically higher and wholly contained within the Pomerado Conglomerate (Peterson and Kennedy, 1974).

**Tmv Mission Valley Formation (middle Eocene)** – Predominantly light-olive-gray, soft and friable, fine- to medium-grained marine and non-marine sandstone containing cobble conglomerate tongues. Contains a diverse late Uintan mammal fauna (Walsh and others, 1996) and a robust molluscan fauna assigned to the Tejon stage (Givens and Kennedy, 1979). A bentonite bed within the upper part of the Mission Valley Formation yielded a single crystal  $^{40}\text{Ar}/^{39}\text{Ar}$  date of  $42.83 \pm 0.24$  Ma (reported in Walsh and others, 1996). The Mission Valley Formation has a maximum thickness of 60 m and was named for exposures along the south wall of Mission Valley on the west side of

State Highway 163 (Kennedy and Moore, 1971).

**Tst Stadium Conglomerate (middle Eocene)** – Massive cobble conglomerate with a dark-yellowish-brown, coarse-grained sandstone matrix. The conglomerate contains up to 85% of slightly metamorphosed rhyolitic to dacitic volcanic and volcanoclastic rocks and up to 20% quartzite. It yields early Uintan mammals (Walsh and others, 1996) and Tejon stage mollusks (Givens and Kennedy, 1979). The Stadium Conglomerate is 50 m thick at its type section, located between the La Jolla and La Mesa quadrangles along the northern wall of Mission Valley near the San Diego Stadium (Kennedy and Moore, 1971).

**Tf Friars Formation (middle Eocene)** – Yellowish-gray, medium-grained, massive, poorly indurated non-marine and lagoonal sandstone and claystone with tongues of cobble conglomerate. It contains early Uintan mammals (Walsh and others, 1996) and was named for exposures along the north side of Mission Valley near Friars Road (Kennedy and Moore, 1971). The Friars Formation reaches a maximum thickness of 50 m between Mission Valley and Carmel Valley.

**Tsc Scripps Formation (middle Eocene)**  
**Tscu** – The Scripps Formation (**Tsc**) is mostly pale-yellowish-brown, medium-grained sandstone containing occasional cobble-conglomerate interbeds. It contains a middle Eocene Molluscan fauna (Givens and Kennedy, 1979). The Scripps Formation is 56 m thick at its type section, which is 1 km north of Scripps Pier, on the north side of

the mouth of Blacks Canyon (Kennedy and Moore, 1971). Both the basal contact with the Ardath Shale and the upper contact with the Friars Formation are conformable. In upper Carroll Canyon, a tongue of the Scripps Formation (**Tscu**) exists above an intervening part of the Stadium Conglomerate. This "upper" tongue is difficult to separate from the main body of the Scripps Formation where the Stadium Conglomerate is absent.

**Ta Ardath Shale (middle Eocene)** – Mostly uniform, weakly fissile olive-gray silty shale. The upper part contains thin beds of medium-grained sandstone, similar to thicker ones in the overlying Scripps Formation, and concretionary beds with molluscan fossils. The type section of the Ardath Shale is on the east side of Rose Canyon, 800 m south of the Ardath Road intersection with Interstate 5 (Kennedy and Moore, 1971).

**Tt Torrey Sandstone (middle Eocene)** – White to light-brown, medium- to coarse-grained, moderately well indurated, massive and broadly cross-bedded, arkosic sandstone. This unit is the Torrey Sand Member of Hanna (1926) and was named for exposures at Torrey Pines State Park. It is now considered a formation of the La Jolla Group (Kennedy and Moore, 1971).

**Td Delmar Formation (middle Eocene)** – Dusky-yellowish-green, sandy, claystone interbedded with medium-gray, coarse-grained, sandstone. This unit is the Delmar Sand Member of Hanna (1926) and was named for exposures in the sea

cliffs at Del Mar. It is now considered a formation of the La Jolla Group (Kennedy and Moore, 1971).

**Td + Tf Delmar Formation and Friars Formation, undivided (middle Eocene)** – In the upper reaches of La Zanja, McGonigle and Penasquitos Canyons the Delmar and Friars Formations are undivided.

**Tmsc Mount Soledad Formation (middle Eocene)** – The Mount Soledad Formation consists of a massive, reddish-brown, cobble conglomerate (**Tmsc**) and light-brown, medium-grained sandstone (**Tmss**). The Mount Soledad Formation (part of the Rose Canyon Shale Member of Hanna, 1926) was named for exposures that crop out around the Mount Soledad anticline in La Jolla and is a formation of the La Jolla Group (Kennedy and Moore, 1971).

**Teo Undivided Eocene rocks in offshore region (Eocene)** – Well-indurated, massive arkosic sandstone. Also includes interbeds of claystone, siltstone and conglomerate.

**Kcs Cabrillo Formation (Upper Cretaceous)** – Mostly massive medium-grained sandstone (**Kcs**) and cross-bedded cobble conglomerate containing fresh locally derived plutonic and metavolcanic clasts (**Kccg**). Named for exposures at the southern tip of the Point Loma Peninsula near Cabrillo National Monument and assigned to the upper part of the Rosario Group (Kennedy and Moore, 1971). The Cabrillo Formation conformably overlies massive sandstone and siltstone of the Point Loma Formation. Lower Maestrichtian

foraminifera have been found about 30 m below the base of the Cabrillo Formation in siltstone of the Point Loma Formation (Sliter, 1968), and a fossil clam collected on the east flank of Mount Soledad from 2 m below the overlying Eocene unconformity has been identified as "*Pharella" alta* (Gabb) and assigned to the Maestrichtian (L.R. Saul, written communication, 1969). The Cabrillo Formation is correlative in part to the Williams Formation in the Santa Ana Mountains (Popenoe and others, 1960). Arthur and others (1979) and Nilsen and Abbott (1979) provide a detailed description of these rocks.

**Kp Point Loma Formation (Upper Cretaceous)** – Interbedded, fine-grained, dusky-yellow sandstone and olive-gray siltstone. Contains calcareous nannoplankton of Upper Cretaceous (Campanian and Maestrichtian) age. Named for exposures in the sea cliffs along the west side of the Point Loma Peninsula and assigned to the intermediate part of the Rosario

Group (Kennedy and Moore, 1971). The Point Loma Formation is correlative in part to the Williams Formation in the Santa Ana Mountains (Popenoe and others, 1960; Bukry and Kennedy, 1969).

**Kl Lusardi Formation (Upper Cretaceous)** – Reddish-brown, cobble and boulder conglomerate with occasional thin lenses of medium-grained sandstone. Named by Nordstrom (1970) for exposures in Lusardi Creek in the Rancho Santa Fe quadrangle and later assigned to

the basal part of the Rosario Group by Kennedy and Moore (1971). The Lusardi Formation is correlated to the Trabuco Formation in the Santa Ana Mountains (Nordstrom, 1970).

**Kuo Undivided rocks of the Rosario Group in the offshore area (Upper Cretaceous)** – Undivided rocks of the Rosario Group that occur beneath the sea floor offshore from La Jolla and Point Loma.

**UNNAMED CRETACEOUS ROCKS OF THE PENINSULAR RANGES BATHOLITH**  
(See Figure 2 for classification diagram)

**Kgu Granodiorite and tonalite, undivided (mid-Cretaceous)** – Leucocratic, fine-, medium- and coarse-grained granodiorite and tonalite with minor amounts of leucocratic granophyre and dark-gray to black gabbro and diorite.

**Kgd Granodiorite, undivided (mid-Cretaceous)** – Medium- to coarse-grained hornblende-biotite granodiorite.

**Kt Tonalite, undivided (mid-Cretaceous)** – Massive, coarse-grained, light-gray, hornblende-biotite tonalite.

**Kd Diorite, undivided (mid-Cretaceous)** – Massive, medium- to coarse-grained, dark-gray hornblende diorite.

**Kgh Hypabyssal rocks, undivided (mid-Cretaceous)** – Hornblende tonalite and leucocratic granophyre.

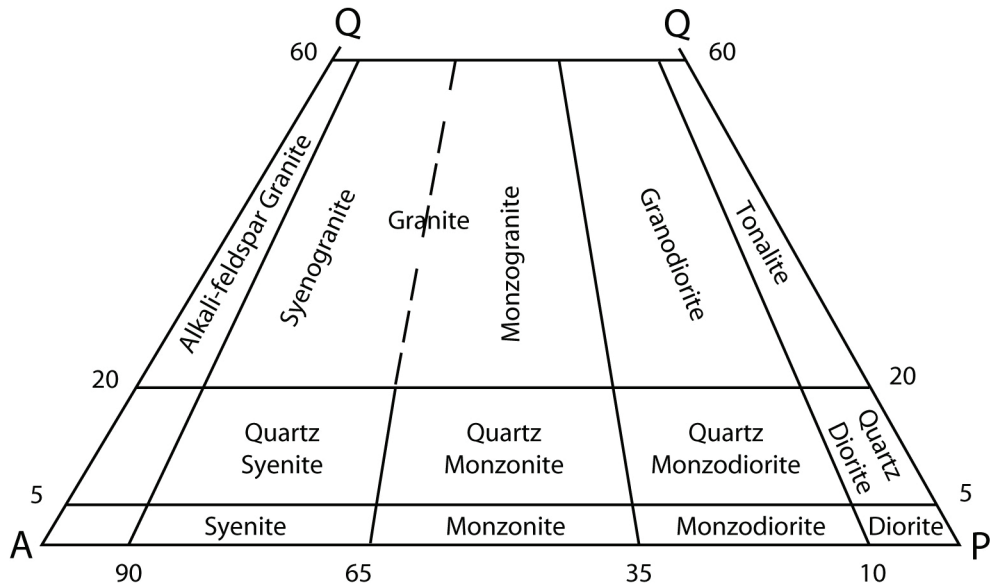


Figure 2. Classification of plutonic rock types (from IUGS, 1973, and Streckeisen, 1973). A, alkali feldspar; P, plagioclase feldspar; Q, quartz.

**JURASSIC AND CRETACEOUS  
METAMORPHOSED AND UN-  
METAMORPHOSED VOLCANIC  
AND SEDIMENTARY ROCKS**

and siltstone) interlayered and mixed with metavolcanic rocks consisting of flows, tuffs, and volcaniclastic breccia.

**Mzu Metamorphosed and unmetamorphosed volcanic and sedimentary rocks, undivided (Mesozoic)** – Low-grade (greenschist facies) metasedimentary rocks (conglomerate, sandstone,

**Mzo Undivided metamorphic rocks in offshore region (Mesozoic)** – Massive, low-grade, metavolcanic and metasedimentary rocks. Correlative in large part with rocks designated Mzu onshore.



# INDEX MAP

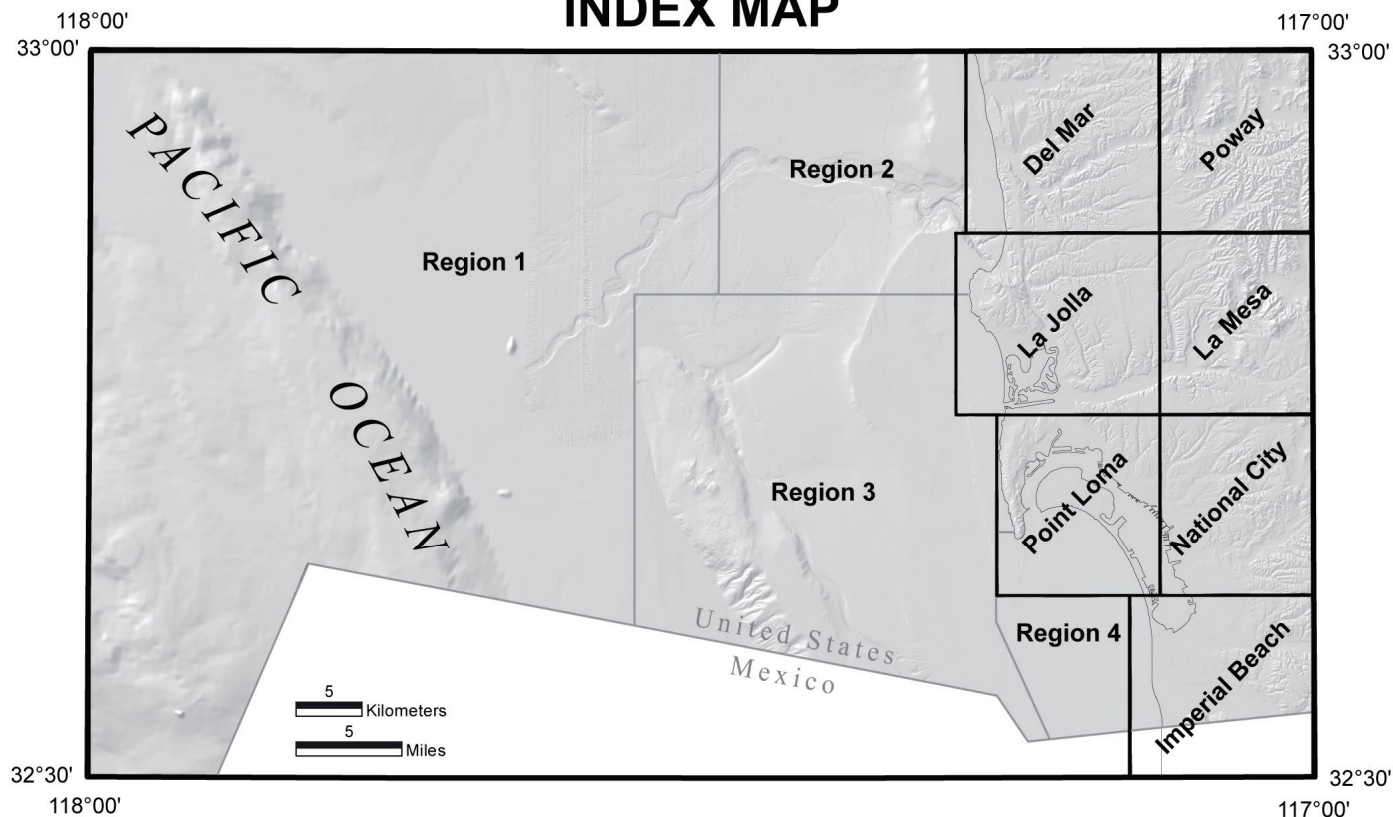


Figure 3. Index map showing the 7.5-minute quadrangles and offshore compilation regions in the San Diego 30' x 60' quadrangle. DEM from U.S. Geological Survey.

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Sources of mapping for the San Diego 30' x 60' quadrangle (primary compilation sources shown in bold type). For complete citation see the reference section following this list. Digital preparation of the onshore geology by Diane Burns and the offshore geology by Rachel Alvarez and Carlos Gutierrez.

## Del Mar Quadrangle

**Kennedy, 1975**; Kern, 1996a,b; Tan and Giffen, 1995.

## Imperial Beach Quadrangle

Kennedy and others, 1975; **Kennedy and Tan, 1977**; Kern, 1996a,b; Tan, 1995.

## La Jolla Quadrangle

**Kennedy, 1975**; Kennedy and others, 1975; Kern, 1996a,b; Tan, 1995.

## La Mesa Quadrangle

**Kennedy and Peterson, 1975**; Kennedy and others, 1975; Kern, 1996a,b; Tan, 1995.

## National City Quadrangle

Kennedy and others, 1975; **Kennedy and Tan, 1977**; Kern, 1996a,b; Tan, 1995.

**Point Loma Quadrangle**

**Kennedy, 1975; Kennedy and Clarke, 1999a,b;** Kennedy and others, 1975; Kern, 1996a,b; Tan, 1995.

**Poway Quadrangle**

**Kennedy and Peterson, 1975;** Kern, 1996a,b; Tan and Giffen, 1995.

**Offshore Region 1**

Clarke and others, 1987; Ryan and others, (in press).

**Offshore Region 2**

Clarke and others, 1987; **Kennedy and others, 1980b;** Ryan and others, (in press).

**Offshore Region 3**

Clarke and others, 1987; **Kennedy and others, 1980a;** Ryan and others, (in press).

**Offshore Region 4**

**Kennedy and Welday, 1980.**



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